

NASA Conference Publication 3330

National Educators' Workshop: Update 95

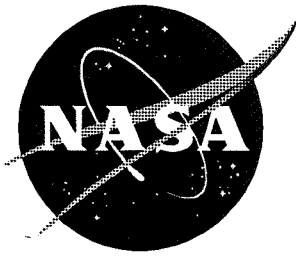
Standard Experiments in Engineering Materials Science and Technology

Compiled by
James E. Gardner, James A. Jacobs, and Michael A. Karnitz

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Proceedings of a workshop sponsored jointly by the
United States Department of Energy, Oak Ridge,
Tennessee, the National Aeronautics and Space
Administration, Washington, D.C., the Norfolk State
University, Norfolk, Virginia, and the National Institute
of Standards and Technology, Gaithersburg, Maryland,
and held in Oak Ridge, Tennessee
November 5-8, 1995

May 1996



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James E. Gardner
Langley Research Center • Hampton, Virginia

James A. Jacobs
Norfolk State University • Norfolk, Virginia

Michael A. Karnitz
Oak Ridge National Laboratory • Oak Ridge, Tennessee

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National Aeronautics and Space Administration
Langley Research Center • Hampton, Virginia 23681-0001

May 1996

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PREFACE

NEW:Update 95 marked a milestone, 10th annual workshop. Hosted by Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, on November 5-8, 1995, the event was a fitting milestone in terms of interaction and quality presentations. Building on past workshops and extensive workshop evaluations, the 10th annual **NEW:Update** continued to follow the theme of strengthening materials education. About 80 participants witnessed demonstrations of experiments, discussed issues of materials science and engineering (MS&E) with people from education, industry, government, and technical societies, heard about new MS&E developments, and participated in eleven 3-hour mini workshops in state-of-the-art ORNL laboratories. Faculty in attendance represented high schools, community colleges, smaller colleges, and major universities. Undergraduate and graduate students also attended and presented papers.

Professor Xavier Spiegel, representing the American Society for Engineering Education's (ASEE) Materials Division, presented a special 10 Year commemorative plaque to ORNL personnel Edward Aebischer, Douglas Craig, Linda Horton, Michael Karnitz, Joy Lee, Shirley North, and Richard Lowden for their valuable contributions to MS&E education through their ten years of support to **NEW:Updates** and other materials education efforts. The overwhelming success of **NEW:Updates** results, in a large measure, from the considerable work and sacrifices of the host agencies: Oak Ridge National Laboratory (ORNL), National Institute of Standards and Technology (NIST), National Aeronautics and Space Administration (NASA) Langley Research Center, and Norfolk State University (NSU).

NEW:Update 95 participants aided in evaluating over thirty-two experiments that were presented before the group. Additional updating information relating to materials science, engineering and technology was also presented as mini plenary sessions that focused on technology from ORNL's CFCC (Continuous Fiber Ceramic Composites) program, processing and the total materials cycle, multimedia in materials science and engineering, NIST's Advanced Technology's collaborative programs among industry and universities, designing with brittle matrix composites, and diamond research overview. You will find transparency masters for the mini plenary sessions included in this publication. A panel of materials educators provided updates on various curricula and pedagogical innovations.

The experiments in this publication can serve as a valuable guide to faculty who are interested in useful activities for their students. The material was the result of years of research aimed at better methods of teaching materials science, engineering and technology. The experiments were developed by faculty, scientists, and engineers throughout the United States. There is a blend of experiments on new materials and traditional materials. Uses of computers in MS&E, experimental design, and a variety of low cost experiments were among the demonstrations presented. Transparency masters of technical presentations are also included.

Experiments underwent an extensive peer review process. After submission of abstracts, selected authors were notified of their acceptance and given the format for submission of experiments. Experiments were reviewed by a panel of specialists through the cooperation of the Materials Education Council. Authors received comments from the panel prior to **NEW:Update 95**, allowing them to make necessary adjustments prior to demonstrating their experiments. Comments from

workshop participants provided additional feedback which authors used to make final revisions which were submitted for the NASA editorial group for this publication.

The Materials Education Council of the United States publishes selected experiments in the *Journal of Materials Education (JME)*. The *JME* offers materials educators valuable teaching and curriculum aids including instructional modules on emerging materials technology, experiments, book reviews, and editorials.

Videotapes were made of the workshop by ORNL. As with previous **NEW:Updates**, critiques were made of the workshop to provide continuing improvement of this activity. The evaluations and recommendations made by participants provide valuable feedback for planning of subsequent **NEW:Updates**.

NEW:Update 95 and the series of workshops that go back to 1986 are, to our knowledge, the only national workshops or gatherings for materials educators that have a focus on the full range of issues on strategies for better teaching about the full complement of materials. Recognizing the problem of motivating young people to pursue careers in MSE, we have included exemplary pre-university activities such as Adventures in Science, ASM International Education Foundation's Career Outreach Program, Engineers for Education, National Teachers Institute for Materials Science and Technology, and several programs run through high schools.

NEW:Update 95, with its diversity of faculty, industry, and government MSE participants, served as a forum for both formal and informal issues facing MSE education that ranged from the challenges of keeping faculty and students abreast of new technology to ideas to ensure that materials scientists, engineers, and technicians maintain the proper respect for the environment in the pursuit of their objectives.

We hope that the experiments presented in this publication will assist you in teaching about materials science, engineering and technology. We would like to have your comments on their value and means of improving them. Please send comments to James A. Jacobs, School of Technology, Norfolk State University, Norfolk, Virginia 23504.

We express our appreciation to all those who helped to keep this series of workshops viable.

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American Society for Engineering Education

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REVIEWERS FOR NEW:Update 95

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Technical University of Radom

Technical notebooks and announcements of the workshop were provided by
NASA LANGLEY RESEARCH CENTER

OAK RIDGE NATIONAL LABORATORY

MINI WORKSHOPS

◆ **Continuous Fiber Ceramic Composites**

Rick Lowden, Metals and Ceramics

The focus will be on thermomechanical behavior and failure mechanisms of CFCCs. Testing and characterization will be combined with the effects of exposure to service environments. Techniques and analyses used to qualify and understand these materials for applications will be demonstrated.

◆ **Gelcasting for Ceramics Processing**

Mark Janney, Metals and Ceramics

This workshop will survey ceramic processing technologies from powder processing to sintering, with emphasis on gelcasting technologies. Gelcasting will be compared to traditional processing techniques, including pottery ceramics, a common foundation for most students.

◆ **Friction, Lubrication, and Wear**

Peter Blau, Metals and Ceramics

Experiments will demonstrate test methods and standards for friction, the different functions and types of lubricants, and methods to measure and control wear behavior--all part of the multidisciplinary field called tribology to which courses in physics and mechanics often provide only very limited exposure.

◆ **Properties and Applications of Superconductors**

Rich Kerchner, Solid State

The current/voltage characteristics of superconductive bismuth-strontium-calcium-copper-oxide (BSCCO) tape will be measured, including the effects of applying magnetic fields and varying temperatures. A simple electric motor that uses such tape will be demonstrated and its critical features discussed.

◆ **Scanning Tunneling Microscopy**

John Wendelken, Solid State

STMs, with the power to resolve individual atoms, find ready application in surface science. Among current examples: diagnostics for the growth of thin films, nanofabrication processes to create special surface structures and compositions, and analysis of the electronic structures of materials.

◆ **Direct Images of Atoms in Materials**

Steve Pennycook, Solid State

This is accomplished with a 300-kilovolt scanning transmission electronic microscope that applies "Z-contrast imaging". The technique provides the sharpest direct images yet of atoms in a solid--allowing researchers to better observe interfaces where different crystalline grains of materials come together.

◆ **Small-Angle Neutron/X-Ray Scattering**

George Wignall, Solid State

The basic physics and current experiments will be followed by "hands-on" calculation exercises based on a data from small-angle scattering runs, e.g., determining the structure of a two-phase polymer-polymer composite via contrast variation or the size and volume fraction of voids in aluminum.

◆ **Ion Beam Processing of Materials**

Wayne Holland, Solid State

In a unique particle-accelerator facility, near-surfaced properties are altered and characterized using ion beams. Ion-implantation doping and ion beam mixing, deposition, and annealing are employed to alter physical, chemical, or electrical properties and create "non-equilibrium" materials.

◆ **Optical Materials**

Mike Cates, Engineering Technology

Research in advanced photonics finds applications ranging from energy generation to detection to communications and information processing. This session will focus on work with lasers, fiber optics, and other optical tools for sensing things that cannot be measured by conventional methods.

◆ **Polymer Processing**

George Wrenn, Engineering Technology

This session will feature prototype development in partnership with industry that applies state-of-the-art equipment and 30 years of experience in developing and producing polymer matrix composite structures. Topics will include resin synthesis, adhesive joints, and forming a composite.

◆ **Application-Specific Integrated Circuits**

Nance Ericson, Instrum. & Controls

Steps in the customized design and fabrication of Very Large Scale Integrated (VLSI) chips for specific applications will be demonstrated. The process will be detailed from design of the integrated circuit to prototype production, including microscopic examination and diagnostic techniques.

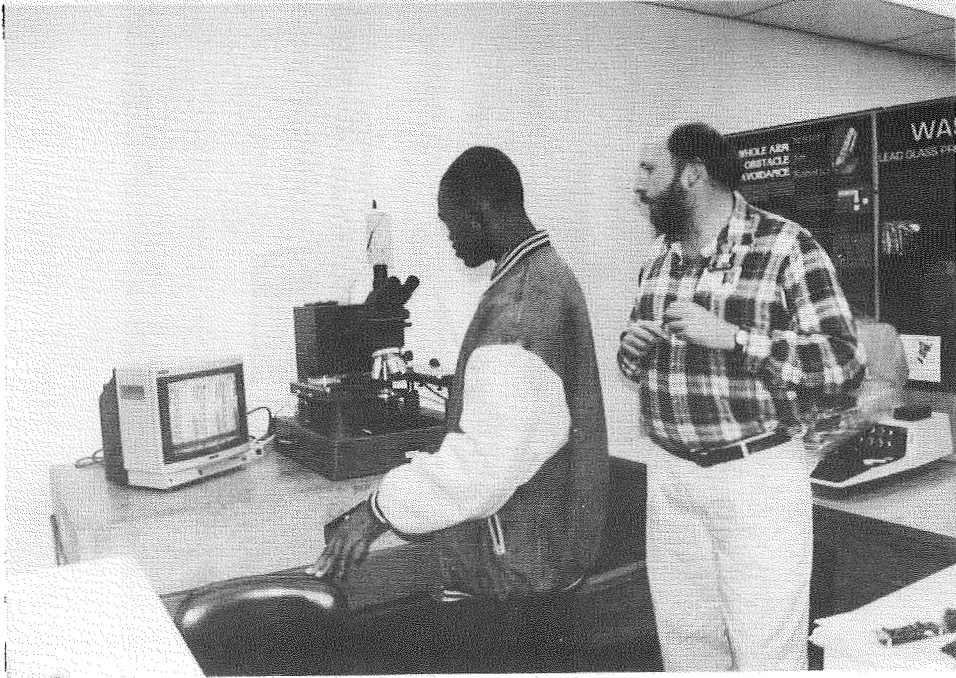
Mini Workshops



Mini Workshops (continued)



Mini Workshops (concluded)



LISTING OF EXPERIMENTS FROM NEW:UPDATES

EXPERIMENTS & DEMONSTRATIONS IN STRUCTURES, TESTING, AND EVALUATION

NEW:Update 88

NASA Conference Publication 3060

Sastri, Sankar. "Fluorescent Penetrant Inspection"

Sastri, Sankar. "Magnetic Particle Inspection"

Sastri, Sankar. "Radiographic Inspection"

NEW:Update 89

NASA Conference Publication 3074

Chowdhury, Mostafiz R. and Chowdhury, Farida. "Experimental Determination of Material Damping Using Vibration Analyzer"

Chung, Wenchiang R. "The Assessment of Metal Fiber Reinforced Polymeric Composites"

Stibolt, Kenneth A. "Tensile and Shear Strength of Adhesives"

NEW:Update 90

NIST Special Publication 822

Azzara, Drew C. "ASTM: The Development and Application of Standards"

Bates, Seth P. "Charpy V-Notch Impact Testing of Hot Rolled 1020 Steel to Explore Temperature Impact Strength Relationships"

Chowdhury, Mostafiz R. "A Nondestructive Testing Method to Detect Defects in Structural Members"

Cornwell, L. R., Griffin, R. B., and Massarweh, W. A. "Effect of Strain Rate on Tensile Properties of Plastics"

Gray, Stephanie L., Kern, Kristen T., Harries, Wynford L., and Long, Sheila Ann T.

"Improved Technique for Measuring Coefficients of Thermal Extension for Polymer Films"

Halperin, Kopl. "Design Project for the Materials Course: To Pick the Best Material for a Cooking Pot"

Kundu, Nikhil. "Environmental Stress Cracking of Recycled Thermoplastics"

Panchula, Larry and Patterson, John W. "Demonstration of a Simple Screening Strategy for Multifactor Experiments in Engineering"

Taylor, Jenifer A. T. "How Does Change in Temperature Affect Resistance?"

Wickman, Jerry L. and Corbin, Scott M. "Determining the Impact of Adjusting Temperature Profiles on Photodegradability of LDPE/Starch Blown Film"

Widener, Edward L. "It's Hard to Test Hardness"

Widener, Edward L. "Unconventional Impact-Toughness Experiments"

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NASA Conference Publication 3151

Bunnell, L. Roy. "Tempered Glass and Thermal Shock of Ceramic Materials"

Lundeen, Calvin D. "Impact Testing of Welded Samples"

Gorman, Thomas M. "Designing, Engineering, and Testing Wood Structures"

Strehlow, Richard R. "ASTM - Terminology for Experiments and Testing"

Karplus, Alan K. "Determining Significant Material Properties, A Discovery Approach"

Spiegel, F. Xavier and Weigman, Bernard J. "An Automated System for Creep Testing"

Denton, Nancy L. and Hillsman, Vernon S. "Isotropic Thin-Walled Pressure Vessel Experiment"

Allen, David J. "Stress-Strain Characteristics of Rubber-Like Materials: Experiment and Analysis"

Dahl, Charles C. "Computer Integrated Lab Testing"

Cornwell, L. R. "Mechanical Properties of Brittle Material"

NEW:Update 92**NASA Conference Publication 3201**

- Bunnell, L. Roy. "Temperature-Dependent Electrical Conductivity of Soda-Lime Glass and Construction and Testing of Simple Airfoils to Demonstrate Structural Design, Materials Choice, and Composite Concepts"
- Marpet, Mark I. "Walkway Friction: Experiment and Analysis"
- Martin, Donald H. "Application of Hardness Testing in Foundry Processing Operations: A University and Industry Partnership"
- Masi, James V. "Experiments in Corrosion for Younger Students By and For Older Students"
- Needham, David. "Micropipet Manipulation of Lipid Membranes: Direct Measurement of the Material Properties of a Cohesive Structure That is Only Two Molecules Thick"
- Perkins, Steven W. "Direct Tension Experiments on Compacted Granular Materials"
- Shih, Hui-Ru. "Development of an Experimental Method to Determine the Axial Rigidity of a Strut-Node Joint"
- Spiegel, F. Xavier. "An Automated Data Collection System For a Charpy Impact Tester"
- Tipton, Steven M. "A Miniature Fatigue Test Machine"
- Widener, Edward L. "Tool Grinding and Spark Testing"

NEW:Update 93**NASA Conference Publication 3259**

- Borst, Mark A. "Design and Construction of a Tensile Tester for the Testing of Simple Composites"
- Clum, James A. "Developing Modules on Experimental Design and Process Characterization for Manufacturing/Materials Processes Laboratories"
- Diller, T. E. and A. L. Wicks, "Measurement of Surface Heat Flux and Temperature"
- Denton, Nancy and Vernon S. Hillsman, "An Introduction to Strength of Materials for Middle School and Beyond"
- Fisher, Jonathan H. "Bridgman Solidification and Experiment to Assess Boundaries and Interface Shape"
- Gray, Jennifer "Symmetry and Structure Through Optical Diffraction"
- Karplus, Alan K. "Knotty Knots"
- Kohne, Glenn S. "An Automated Digital Data Collection and Analysis System for the Charpy Impact Tester"
- Olesak, Patricia J. "Scleroscope Hardness Testing"
- Speigel, F. Xavier, "Inexpensive Materials Science Demonstrations"
- Wickman, J. L. "Plastic Part Design Analysis Using Polarized Filters and Birefringence"
- Widener, Edward L. "Testing Rigidity by Torque Wrench"

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- Bruzan, Raymond and Baker, Douglas, "Density by Titration"
Dahiya, Jai N., "Precision Measurements of the Microwave Dielectric Constants of Polyvinyl Stearate and Polyvinylidene Fluoride as a Function of Frequency and Temperature"
Daufenbach, JoDee and Griffin, Alair, "Impact of Flaws"
Fine, Leonard W., "Concrete Repair Applications and Polymerization of Butadiene by an "Alfin" Catalyst"
Hillsman, Vernon S., "Stress Concentration: Computer Finite Element Analysis vs. Photoelasticity"
Hutchinson, Ben, Giglio, Kim, Bowling, John, and Green, David, "Photocatalytic Destruction of an Organic Dye Using TiO_2 "
Jenkins, Thomas J., Comtois, John H., and Bright, Victor M., "Micromachining of Suspended Structures in Silicon and Bulk Etching of Silicon for Micromachining"
Jacobs, James A. and Jenkins, Thomas J., "Mathematics for Engineering Materials Technology Experiments and Problem Solving"
Karplus, Alan K., "Paper Clip Fatigue Bend Test"
Kohne, Glenn S., "Fluids With Magnetic Personalities"
Liu, Ping and Waskom, Tommy L., "Ultrasonic Welding of Recycled High Density Polyethylene (HDPE)"
Martin, Donald H., Schwan, Hermann, Diehm, Michael, "Testing Sand Quality in the Foundry (A Basic University-Industry Partnership)"
Shull, Robert D., "Nanostructured Materials"
Werstler, David E., "Introduction to Nondestructive Testing"
White, Charles V., "Glass Fracture Experiment for Failure Analysis"
Wickman, Jerry L. and Kundu, Nikhil K., "Failure Analysis of Injection Molded Plastic Engineered Parts"
Widener, Edward L., "Dimensionless Fun With Foam"

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- Brown, Scott, "Crystalline Hors D'Oeuvres"
Karplus, Alan K., "Craft Stick Beams"
Kern, Kristen, "ION Beam Analysis of Materials"
Kozma, Michael, "A Revisit to the Helicopter Factorial Design Experiment"
Pond, Robert B., Sr., "Recrystallization Art Sketching"
Roy, Rustom, "CVD Diamond Synthesis and Characterization: A Video Walk-Through"
Saha, Hrishikesh, "Virtual Reality Lab Assistant"
Spiegel, F. Xavier, "A Novel Approach to Hardness Testing"
Spiegel, F. Xavier, "There are Good Vibrations and Not So Good Vibrations"
Tognarelli, David, "Computerized Materials Testing"
Wickman, Jerry L., "Cost Effective Prototyping"

EXPERIMENTS & DEMONSTRATIONS IN METALS

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- Nagy, James P. "Sensitization of Stainless Steel"
Neville, J. P. "Crystal Growing"
Pond, Robert B. "A Demonstration of Chill Block Melt Spinning of Metal"
Shull, Robert D. "Low Carbon Steel: Metallurgical Structure vs. Mechanical Properties"

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NASA Conference Publication 3074

- Balsamel, Richard. "The Magnetization Process - Hysteresis"
Beardmore, Peter. "Future Automotive Materials - Evolution or Revolution"
Bunnell, L. Roy. "Hands-On Thermal Conductivity and Work-Hardening and Annealing in Metals"
Kazem, Sayyed M. "Thermal Conductivity of Metals"
Nagy, James P. "Austempering"

NEW:Update 90

NIST Special Publication 822

- Bates, Seth P. "Charpy V-Notch Impact Testing of Hot Rolled 1020 Steel to Explore Temperature Impact Strength Relationships"
Chung, Wenchiang R. and Morse, Margery L. "Effect of Heat Treatment on a Metal Alloy"
Rastani, Mansur. "Post Heat Treatment in Liquid Phase Sintered Tungsten-Nickel-Iron Alloys"
Spiegel, F. Xavier. "Crystal Models for the Beginning Student"
Yang, Y. Y. and Stang, R. G. "Measurement of Strain Rate Sensitivity in Metals"

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NASA Conference Publication 3151

- Cowan, Richard L. "Be-Cu Precipitation Hardening Experiment"
Kazem, Sayyed M. "Elementary Metallography"
Krepski, Richard P. "Experiments with the Low Melting Indium-Bismuth Alloy System"
Lundeen, Calvin D. "Impact Testing of Welded Samples"
McCoy, Robert A. "Cu-Zn Binary Phase Diagram and Diffusion Couples"
Patterson, John W. "Demonstration of Magnetic Domain Boundary Movement Using an Easily Assembled Videocam-Microscope System"
Widener, Edward L. "Heat-Treating of Materials"

NEW:Update 92

NASA Conference Publication 3201

- Dahiya, Jai N. "Phase Transition Studies in Barium and Strontium Titanates at Microwave Frequencies"
Rastani, Mansur. "Improved Measurement of Thermal Effects on Microstructure"
Walsh, Daniel W. "Visualizing Weld Metal Solidification Using Organic Analogs"

NEW:Update 93

NASA Conference Publication 3259

- Guichelaar, Philip J. "The Anisotropy of Toughness in Hot-Rolled Mild Steel"
Martin, Donald H. "From Sand Casting TO Finished Product (A Basic University-Industry Partnership)"
Petit, Jocelyn I. "New Developments in Aluminum for Aircraft and Automobiles"
Smith, R. Carlisle "Crater Cracking in Aluminum Welds"

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- Gabrykewicz, Ted, "Water Drop Test for Silver Migration"
Kavikondala, Kishen and Gambrell, S. C., Jr., "Studying Macroscopic Yielding in Welded Aluminum Joints Using Photostress"
Krepski, Richard P., "Exploring the Crystal Structure of Metals"
McClelland, H. Thomas, "Effect of Risers on Cast Aluminum Plates"
Weigman, Bernard J. and Courpas, Stamos, "Measuring Energy Loss Between Colliding Metal Objects"

NEW:Update 95

Callister, William, "Unknown Determination of a Steel Specimen"

Elban, Wayne L., "Metallographic Preparation and Examination of Polymer-Matrix Composites"

Shih, Hui-Ru, "Some Experimental Results in the Rolling of Ni₃Al Alloy"

EXPERIMENTS & DEMONSTRATIONS IN POLYMERS

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- Chung, Wenchiang R. "The Assessment of Metal Fiber Reinforced Polymeric Composites"
Greet, Richard and Cobaugh, Robert. "Rubberlike Elasticity Experiment"
Kern, Kristen T., Harries, Wynford L., and Long, Sheila Ann T. "Dynamic Mechanical Analysis of Polymeric Materials"
Kundu, Nikhil K. and Kundu, Malay. "Piezoelectric and Pyroelectric Effects of a Crystalline Polymer"
Kundu, Nikhil K. "The Effect of Thermal Damage on the Mechanical Properties of Polymer Regrinds"
Stibolt, Kenneth A. "Tensile and Shear Strength of Adhesives"
Widener, Edward L. "Industrial Plastics Waste: Identification and Segregation"
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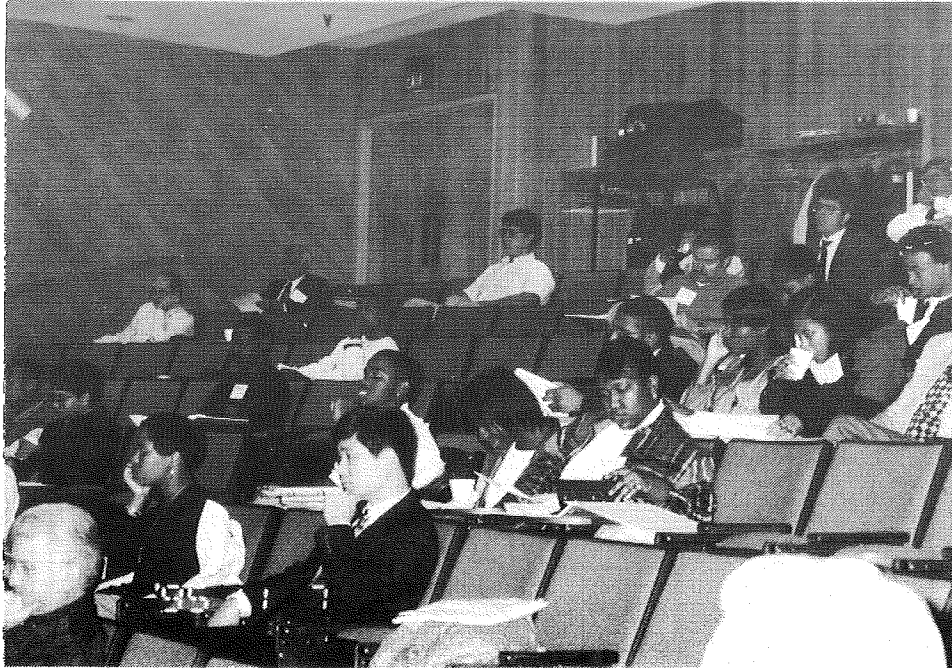
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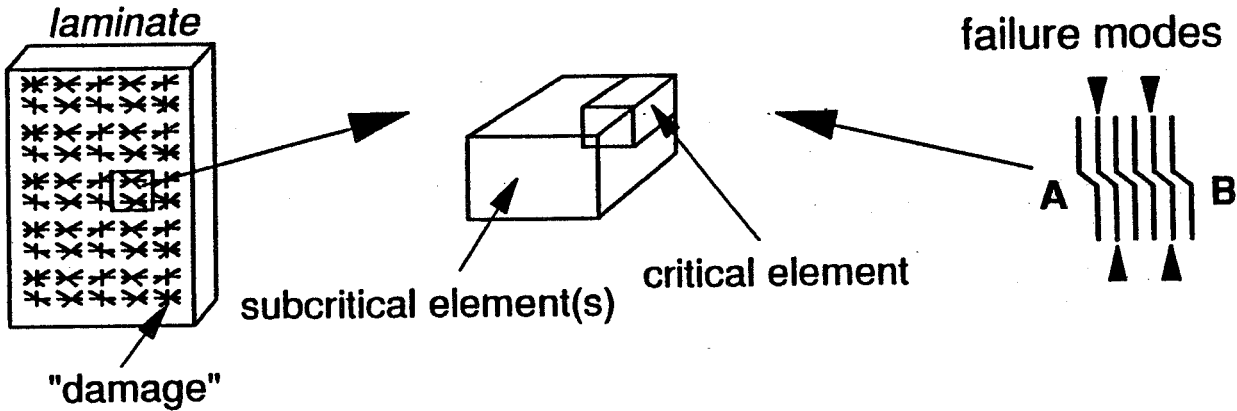
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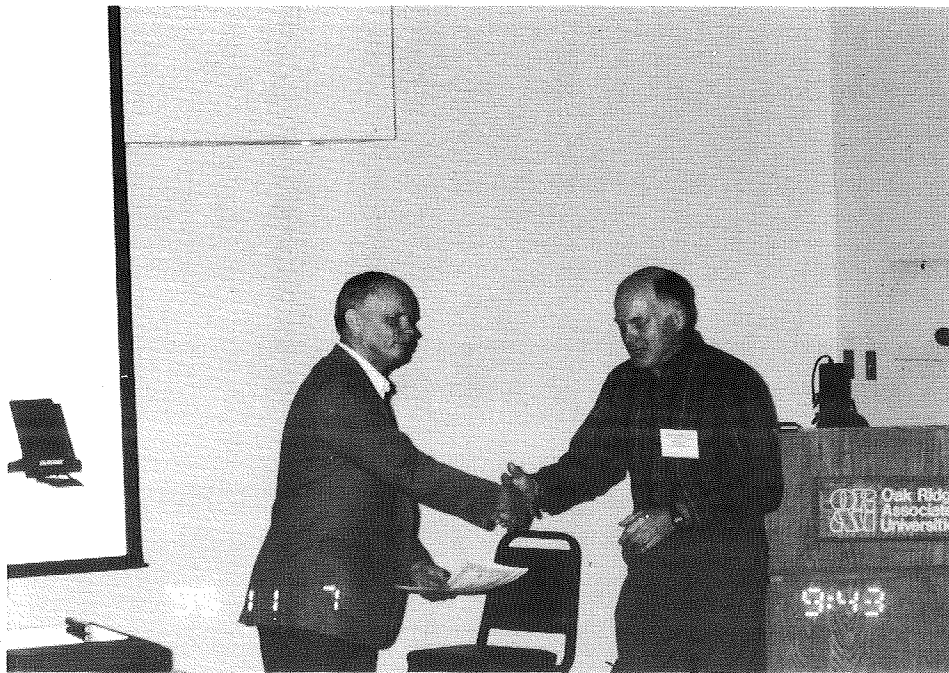
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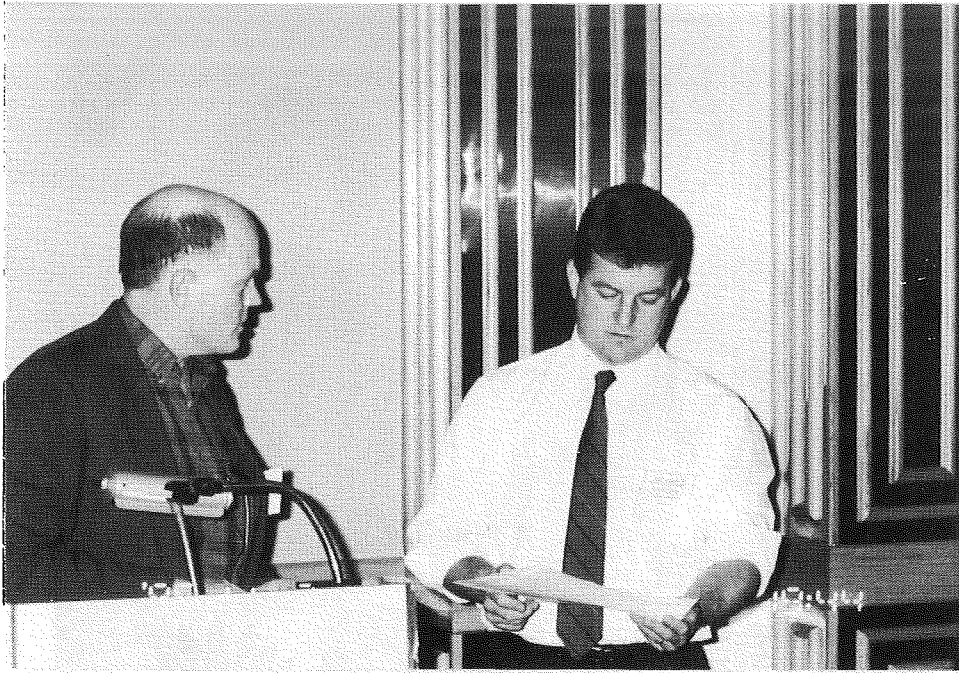
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Registration



Displays



Displays (concluded)



A Lot of Work ...



... A Little Play



... A Little Play
(concluded)



**THE ADVANCED TECHNOLOGY PROGRAM:
OPPORTUNITIES FOR
INDUSTRY/UNIVERSITY COLLABORATION**

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Deputy Director, Advanced Technology Program
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Gaithersburg, MD 20899

Telephone 301-975-3778



Presented by

David S. King
National Institute of Standards and Technology

**THE ADVANCED TECHNOLOGY PROGRAM:
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**Brian Belanger
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The Advanced Technology Program (ATP) is an extramural program operated by the Department of Commerce's National Institute of Standards and Technology. The ATP stimulates economic growth in the United States by cost sharing high-risk, but potentially high-payoff industrial R&D--projects that are too risky for industry to undertake alone.

Projects are selected on merit, based on published selection criteria. Both technical merit and business promise are considered.

While all project proposals must be submitted by industrial firms or consortia of industrial firms, universities often do collaborate as subcontractors or joint venture partners. Approximately 70 percent of ongoing ATP projects involve one or more university or Federal laboratory participants.

This talk will review the current status of the ATP and outline opportunities for university/industry collaboration.

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**THE VTLA SYSTEM OF COURSE DELIVERY
AND FACULTY DEVELOPMENT IN
MATERIALS EDUCATION**

Robert Berrettini

and

Rustum Roy

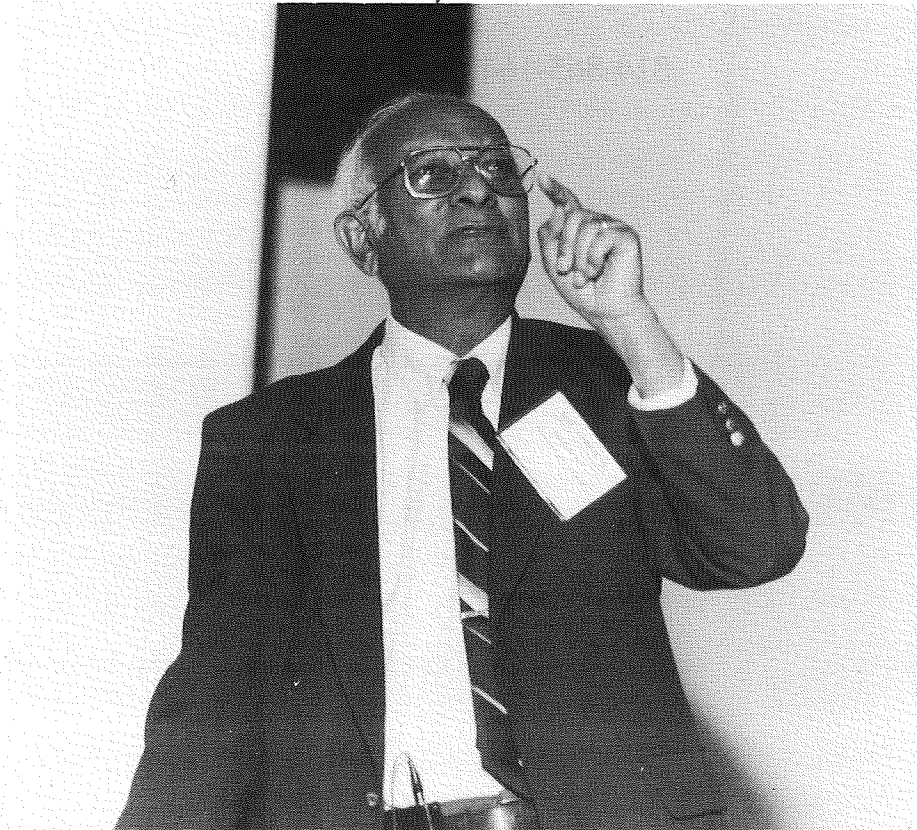
Materials Research Laboratory
The Pennsylvania State University
University Park, PA 16802

814-865-1643 and 9951

Robert Berrettini



Rustum Roy



The VTLA System of Course Delivery and Faculty Development in Materials Education*

Robert Berrettini and Rustum Roy
Intercollege Materials Research Laboratory
The Pennsylvania State University
University Park, PA 16802

Introduction and Description

The National Academy's Materials Science and Engineering (MSE) study¹ made two observations long apparent to those knowledgeable about the field: (1) the decided weakness of the U.S. is in research on materials synthesis and processing; (2) the U.S. has relatively few faculty trained in this specialty. Thus, there is a clear and pressing national need for high-quality, upper division courses that address critical topics in materials synthesis, particularly those beyond the present expertise of the typical department's faculty.

In an era of declining enrollments, shrinking budgets and few new appointments, the question will arise over and over again: How does a department cost-effectively cover the newly emerging fields? A new project has been started to test a novel distance education and faculty development system, called Video Tape Live Audio (VTLA). This, if successful, would at once enlarge the national MSE student cohort studying material synthesis *and* develop faculty expertise at the receiving sites. The mechanics for the VTLA scheme are as follows:

A course is designed in the field selected for emphasis and for which there is likely to be considerable demand, in this case "Ceramic Materials Synthesis: Theory and Case Studies" (Table 1). One of the very best researcher/teachers records lectures of TV studio quality with appropriate visuals. Universities and colleges which wish to offer the course agree to offer it at the same hour at least once a week. The videotaped lectures and accompanying text, readings and visuals are shipped to the professor in charge. This person, selected by the department, has an appropriate/related background. She/he arranges the classroom TV presentation equipment with our detailed suggestions and supervises the course. Video lectures are played during regular course hour(s) twice a week with time for discussion by the supervising professor. Typically the third weekly classroom period is scheduled by all sites at a common designated hour, during which the course author/presenter answers questions, provides greater depth, etc., on a live audio link on a multiplexed phone bridge to all of the course sites. Questions are submitted by individual course participants via fax and e-mail prior to the audio tutorial. Coordinating professors at various sites have separate audio teleconferences at the beginning and end of the course, dealing with the philosophical and pedagogical approach to the course, content and mechanics. Following service once or twice as an "apprentice" to the course, the coordinating professors may then offer it without the necessity of the live audio tutorial. The VTLA sequence of activities is outlined in Figure 1.

Initial Offering

Six sites were selected for participation in the first offering of Ceramic Materials Synthesis via the VTLA method. In addition to Penn State, departments at Clemson, Johns Hopkins, Nebraska, Stevens Institute and Georgia Tech participated in the spring semester of 1995.

Preliminary indications are that all faculty and a large majority of the students were enthusiastic about both the VTLA delivery system and content of the course. After one or two times as an "apprentice" to the

* This work supported by NSF Award DUE9354440.

course, these professors may then offer it without the necessity of the live audio tutorial. This was one of the goals of the project: faculty empowerment to offer such key courses in mainstream materials science, unaided, on a regular basis using the video segments as extensively as they choose. Both faculty and students offered suggestions in terms of refinement of certain presentations, but the VTLA's crucial concept of sharing faculty expertise appears to have been validated in this initial offering.

Table 1.

Week	Speaker	Topic
1	Rustum Roy, Penn State	Introduction to VTLA and Materials Synthesis
1	Rustum Roy	Techniques of Materials Preparation
2	Rustum Roy	Requisite Crystal Chemistry
2	Rustum Roy	Crystal Chemistry and Phase Diagrams
3	Rustum Roy	Low Thermal Expansion Materials
3	Rustum Roy	Composites and Nanocomposites
4	Rustum Roy	Introduction to Case Studies
4	George Beall, Corning Glass	Synthesis and Design of Glass Ceramics
5	David Vaughan, Exxon	Zeolites, Clays and Related Materials
5	David Double, Alcan Ltd.	Chemically Bonded Ceramics
6	David Double	Chemically Bonded Ceramics (continued)
6	Kenneth Jack, U. of Newcastle	Sialons: Ceramic Alloys
7	Kenneth Jack	Sialons: Ceramic Alloys (continued)
7	Mark Newkirk, Lanxide	Ceramic-Matrix Composites
8	C. N. R. Rao, Indian Inst. Sci.	Synthesis of Complex Oxide Phases
8	Robert Newnham, Penn State	Smart Ceramics
9	Robert Newnham	Smart Ceramics (continued)
9	R. C. DeVries, GE (retired)	Synthesis of Diamonds—Traditional
10	Rustum Roy	Synthesis of Diamonds—CVD
10	T. Nakahara, Sumitomo Electric	Compound Semiconductors
11	Joseph Davidovits	Very Early High-strength Cement
11	L. J. Gauckler	Enzyme Catalysis of Ceramic Forming
11	Philippe Becker	Erbium Doped Optical Fibers
11	Charles Greskovich	HiLight Ceramic for Improved Medical X-ray
12	John Blum	Metallic Glasses for High Frequency Applications
12	David Caspell	Rare Earth Boride Magnets
12	Edith Flanigen	Zeolites Based on $AlPO_4$
12	Alfred Cho	Materials for Cascade Lasers
13	Raymond Hemphill	High Strength and Toughness Steel
13	Edward Steigerwald	Single Crystal Aircraft Turbine Blades
13	Carlton Ash	New Polyketone Thermoplastics
13	Sheldon Kaves	Spectra Polyethylene Fiber
14	Rustum Roy	Course Summary and Review
14	Examination	

Future Offerings

With the cost and scheduling problems associated with satellite distance education, and the limited number of departments with compressed video capabilities, the VTLA methodology provides a low-tech, low-cost route to boosting departmental treatment of critical and emerging MSE fields. Further, we believe that faculty will be attracted to the opportunity to develop/extend teaching capability while immediately gaining credit for a regular departmental course offering. Of particular value to junior faculty will be a weekend

orientation workshop help at Penn State in the summer to acquaint them with the VTLA system. We envision the schedule as follows:

Friday Evening	Orientation to distance education and the VTLA system.
Saturday Morning	Viewing of selected course tapes, followed by questions to the course author (by telephone if he is unable to be present); classroom setup.
Saturday Afternoon	Viewing of additional tapes; consideration of sample questions faxed to previous course authors; identifying students who are sufficiently prepared.
Sunday Morning	Review of course readings; constructing examination questions; dealing with schedule problems; preparing to teach course without audio tutorial.

Participants would take away sample course lesson tapes, a complete set of readings and other supplementary sources. Except in hardship cases, the departments of the faculty involved would be responsible for purchasing transportation, providing a measure of their commitment to the process. A modest per diem for room and food will be provided. All participants must agree to be a supervising faculty member for the next offering of the course they have selected.

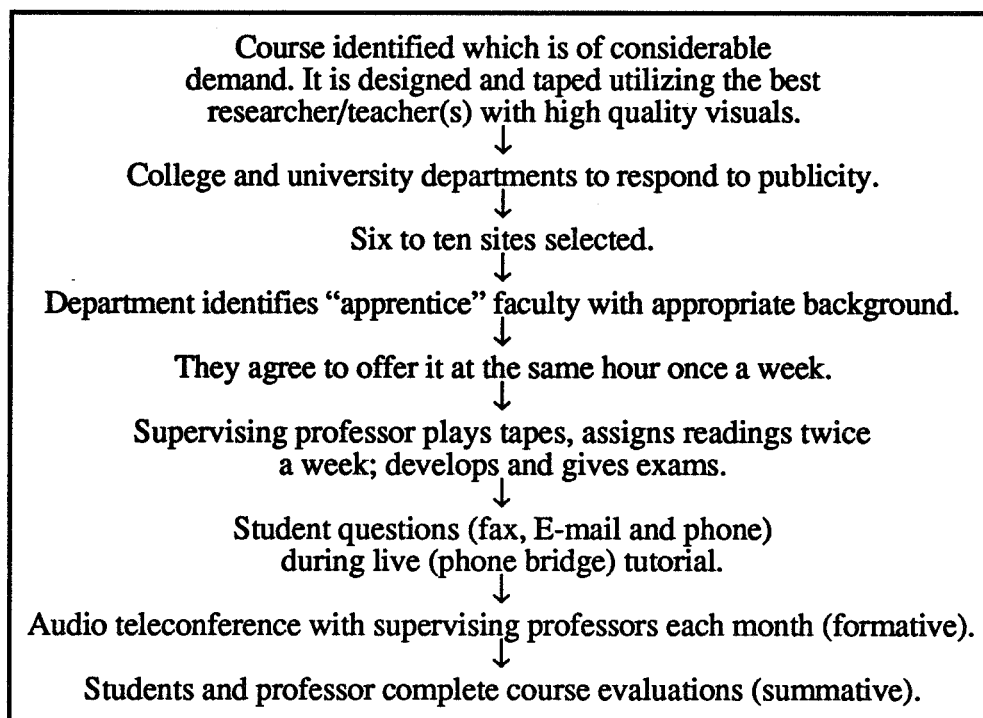


Figure 1. VTLA Sequence of Activities.

In anticipation of further external support, a series of additional VTLA courses in important ceramic materials synthesis and processing has been planned. The schedule is displayed in Table 2.

Table 2. Course Development (Calendar Year)

1996	1997	1998
Spring: "Crystal Chemistry," Professors R. Roy, R. E. Newnham, W. B. White (Penn State)	Spring: "Theory of Diffusion and Sintering of Ceramics," Professor W. D. Kingery (University of Arizona)	Spring: "Design of Ferroic Materials and Composites for Electronic Applications," Professors L. E. Cross, R. E. Newnham (Penn State)
Fall: "Solidification and Applications to Crystalline and Glassy Materials," Professors K. A. Jackson, D. R. Uhlmann (University of Arizona)	Fall: "Strength and Fracture of Ceramics," Professor A. Evans (Harvard)	Fall: "Chemically Bonded Ceramics and Low-Temperature Materials," J. Derek Birchall (University of Keele)

Contribution to Distance Education

We believe this system has great potential significance if the U.S. is to be able to move ahead in ceramic materials. It seeks to place in the hands of MSE teachers in a wide range of universities, most of whom do not have faculty trained in key ceramic materials topics, first-rate, re-usable video teaching tapes by outstanding teachers. But VTLA also has implications for the burgeoning area of distance education. The technique captures several valuable features of pedagogy and deals with the academic situation in the real world; further use of this method is a very important one since it will help us answer the question: Can universities learn to *share* faculty expertise? Of course VTLA will be refined in the future, but if the basic idea can be sold to colleges and universities, it would be a significant advance in *cost-effective* pedagogy.

Indeed, if this notion catches on, it could well revolutionize distance learning. Using taped lectures from the *very best lecturers* (augmented with effective visuals) with local faculty serving as tutorial supervisor, could become a U.S. counterpart to the Oxbridge tutorial. In addition, of absolute benefit will be the permanent record of some of the world's best teachers of syntheses and processing in MSE (or ultimately any field) plying their craft. Future plans also include the development of a manual that will enable educators in other disciplines to successfully plan, develop, implement and evaluate courses using the VTLA system of distance education.

References

1. Materials and Man's Needs, Vol. II, The Needs, Priorities and Opportunities for Materials Research, National Academy of Sciences, Washington, DC, 1995.

CRYSTALLINE HORS D'OEUVRES

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Crystalline Hors D'oeuvres

Scott R. Brown
Materials Science Technology Teacher
Ocean Lakes High School
Virginia Beach, VA

Key Words: Crystal lattice, body centered cubic, face centered cubic, body centered tetragonal, closest packed hexagonal

Objective: To develop macroscopic models for several types of crystal lattices.

Equipment:

1. round toothpicks
2. individually wrapped soft candies
3. scissors
4. ruler

Introduction:

Covalent bonding in solid state materials happens in two forms, amorphous and crystalline structures. The amorphous materials have atoms arranged in random patterns. Atoms of crystalline solids form together in three dimensional geometric patterns.

Two of the basic geometric shapes are a cube and a tetragon. These basic geometric arrangements are called unit cells. The unit cells join together, repeating the geometric shape, forming a crystal lattice.

The body centered cubic cell has equal length sides. Each of the six corners has an atom. Additionally, an atom is centered within the unit cell (see figure 1 at right).

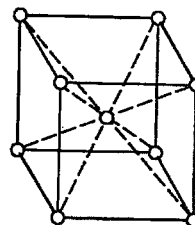


Figure 1 The body centered cubic unit cell diagram.

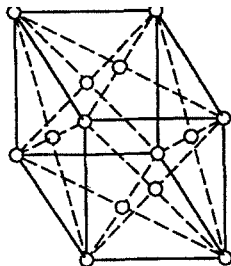


Figure 2 The face centered cubic unit cell diagram.

The face centered cubic unit cell has equal length sides, similar to the bcc unit cell. An atom is located at each of the eight corners. Each of the eight faces will have an atom located in the center (see figure 2 at left).

A second geometric shape for crystal unit cells is a tetragon. This unit cell will resemble a three dimensional rectangular box. Two dimensions of the box will be the same. The third side will be different (see figure 3 below).

Other crystal systems that are found include hexagonal, monoclinic, orthorhombic, triclinic, and rhombohedral.

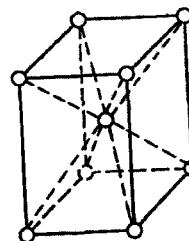


Figure 3 The body centered tetragonal unit cell.

Procedure:

Identify the type of unit cell to be constructed. Collect enough of the atoms (candies) and toothpicks for assembly. Using the figures 1-3 as a guide, make one each body centered cubic (bcc), face centered cubic (fcc) and body centered tetragonal (bct) unit cell. The toothpicks will need to be custom fitted for attaching the atoms on the faces and in the body centers. Cut 1/2 inch from the toothpick length when making the short side of the tetragonal unit cell. When finished, join your unit cells with the unit cells of the other students. Make sure not to mix the different types of unit cells. Upon completion, three macroscopic crystal lattices will have been created.

Instructor Notes:

The lab described in this paper is designed to be used as an introductory activity in the high school MST classroom. The introduction of food items tends to spur interaction among students that may not know each other well.

The lab has also been beneficial as an outreach activity to a local middle school. The high school students act as mentors to an 8th grade physical science class during the activity.

References:

Jacobs, James A. and Kilduff, Thomas: Engineering Materials Technology, Second Edition, Prentice Hall Inc., 1994, pp. 77-84.

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**AN INNOVATIVE MULTIMEDIA APPROACH
TO LABORATORY SAFETY**

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and

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K. P. Constant



AN INNOVATIVE MULTIMEDIA APPROACH TO LABORATORY SAFETY

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3053 Gilman Hall, Ames, IA 50011

Key Words: Computer Courseware, Laboratory Safety

Prerequisite Knowledge: Elementary computer skills, freshman-level chemistry

Objective: To improve awareness of safety issues in materials science laboratories.

Equipment: This courseware is presently Macintosh compatible, although a PC version will be available in the near future. The minimum system configuration is system 7.0 or higher, 4 MB of RAM, and prefers 256 colors.

Introduction:

At Iowa State University, laboratory safety is largely the responsibility of the professors teaching a lab course. While each presents safety information relevant to a particular experiment or laboratory, there is no comprehensive safety training for the students in materials science and engineering. Furthermore, increasingly stringent requirements to provide documentation of standardized safety training have brought about a need to update the method of safety training.

A new approach for teaching safe laboratory practices has been developed for materials science laboratories at Iowa State University. Students are required to complete a computerized safety tutorial and pass an exam before working in the laboratory. The safety tutorial includes sections on chemical, electrical, radiation and high temperature safety. The tutorial makes use of a variety of interactions, including "assembly" interactions where a student is asked to drag and drop items with the mouse (either labels or pictures) to an appropriate place on the screen (sometimes in a specific order). This is extremely useful for demonstrating safe lab practices and disaster scenarios. Built into the software is a record tracking scheme so that a professor can access a file that records which students have completed the tutorial and their scores on the exam. This paper will describe the development and assessment of the safety tutorials.

Approach:

Development philosophy

Computer-based development was selected as a mode of delivery largely because of its flexibility. Animations, color photographs and images, and sounds are easily accommodated. Also, courseware allows interactive learning, where the student participates in the lesson. Development of the safety courseware did not require extensive training or expense since the Materials Science and Engineering Department at ISU already has the resources and a group of students who are developing other computerized courseware modules.

The safety courseware provides standardized information and training, as well as documentation of the students test results. The courseware also relieves the professor of the obligation to spend extensive class time on safety training. Students enjoy the safety tutorials because they can learn the material at their own pace in an interactive environment before being tested on the safety material.

Software description

Authorware Professional™ 2.0.0 courseware development software was selected as a vehicle for delivery of these modules for a number of reasons. This software is available for both the Apple Macintosh and IBM-PC compatible platforms, and can be translated from the Macintosh to the PC, utilizing a large fraction of educational computing equipment already in place. This software also allows the "packaging" of programs so that the end product is self-contained. The user does not need to own the software in order to use the product. This software also has a full range of multi-media capabilities.

Navigating through the courseware is through pull-down menus and click-touch areas similar to those familiar to most students who have worked either in the Macintosh or Windows-environments. Within each section, push-button forward and backward arrows allow the students to review material already presented. The program is linear, so that the student must cover each area of safety training before proceeding to the test.

The effectiveness of this approach will be tested on materials science lab students next spring. Students will be required to complete the safety tutorial and pass the test before they are allowed to proceed with any laboratory experiments. Although the laboratory professor should point out any specific hazards before experiments and answer any safety questions, the students are expected to be aware of all emergency procedures and safety hazards in the laboratory.

Safety Sections

Chemical Safety

The chemical safety portion of this program includes information concerning:

- pre-laboratory preparation
- Materials Safety Data Sheets
- safe laboratory practices
- chemical storage
- "flammable/combustible" chemicals
- "reactive" chemicals
- "corrosive" chemicals
- gas cylinders
- emergency procedures
- waste management

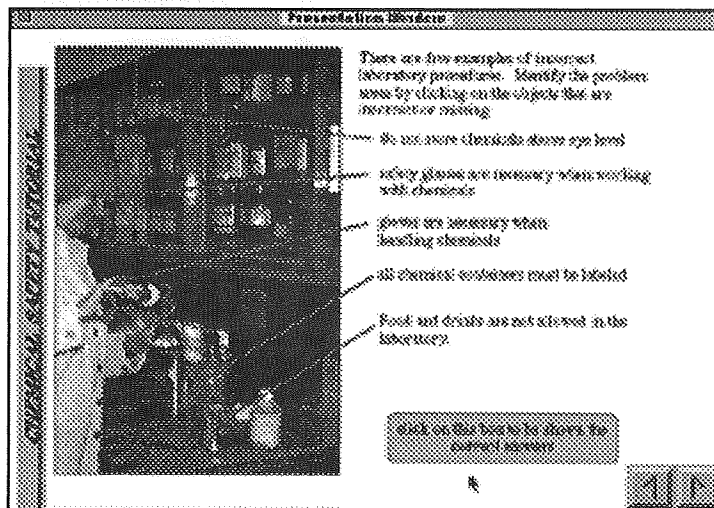


Figure in the chemical safety section where the students must identify bad laboratory procedures.

Electrical Safety

The electrical safety portion of this program includes information concerning:

- conductors
- shock injury
- lockout/tagout
- overloaded circuits
- extension cords
- tools
- apparel
- emergencies

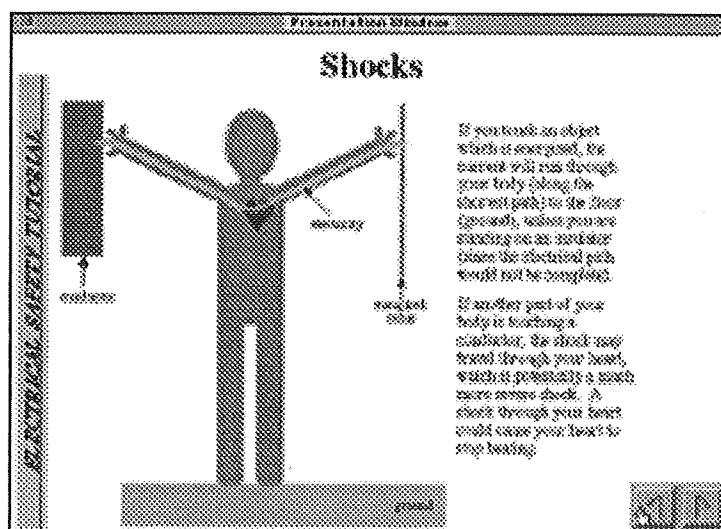


Figure of dangerous electricity flow in a shock.

Radiation Safety

The radiation safety portion of this program includes information concerning:

- what are x-rays?
- x-ray production
- x-ray health effects and precautions
- x-ray producing equipment
- what are lasers?
- laser production
- laser health effects and precautions
- laser producing equipment

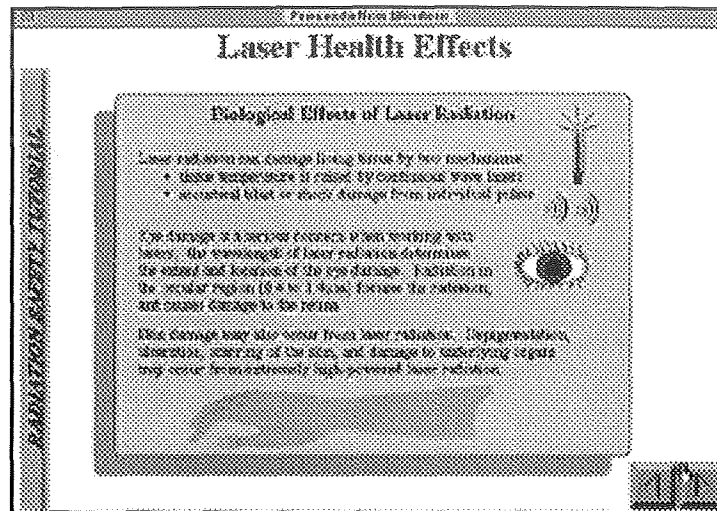


Figure of biological effects of laser radiation.

High Temperature Safety

The high temperature safety portion of this program includes information concerning:

- furnace operation
- burn prevention/treatment
- high temperature equipment

Future Work:

Assessment of Effectiveness

Although the modules have been completed, we anticipate making corrections and adjustments in response to comments collected from student testing. We also plan to test this material at other universities and solicit suggestions for improvement.

This work is funded by Engineering Computing Support Services at Iowa State University.

**PROCESSING OVERVIEW: THE ROLE OF
PROCESSING IN THE TOTAL
MATERIALS CYCLE**

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**PROCESSING OVERVIEW:
THE ROLE OF PROCESSING
IN THE TOTAL MATERIALS CYCLE**

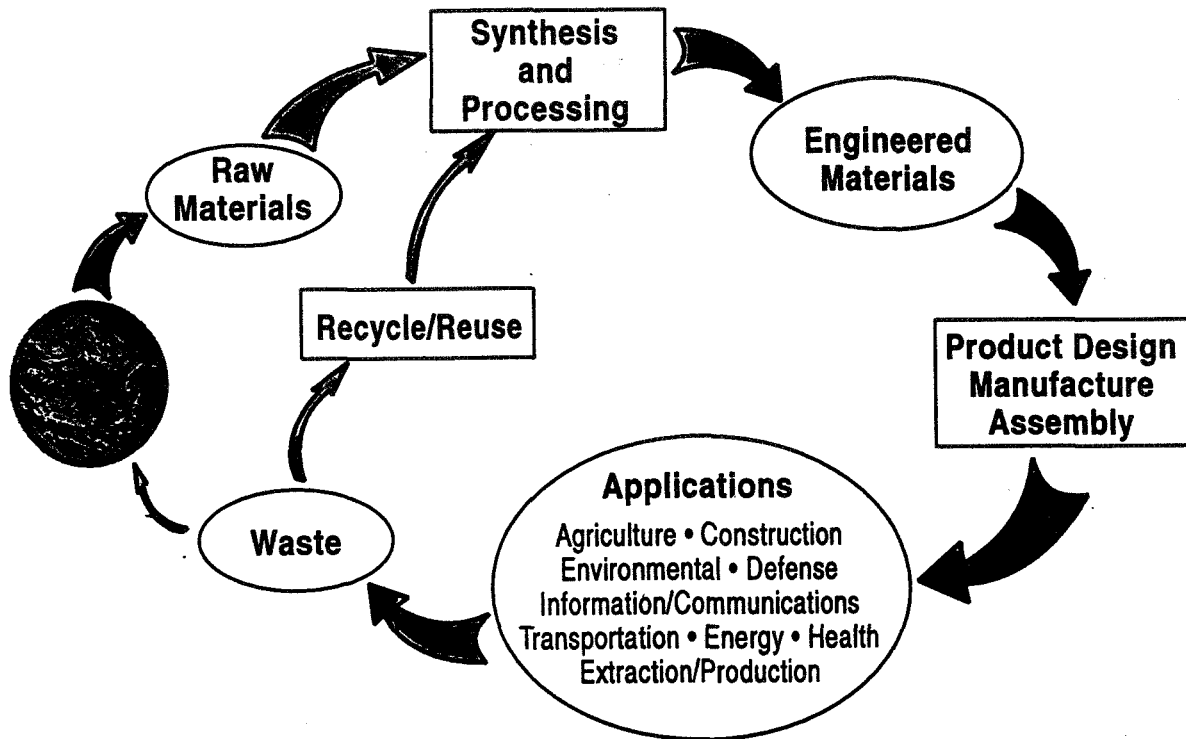
Douglas F. Craig

**Metals and Ceramics Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831**

OUTLINE

- **Changing environment**
- **Cross cutting themes in materials science**
- **Applications to materials processing**
- **The future**

The Total Materials Cycle



THERE IS A CHANGE IN BASIC MATERIALS USE

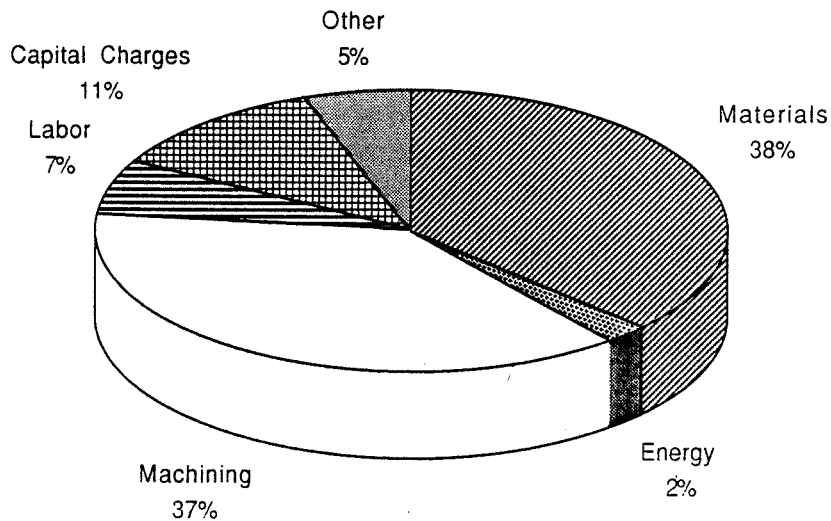
- Substitution of one material for another has slowed the growth of demand for particular materials
- Design changes have increased the efficiency of materials use
- Saturation of markets which were previously expanding has occurred
- Low materials content in products for new markets partly because of the cost of higher performance materials

MARKET IS FOR LIGHTER, STRONGER, MORE DURABLE MATERIALS

Desired Characteristic	Aero.	Auto	Bio	Chem.	Elec.	Energy	Metal	Tele.
Light / strong	✓	✓	✓					
High temp resist.	✓			✓	✓	✓	✓	
Corrosion resist.	✓	✓	✓	✓	✓	✓	✓	
Efficient processing	✓	✓	✓	✓	✓	✓	✓	✓
Near-net-shape	✓	✓	✓	✓	✓	✓	✓	✓
Prediction of life	✓	✓	✓	✓	✓	✓	✓	✓
Prediction of properties	✓	✓	✓	✓	✓	✓	✓	✓
Materials data bases	✓	✓	✓	✓	✓	✓	✓	✓

(Materials Science and Engineering for the 1990s)

MATERIALS AND MACHINING DOMINATE COST OF ADVANCED CERAMICS

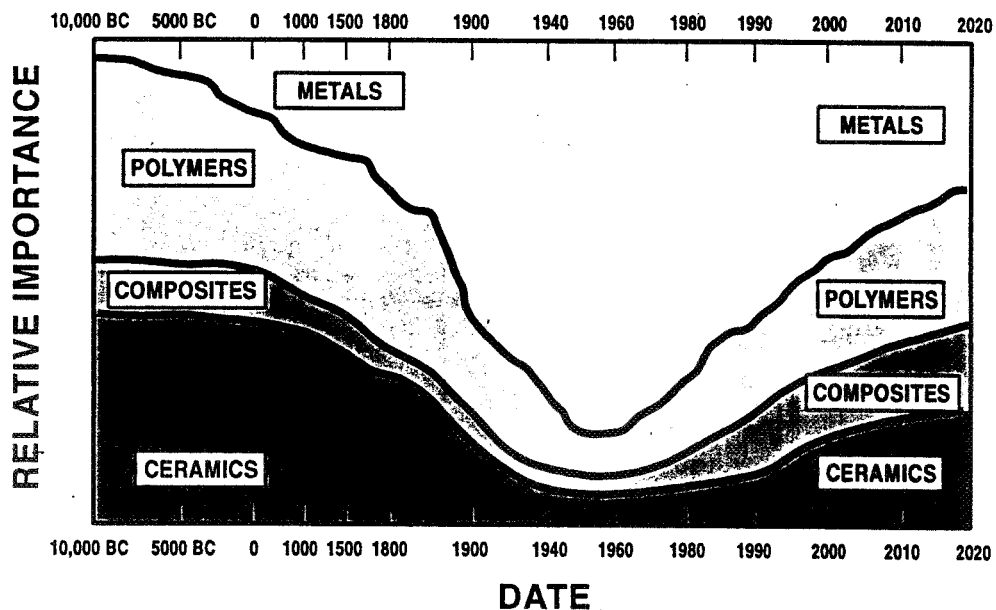


Estimated cost elements of silicon nitride roller followers

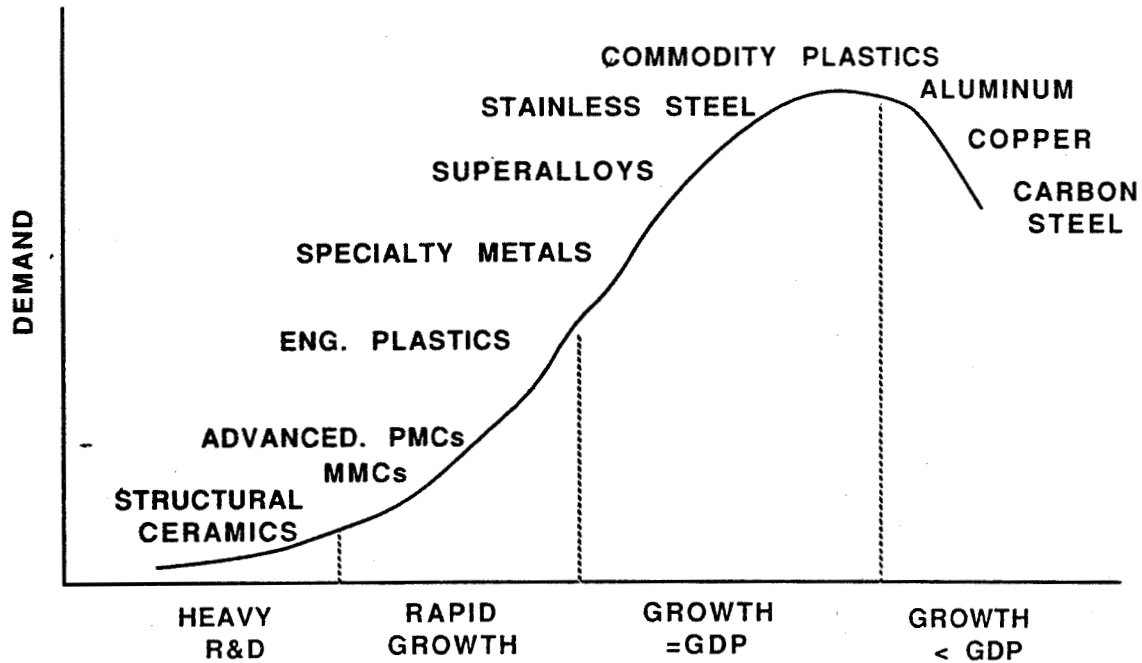
THE CHANGING MATERIALS WORLD

- Technology explosion
- Organizational implosions
- International competition
- Increasing marketplace requirements
- Decreasing demand for basic materials
- Decreasing federal R&D funding
- Regulatory environment

EVOLUTION OF MATERIALS SCIENCE AND ENGINEERING



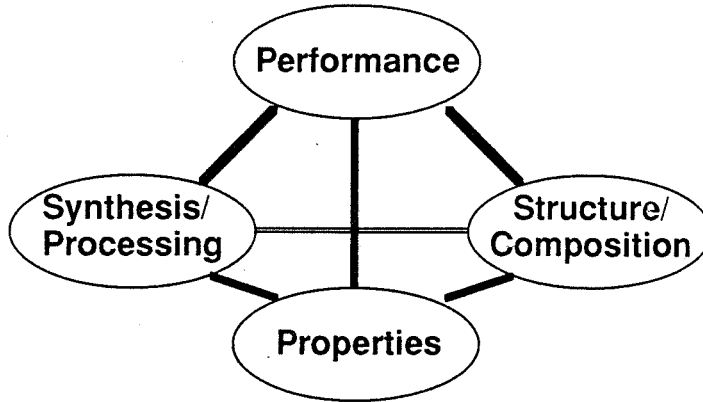
DEMAND FOR BASIC MATERIALS HAS LEVELLED OR IS DECREASING



PROCESSING EFFICIENCY

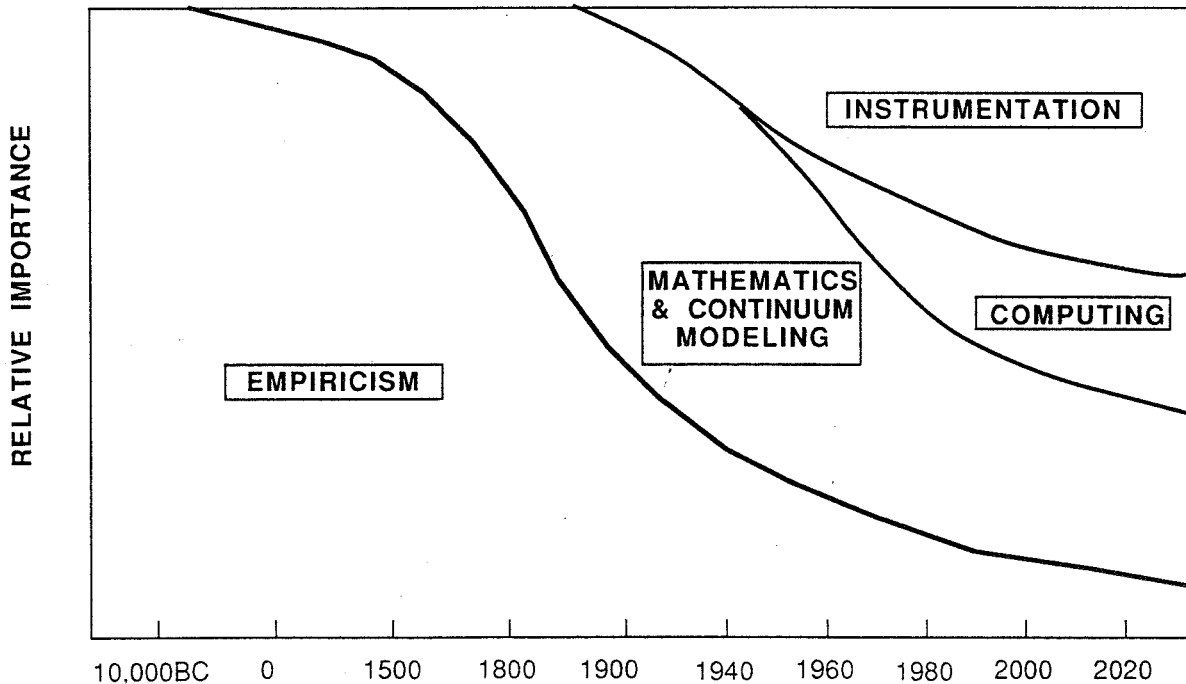
- Reduce cost of operations
 - Capital
 - Labor
 - Energy
- Improve process recovery
 - Net shape production
 - Material recovery rates - scrap losses
 - Recycle
- Minimize defects and rejects
 - Process knowledge
 - Instrumentation and process control
 - TQM

ELEMENTS OF MATERIALS SCIENCE AND ENGINEERING

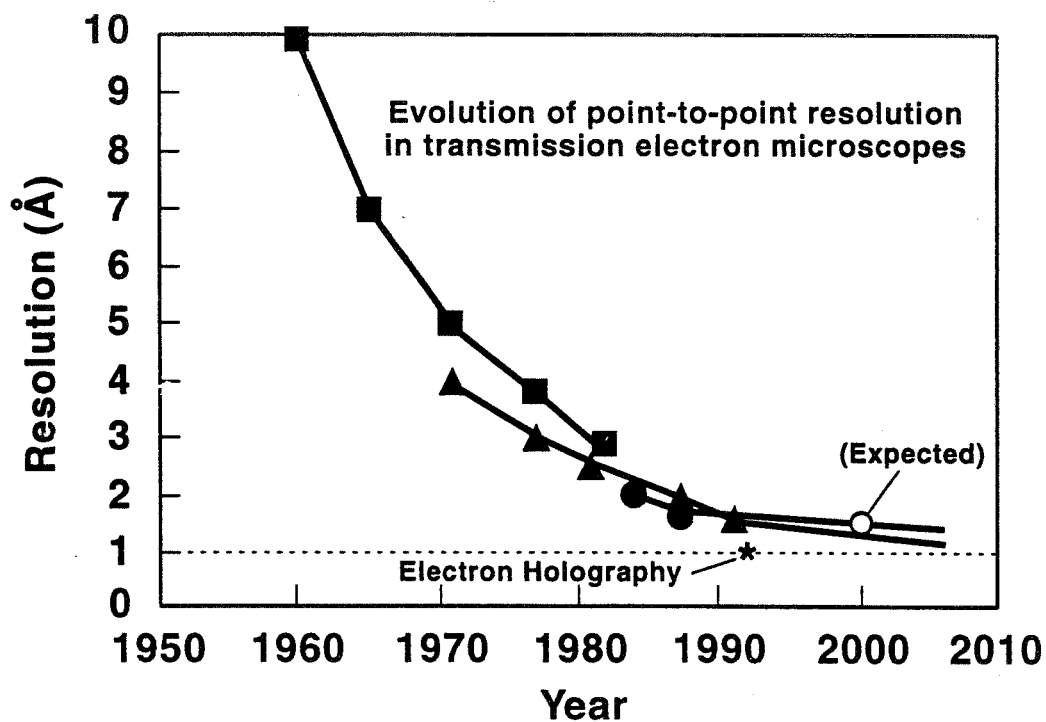


PROPERTIES AND PERFORMANCE DEPEND ON STRUCTURE AND COMPOSITION WHICH IN TURN DEPEND ON PROCESSING

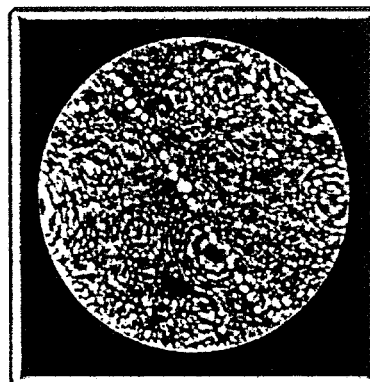
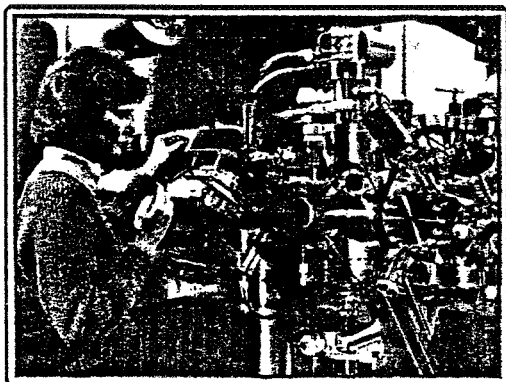
INSTRUMENTATION AND COMPUTING ARE BECOMING INCREASING IMPORTANT IN PROCESSING



ADVANCES IN INSTRUMENTATION

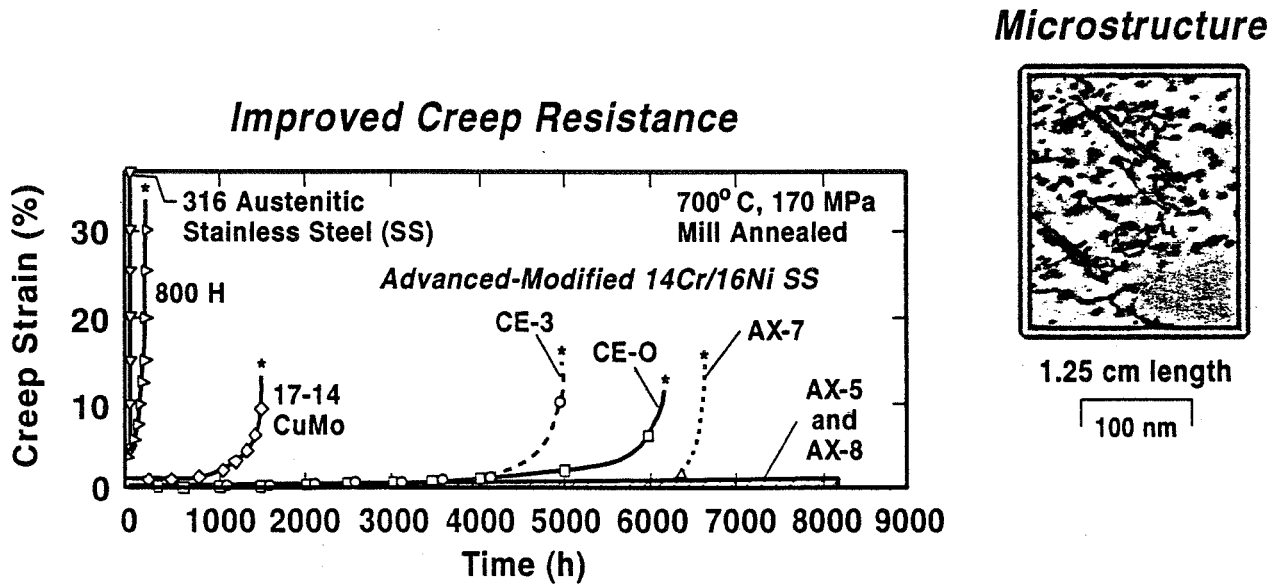


ATOM PROBE SHOWS BORON AT GRAIN BOUNDARIES IN NICKEL ALUMINIDES

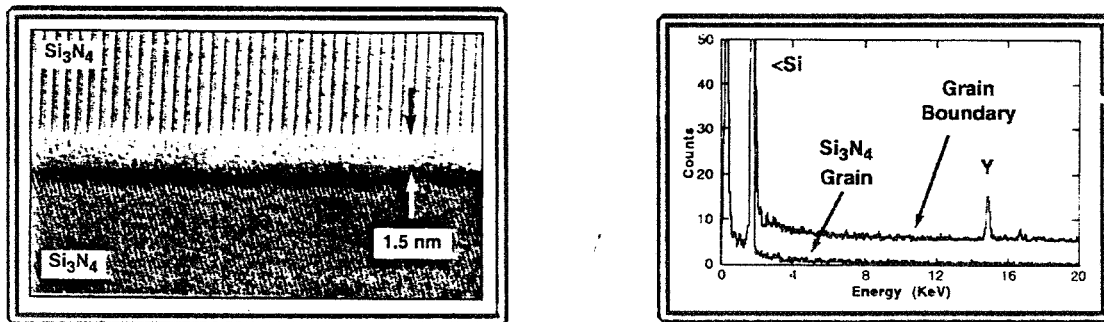


Atom Probe

IMPROVEMENTS IN CREEP RESISTANCE WITH MINOR ALLOYING ADDITIONS

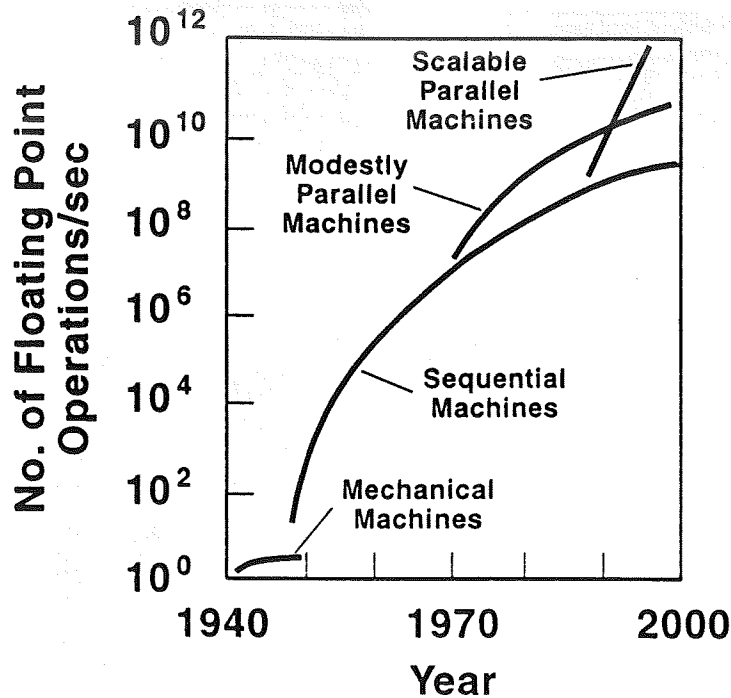


IMPROVED SILICON NITRIDES RESULT FROM UNDERSTANDING GRAIN BOUNDARY PHASES



High resolution transmission electron micrograph and corresponding energy dispersive x-ray spectrum show yttrium present in amorphous grain boundary phase

HIGH PERFORMANCE COMPUTING



Sequential -

CPU with memory

Modestly parallel -

multiple processors sharing one memory

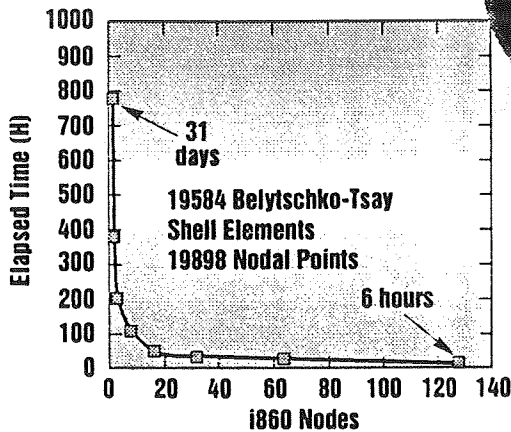
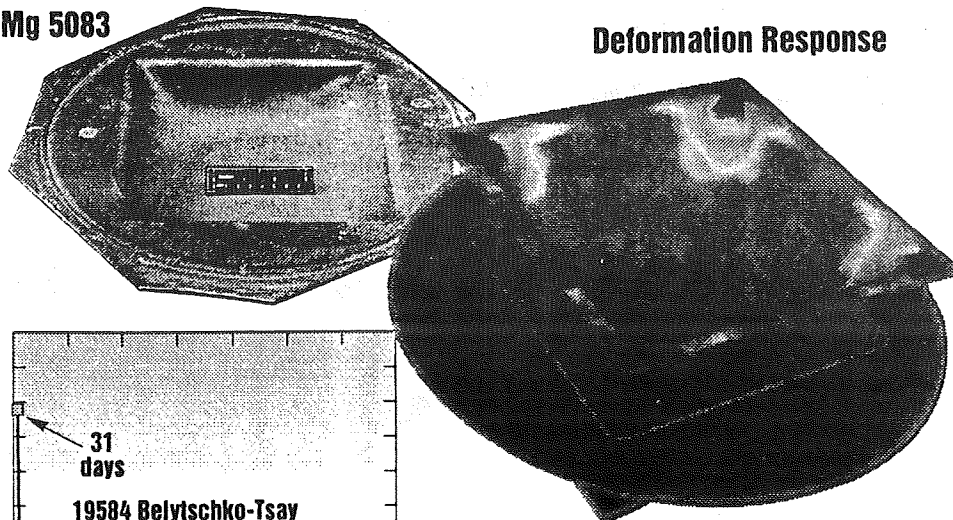
Scalable parallel -

large number of processors with local memories and interprocessor communications

Simulation of Super Plastic Forming of Aluminum

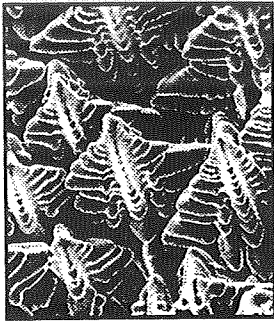
Al-Mg 5083

Deformation Response

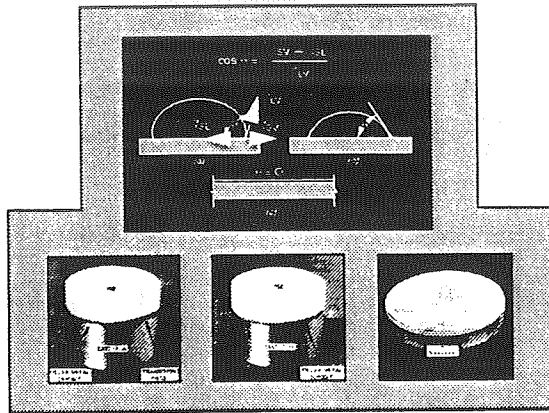


Calculation of Super-Plastic Forming

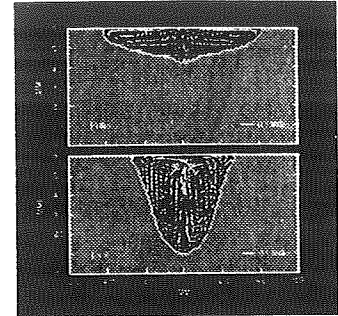
METALS JOINING



Weld Metal Solidification



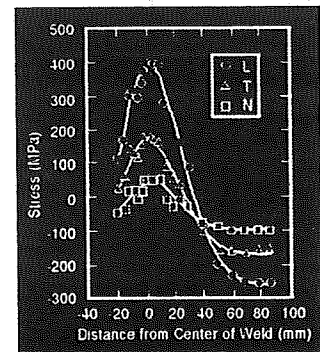
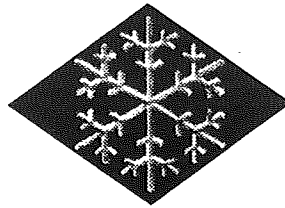
Brazing of Metals and Ceramics



Weld Modeling

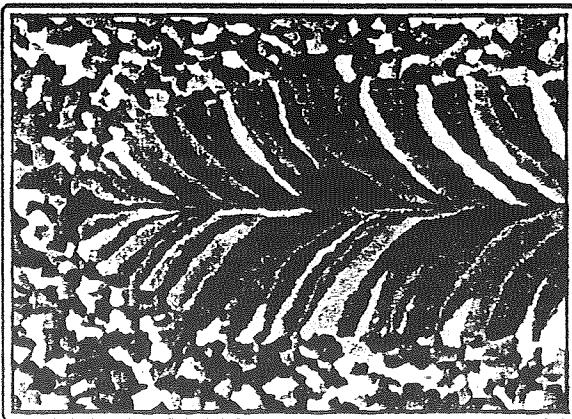


Advanced Welding Processes



Neutron Residual Stress Measurement

Weld Solidification Structure

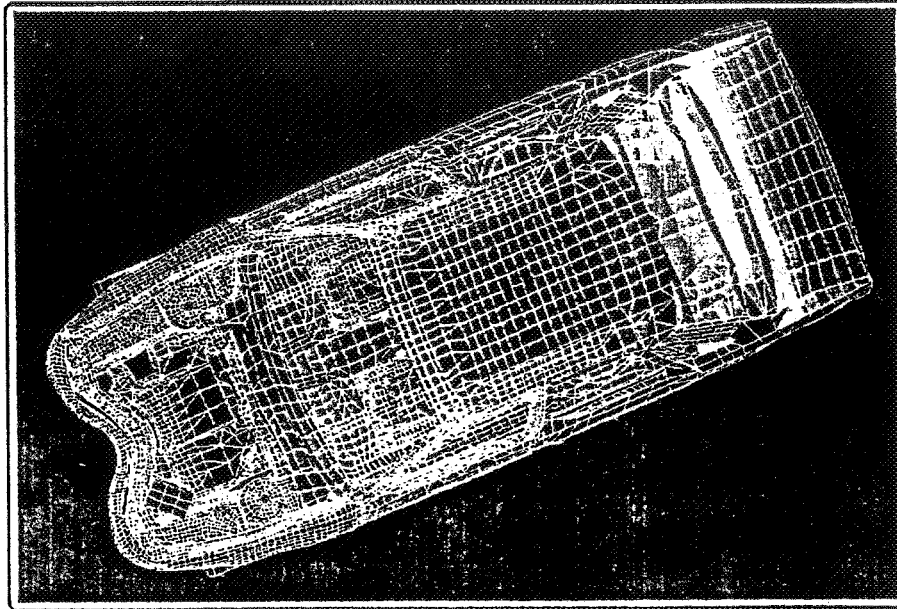


Computer Simulation

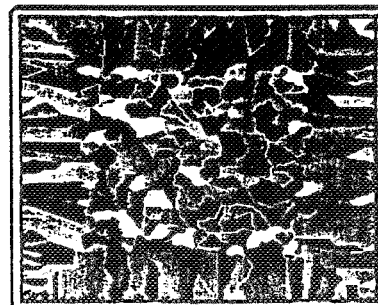
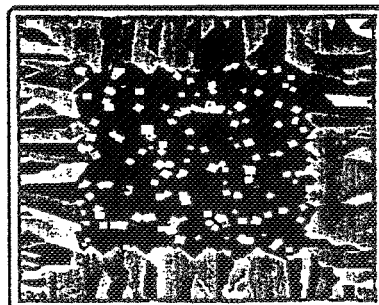
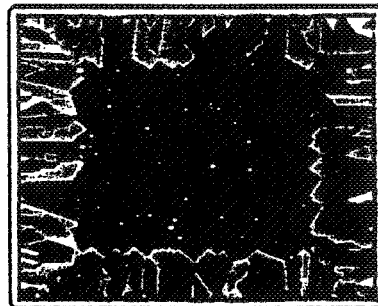
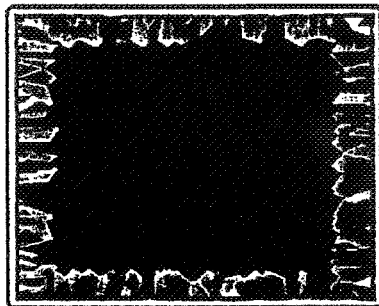


**Experimental Weld Microstructure
(ASM Handbook)**

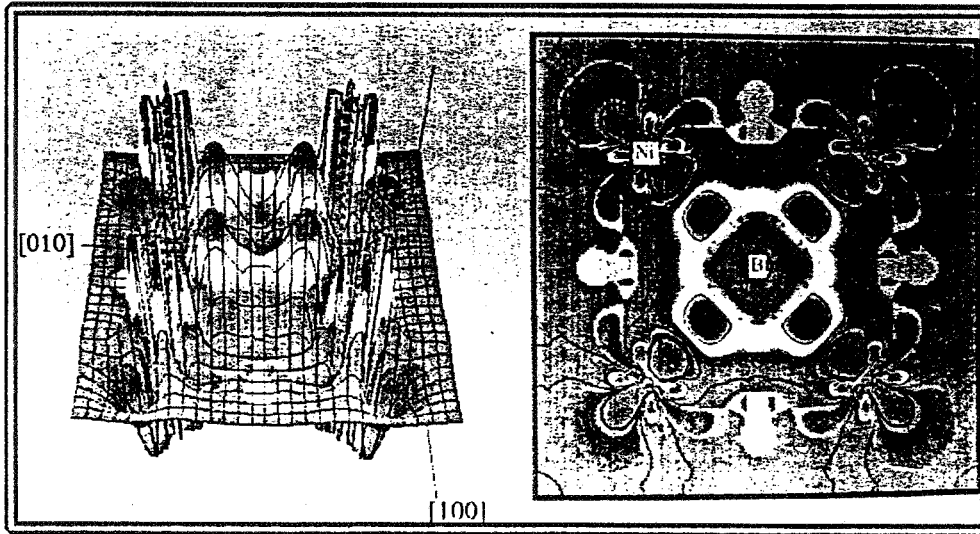
Crash Simulation On The Intel Paragon



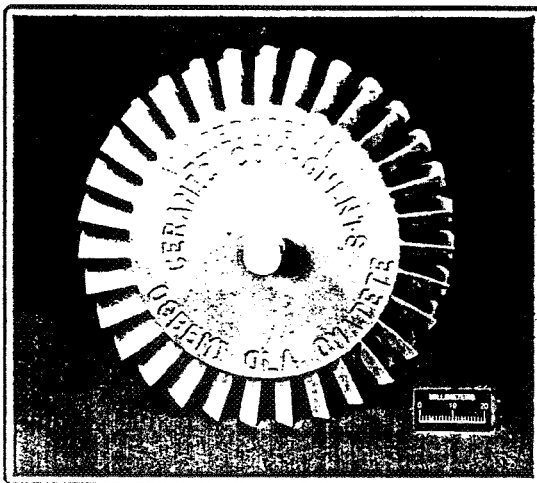
CELLULAR AUTOMATA SIMULATION OF SOLIDIFICATION MICROSTRUCTURE



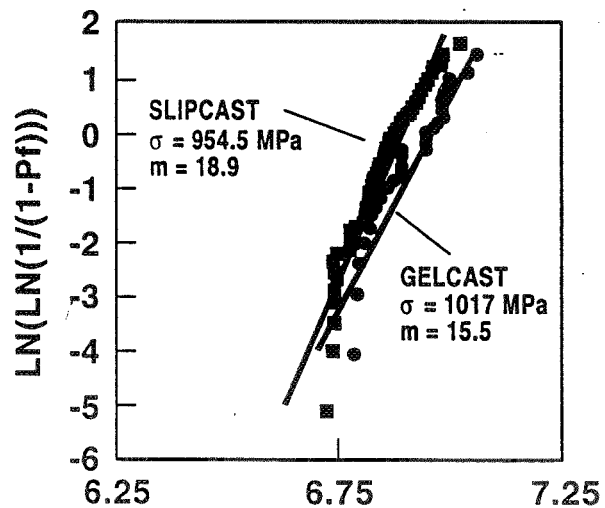
FIRST-PRINCIPLES THEORETICAL INVESTIGATIONS PROVIDE INSIGHT ON THE ROLE OF BORON



GELCASTING: NEAR NET SHAPE CERAMIC FORMING

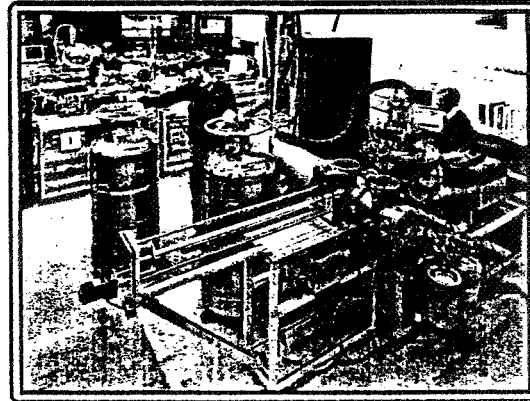
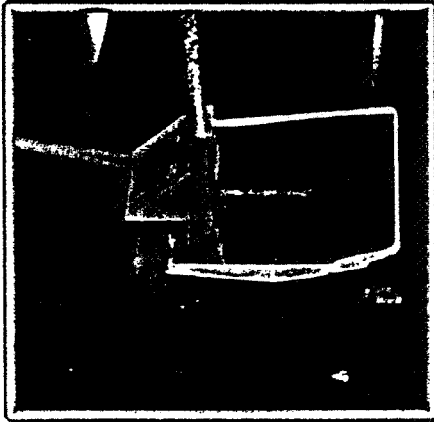


Gelcast silicon nitride rotor: AlliedSignal



Slip- and gelcast parts exhibit similar strength

ATOMISTIC PROCESSING



Perovskite waveguide by MBE

THE FUTURE

Computational materials science will move from research to applications: process simulations, models, and control systems

Advanced instrumentation will accelerate structure - processing - property correlations for microalloying elements for tailored materials and improved properties

Environmental concerns, cost, and ultimately materials availability will drive up recycle /reuse and increased direct casting and powder metallurgy

Atomic scale processing (MBE, CVD, LPCVD, ion beam deposition) for new kinds of devices

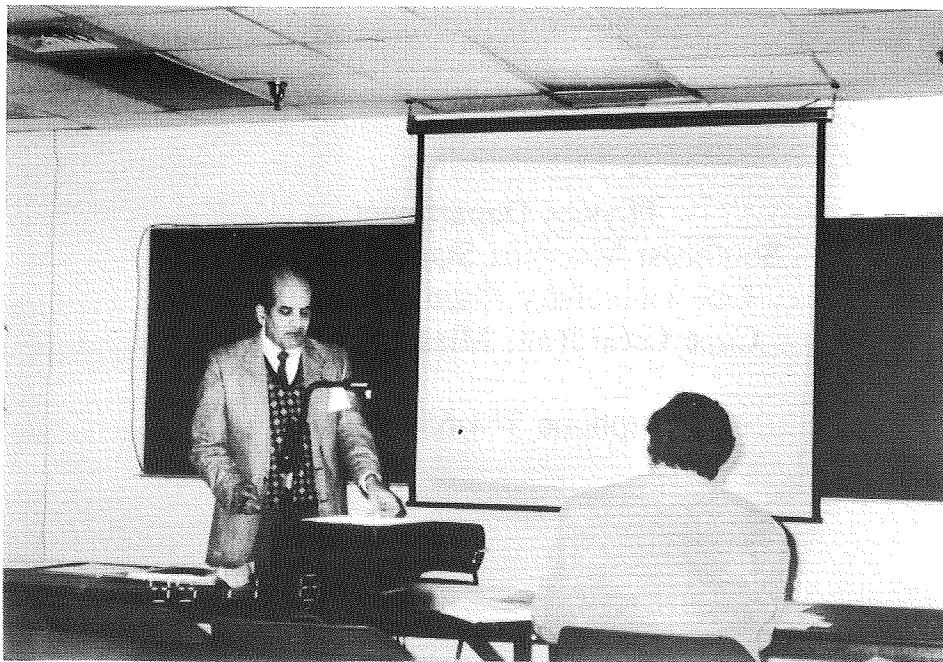
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**TEMPERATURE DEPENDENCE OF THE
MICROWAVE DIELECTRIC BEHAVIOR
OF SELECTED MATERIALS**

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Temperature Dependence of the Microwave Dielectric Behavior of Selected Materials

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KEY WORDS

Resonant cavity; dielectric relaxation; field perturbations; frequency shifts and Q-changes.

OBJECTIVES

1. To learn to tune a resonant cavity in a microwave spectrometer.
2. To learn the technique of producing a marker signal on the oscilloscope.
3. To learn to operate the microwave spectrometer in order to take data as a function of frequency and temperature.
4. To learn about the design of an efficient thermal bath.

SUMMARY

A very sensitive thermal bath is designed to study the effect of temperature on the microwave dielectric response of a sample of nickel oxide and cobalt oxide. The sample under study is placed in a microwave resonant cavity in the TE_{011} mode. The perturbations of the electric field are recorded in terms of the frequency shifts and the width changes of the microwave resonant signal as seen on the oscilloscope. The real and imaginary parts of the dielectric constant are calculated by using the values of the frequency shifts and width changes in the Slater's perturbation equations. The dielectric behavior of nickel oxide and cobalt oxide and also their mixture is studied at a microwave frequency of 9.2 GHz as a function of temperature. A computer program is written to analyze the dielectric constant values at different temperatures. The resonant cavity seems to be very sensitive in studying the dielectric relaxation mechanism in these materials. The dielectric behavior is also analyzed

using Debye's equations and relaxation times for these materials are calculated at microwave frequencies.

INTRODUCTION

The investigation of the dielectric properties of matter has provided an important approach to understand the structure of matter, and without some understanding of the relation of these properties of matter, our extensive knowledge of dielectric behavior loses much of its significance. A number of investigators have studied the dielectric properties of different materials as a function of frequency and temperature (Refs. 1-8). Resonant circuit methods have been used up to 10^8 Hz, but these methods are not suitable beyond this frequency range because of energy loss into the space. A microwave resonant cavity technique has become very useful in studying the dielectric relaxation mechanism in different materials. The microwave resonant cavity displays the same resonant characteristics as a tuned circuit; the basic difference between the two is that the current and voltage of the tuned circuit are replaced by electromagnetic fields. Similar to a waveguide that forms the microwave analogy for the transmission line of ordinary circuit theory, so a hollow cavity forms the analogy for a circuit element. The quality factor Q which is defined as the ratio of the resonant center frequency to the half-power frequency width of the resonant curve is determined either in the resonant circuits or the resonant cavity from the shape of the resonant curve. Because of the low resistances in a resonant cavity, a large value for Q can be obtained as compared to a resonant circuit.

As the material to be studied is placed in the cavity, it perturbs the electric or magnetic field in the cavity depending on what mode the cavity is in, and from this either electric permittivity or magnetic permeability can be determined. Slater's perturbation theory (Ref. 9) is used to explain the interaction of the materials properties and the electromagnetic fields. According to this theory, as the material to be studied is introduced into the cavity it causes the resonant frequency shift and the quality factor Q to change in accordance with the characteristic electric properties of the material loading the cavity.

The relaxation rate is defined as the rate at which a system comes into equilibrium with its surroundings when various physical aspects of its surroundings such as temperature, electric and magnetic fields are changed. The nature of the dependence of the relaxation rates on temperature is very significant in understanding the physical nature of the process. In a process in which the relaxation rate depends on the temperature, it is certain that at some stage in the process a molecule or other unit involved is forced to wait until it has acquired a considerable amount of energy by thermal fluctuations, in excess of the average thermal energy in the medium.

The electron transport properties of transition metal oxides are different than those of germanium and silicon. In case of these semi-conductors, most of the observed phenomena has been on the basis of energy bands. But in the case of transition metal oxides the electron is considered to be localized on a given lattice site and requiring an activation energy to move to an adjacent site. The behavior of electrical conductivity in Li-doped nickel oxide and other mixed systems of transition metal oxides has been studied (Ref. 10). It has been observed in these studies that if nickel oxide due to a deficiency of nickel or an addition of lithium deviates from stoichiometry, it becomes a semi-conductor and its conductivity varies from 10^{-7} to 10^{-1} ($\Omega\text{-cm}$)⁻¹. In this experiment a microwave resonant cavity is used to study the dielectric behavior of nickel oxide, cobalt, oxide and their mixtures. The dielectric relaxation mechanism in these two materials is studied as a function of temperature at a frequency of 9.2 GHz.

EQUIPMENT CONFIGURATIONS, THEORY AND RESULTS

A microwave spectrometer in the x-bands of frequencies is used to study the dielectric behavior of nickel oxide, cobalt oxide and their mixtures. The details of the spectrometer have been discussed elsewhere (Ref. 11). The sample under study is placed in the resonant cavity and the perturbations of the microwave resonant signal are recorded in terms of its frequency shift and width change. This is achieved by placing the frequency markers on the left, center and right peaks of the microwave signal as the material under study goes through

a phase change. This paper will include reasonable details of frequency multiplication. It is often desirable to take an ordinary radio frequency signal, and multiply it to the microwave range, so as to make absolute standardization of microwave frequencies in terms of known standards of lower frequencies. This multiplication can be done by conventional frequency multipliers, using ordinary devices, until we obtain frequencies in the microwave range. The other application would be to produce very high frequencies through harmonic generation from klystrons. Klystrons become more difficult to construct as the frequency becomes higher and higher, on account of the reduced size of the cavities and other parts of the resonant circuit.

Systems which are rich in the generation of harmonics can be used as frequency multipliers. All the single tube amplifiers possess this characteristic due to the non-linearity existing in the plate current curve when the signal e.m.f.'s. are applied in the grid. Therefore, one more intermediate amplifier applied in r-f channel may act as a frequency multiplier.

To produce microwave frequencies, a higher order of multiplication is needed, especially if one starts from an oscillator in the region of 100 kc. In some microwave-frequency standards conventional tubes are used up to a frequency of some hundreds of megacycles, and then followed by a silicon crystal harmonic generator. The crystal harmonic generators receive fundamental microwave power from klystron, and because of the nonlinear response of the semiconductor to the microwave field, they produce harmonics of the fundamental. Generally good harmonic generators involve efficient matching of the fundamental microwave power into a crystal and appropriate nonlinear characteristics. They also require efficient radiation of the generated and desired harmonics into the waveguide region where frequency comparisons are to be made.

In the present investigation, two different kinds of frequency multipliers were used. One kind was Model 900 B Sweep Signal Generator made by Jerrold Electronic Corporation which was calibrated to Model 1112 A and 1112 B General Radio Standards slowed to a 105 B quartz oscillator made by Hewlett-Packward. The frequency multiplication in both of these units is

basically the same. The operation of the frequency standard can be followed from the block diagram shown in Figure 1.

This 1112 A, B frequency standard utilizes a chain of frequency multipliers and r-f amplifiers to produce the higher frequencies from a 5 MHz oscillator stabilized by a quartz crystal. The standard frequencies are 10 MHz, 100 MHz and 1000 MHz. The highest of these frequencies is applied to one electrode of the mixer crystal and the other two lower frequencies and the receiver are connected to the other electrode. To prevent loss of the higher frequency power into the low frequency circuits, a small capacitance and an inductance are provided at the lower frequency end of the crystal. Line stretchers vary the lengths of the coaxial cables, and a tuning stub shorted at the end adjusts the line impedance at the crystal. A meter monitors the crystal current and a variable resistor adjusts the bias on the crystal to optimize the nonlinearities for maximum harmonic production. A plunger in the mixer can be adjusted to give a maximum microwave field at the crystal.

The crystal mixer rectifies the r-f signal and the rectified wave is known to be the resultant of components of a harmonic wave. Through the Fourier analysis of the non-sinusoidal periodic wave form, it can be seen that the rectified wave is made of sinusoidal components whose frequencies are integral multiples of the fundamental frequency of the non-sinusoidal periodic wave form. Through the multiplication process the initial frequency of 5 GHz in the crystal oscillator is increased to the required frequency. This process of multiplication is continued until finally a high order harmonic output is delivered into the mixer and the mixing process occurs. Since the arbitrary nth harmonic wave from the frequency multiplier can be matched to the modulated klystron frequency, the frequency difference can be received by the radio receiver. The radio receiver used for the interpolation method was a model 1330 A bridge oscillator made by General Radio Company. The radio receiver responds to only the frequency difference between the klystron resonant frequency and an nth harmonic from the frequency multiplier. This difference of frequency can be expressed mathematically by the following equation:

$$f_m = n f_a \pm l f_b \pm m f_c \pm f_r \quad (1)$$

where f_m is the microwave frequency, f_a , f_b , and f_c are the standard frequencies, f_r is the frequency to which the interpolation receiver is tuned, and l , m , and n are integers. The plus or minus sign in the above equation shows that the local oscillator signal can mix from either a sum or difference with the center frequency of the klystron. The resulting frequency difference yields two frequency markers which are displayed on the oscilloscope. The appearance of the markers, displayed on one channel of a dual trace oscilloscope, depends strongly upon the wave form, frequency, and amplitude of the klystron modulation.

A cylindrical resonating cavity in the TE_{011} mode is used in this study. For such a cavity the solutions of Maxwell's frequency dependent field equations yield solutions for E and H fields which can be expressed as follows:

$$E_r = E_z = 0 \quad (2)$$

$$E_\theta = CD\gamma J_1(\gamma r) \sin\left(\frac{\pi}{b}z\right) e^{i\omega t} \quad (3)$$

$$H_z = CD\left[\omega\epsilon - \frac{\pi^2}{\mu\omega b^2}\right] J_0(\gamma r) \sin\left(\frac{\pi}{b}z\right) e^{i(\omega t - \pi/2)} \quad (4)$$

$$H_r = \frac{-\gamma\pi CD}{\mu\epsilon b} J_1(\gamma r) \cos\left(\frac{\pi}{b}z\right) e^{i(\omega t - \pi/2)} \quad (5)$$

and

$$H_\theta = 0 \quad (6)$$

where J_0 and J_1 are the Bessel functions of the first kind, C and D are the constants, and γ is given by

$$\gamma = \left[\mu\epsilon\omega^2 - \left(\frac{\pi}{b}\right)^2\right]^{1/2} \quad (7)$$

μ and ϵ are the dielectric permeability and dielectric permittivity of the medium, respectively, and P is an integer. As shown in Figure 2 for the electric and magnetic fields configurations of a resonant cavity in TE_{011} mode, the radius of the cavity is 'a' and Z is the vertical dimension of the cavity. It is also seen from this figure that the E field has a circular component in this mode. It does not have a Z or r component and is maximum at $r = a/2$ and $Z = b/2$. Magnetic field has no θ dependence. Just like E -field, it is also symmetric with respect to θ . Note that there is no tangential component of the electric field inside the cavity. It is because of the physics of electromagnetic waves inside a conductor, and not because of the existence of currents in the inside walls, and that is the reason we always have a finite Q of a cavity.

In this experiment each sample studied is cooled below its freezing point by heat exchange mechanism. The samples are placed along the symmetry axis of the cavity. Temperature control of the sample is achieved by flushing cold air around the resonant cavity with the air passed through a heat exchanger mechanism. The rate of flow of air through the heat exchanger determines the rate of cooling. The details of the heat exchange mechanism are discussed elsewhere (Ref. 12). The cavity temperature is monitored using a thermocouple that is in physical contact with the sample inside the capillary tube.

As the sample to be studied is introduced into the cavity, it perturbs the electric and magnetic fields in the cavity and as a result of this quality factor Q of the cavity changes and there is a shift in the resonant frequency of the cavity. The cavity Q changes and the resonant frequency shifts are functions of the dielectric properties of the sample producing the perturbation. These changes in Q and frequency shifts are related to the real and imaginary parts of the dielectric constant through Slater's perturbation equations (Ref. 11). The frequency shifts and the Q -changes were calculated at different temperatures for cobalt oxide; nickel oxide and their mixtures. Figures 3-6 show the behavior of frequency shifts and Q -changes for a sample of cobalt oxide and nickel oxide. From Slater's equations (Ref. 11), frequency shifts and Q -changes are related to the real and imaginary parts of the dielectric constant. The imaginary part of the dielectric constant is also the measure of dielectric loss in the sample studied at a given resonant frequency. As can be seen from these figures, the

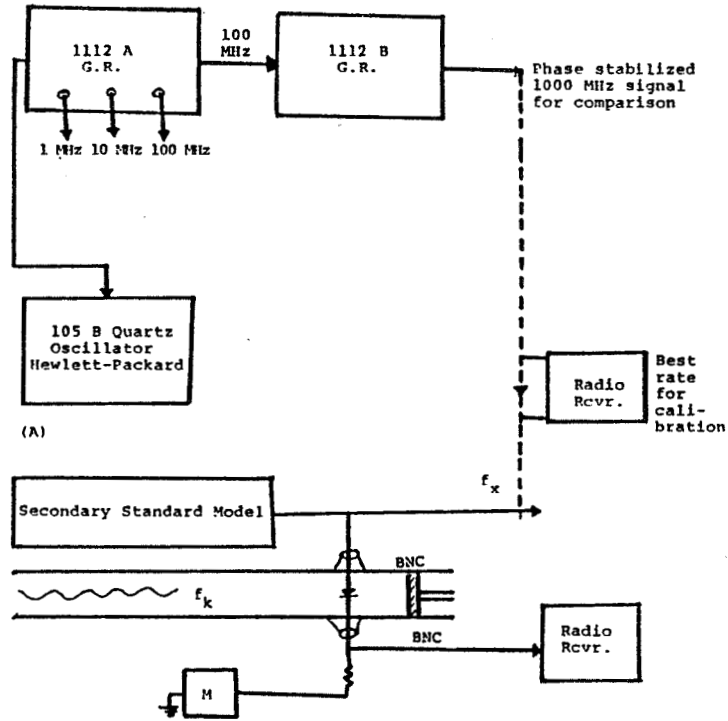
real part of the dielectric constant seems to be temperature dependent for nickel oxide and also for cobalt oxide. The dielectric constant basically remains constant up to 80°C and after that temperature seems to have a dramatic effect on it. There is also a temperature dependence on the dielectric loss term after the sample attains a temperature greater than 0°C. This behavior in the real and imaginary parts of the dielectric constant changes abruptly in a sample that has mixed crystals of cobalt oxide and nickel oxide in the ratio of 50:50. This behavior is shown in Figures 7 and 8. Two major changes are observed in the dielectric data for mixed crystals of nickel oxide and cobalt oxide as compared to their individual dielectric data. First of all, the transition temperature shifts dramatically in the mixed crystals to around 160°C and the real and imaginary parts of dielectric constant show a strong discontinuity around that temperature. Secondly, the dielectric constant attains a much higher value and at the same time the dielectric loss term also changes significantly.

Temperature certainly seems to have a strong effect on the dielectric constant of nickel oxide and cobalt oxide. The dielectric constant is a measure of the electronic and ionic polarizations that are able to follow the electric field orientations at a microwave frequency of 9.2 GHz. As the temperature of the sample under study increases, it increases the atomic distance which in turn affects the ionic and electronic polarizations. More of these dipoles are able to follow the field at higher temperature as is indicated by the higher value of the dielectric constant. In other words, the number of atomic oscillations per unit volume for the sample under study seems to be going down. This behavior seems to be a bit complicated at this point and it will require this study to be extended for the dielectric relaxation of these crystals at a number of microwave frequencies. At each frequency data needs to be taken as a function of temperature and also different ratios of nickel and cobalt oxides. These results will be presented in a different paper that will hopefully simplify the temperature behavior of these transition metal oxides.

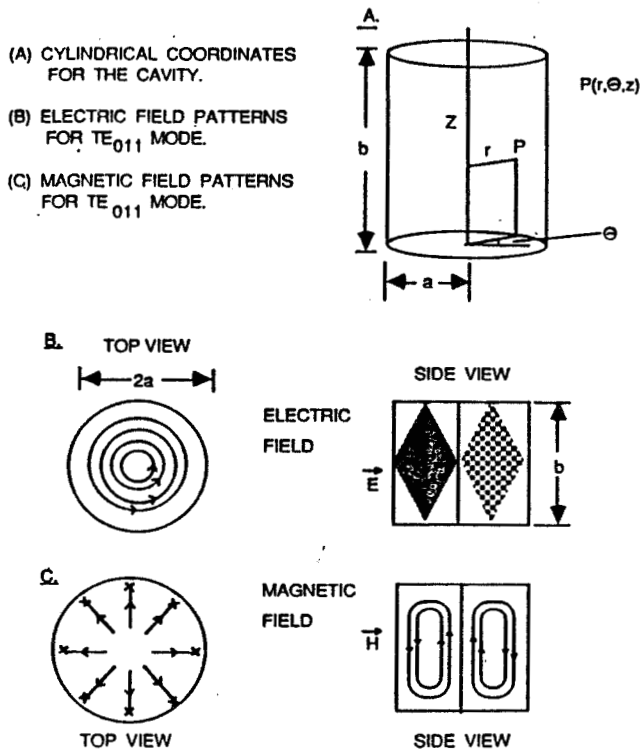
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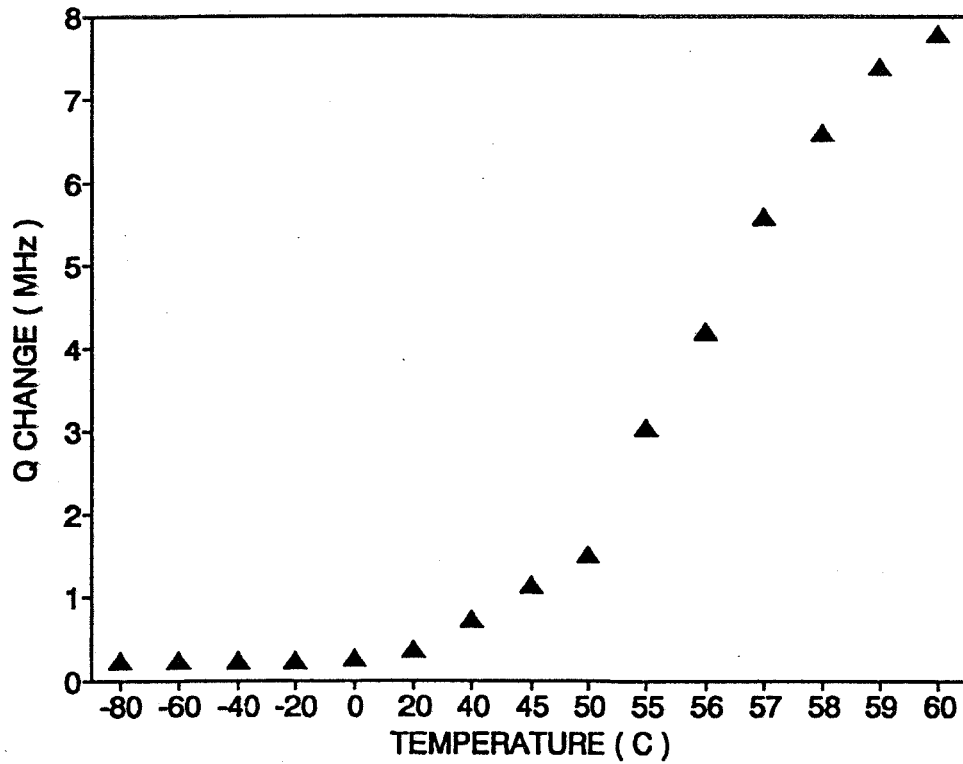
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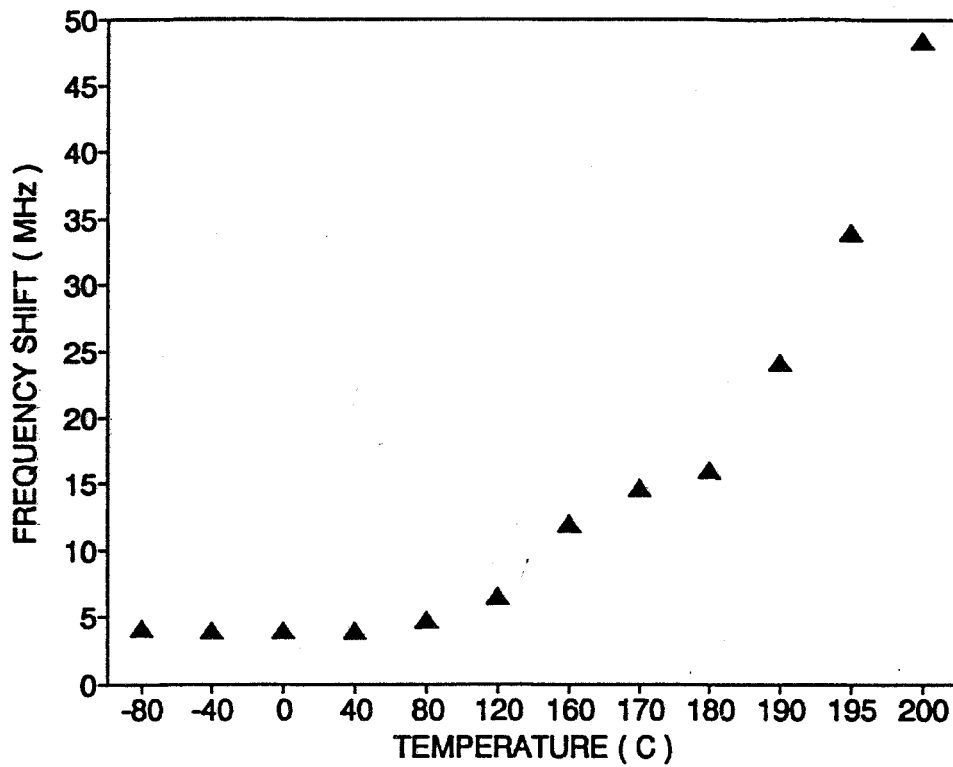
1. Block diagram of the frequency multiplication mechanism used in this experiment.



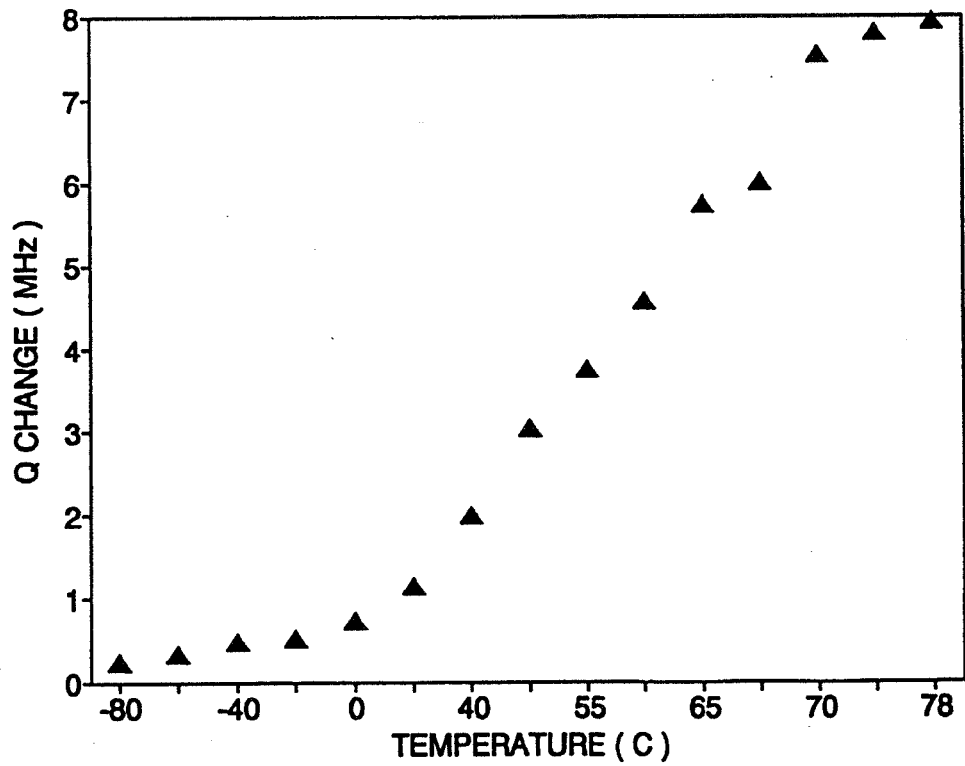
2. Electric and magnetic field patterns of a cylindrical cavity in TE_{011} mode used in this experiment.



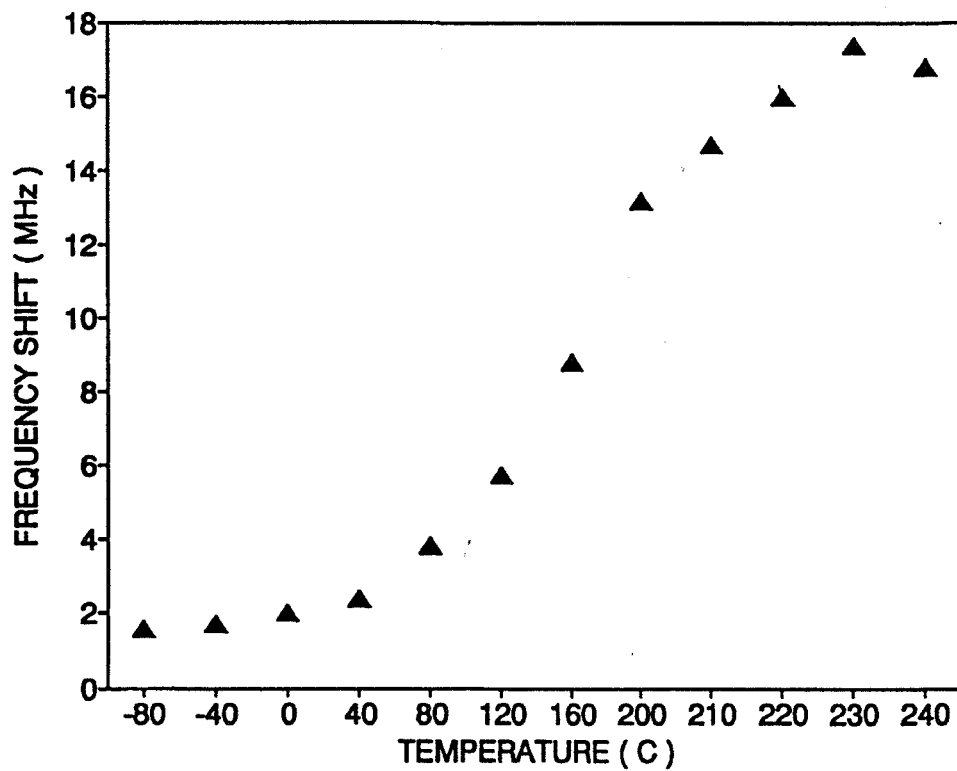
3. Q-change vs temperature for a sample of nickel oxide at a microwave frequency of 9.2 GHz.



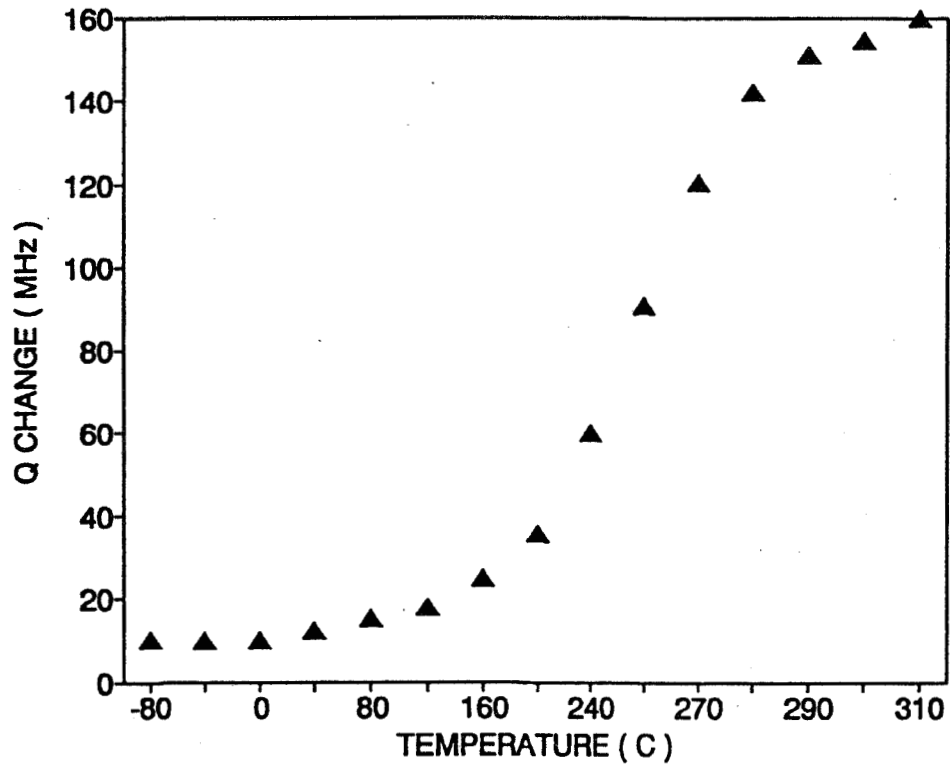
4. Frequency shift vs temperature for a sample of nickel oxide at a microwave frequency of 9.2 GHz.



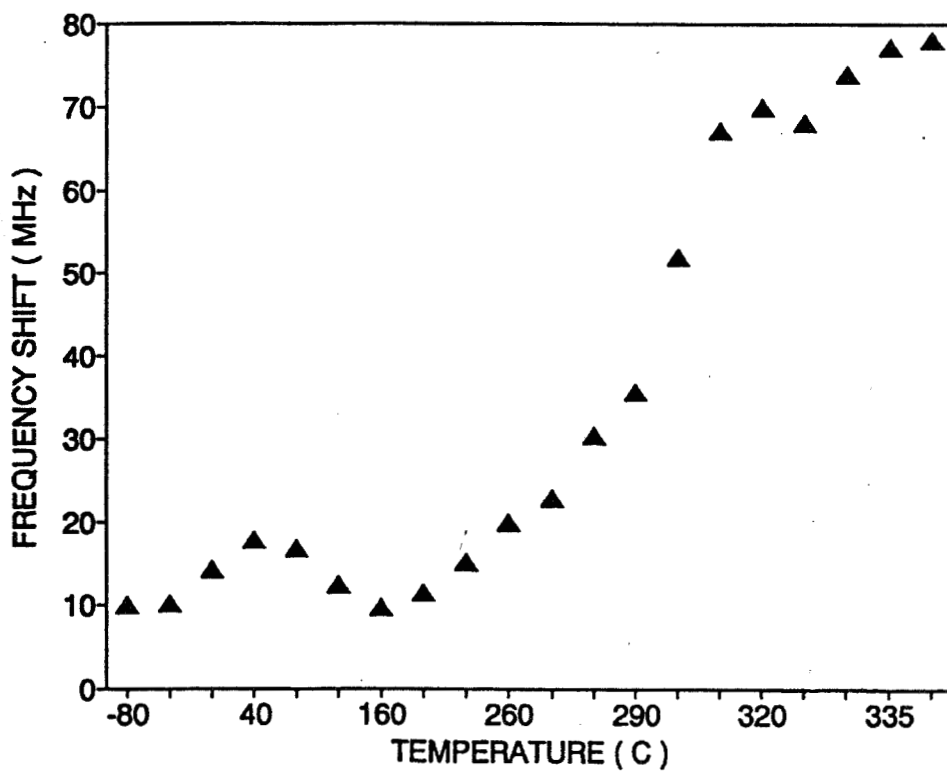
5. Q-change vs temperature for a sample of cobalt oxide at a microwave frequency of 9.2 GHz.



6. Frequency shift vs temperature for a sample of cobalt oxide at a microwave frequency of 9.2 GHz.



7. Q-change vs temperature for a sample of a mixture of nickel oxide and cobalt oxide (50:50) at a microwave frequency of 9.2 GHz.



8. Frequency shift vs temperature for a sample of a mixture of nickel oxide and cobalt oxide (50:50) at a microwave frequency of 9.2 GHz.

**MICROSTRUCTURAL PREPARATION AND
EXAMINATION OF POLYMER-MATRIX
COMPOSITES**

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MICROSTRUCTURAL PREPARATION AND EXAMINATION OF POLYMER-MATRIX COMPOSITES

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ABSTRACT: Adapting procedures widely used in the metallographic characterization of metals and alloys, the microstructural preparation and examination of three polymer-matrix composites (PMC's) is described. The materials investigated contained either hollow ceramic filler particles or woven, continuous carbon/graphite fibers. Since the two particulate composites were considered to be isotropic, only one sample orientation was prepared. For the fiber composite, both longitudinal and planar orientations were studied. Once prepared, the samples were examined using reflected light microscopy. A number of microstructural features were evaluated qualitatively, including porosity and cracks, filler-matrix interfacial bonding, filler particle characteristics (shape, size, size distribution, and loading variation) and fiber characteristics (orientation, packing variation, and discontinuities).

KEY WORDS: microstructure, metallography, optical microscopy, polymer-matrix composite (PMC), particulate filler, carbon/graphite fiber, cyanate ester resin, epoxy resin.

PREREQUISITE KNOWLEDGE: sophomore-level undergraduate laboratory experiment requiring basic knowledge of microscopy, material microstructure, and composites as described in an introductory materials science course and accompanying laboratory course; also suitable for an upper-level undergraduate metallography course having an emphasis on metallic samples. (Instructor Note 1)

OBJECTIVES:

(a) Experimental Goals:

1. to prepare PMC samples using adapted metallographic techniques and
2. to examine microstructurally-prepared samples using reflected light microscopy to characterize their microstructures qualitatively.

(b) Learning Goals:

1. to become familiar with metallographic sample preparation techniques widely used for a variety of metallic and non-metallic materials;
2. to become familiar with reflected light microscopy as a materials characterization tool; and
3. to become familiar with particulate and continuous fiber composites and their microstructural characteristics.

EQUIPMENT AND SUPPLIES: (1) Particulate PMC samples; (2) Carbon/graphite continuous fiber PMC sample; (3) Standard metallographic sample mounting, grinding, and polishing equipment and consumables -- models/designations specified in Procedure or equivalent; (4) Reflected light microscope, preferably with capability to obtain photomicrographs -- model specified in Procedure or equivalent.

PROCEDURE:

Introduction

Originally, metallography [1] was developed to examine and characterize the deformation-free microstructure in the interior of metals and alloys. A sample was sectioned, and the surface-damage layer that resulted was removed through a successive series of grinding and polishing steps using increasingly smaller particle size abrasives. With the emergence of new classes of materials, such as polymers, ceramics, and composites, sample preparation procedures were either adapted or created to allow their structures to be investigated as well (e.g., [2,3] specifically for composites). In addition, metallography is being used increasingly as a microstructural analysis tool for such diverse topics as failure analysis, weldment integrity, product quality control, and microelectronic packages and devices. Microstructural characterization of composites occupied a major portion of the 1994 Technical Meeting of the International Metallographic Society [4].

An engineered composite [5] is a materials system with at least two phases. There is a continuous phase, termed the matrix, which typically is reinforced with either discrete filler particles, discontinuous fibers (or whiskers), or continuous fibers. The variation possible with composites is enormous because both the matrix and reinforcement

can be either metallic, ceramic, or polymeric [6]. One technologically important material type has a polymer matrix.

This work consists of microstructurally preparing three PMC samples for characterization using reflected light microscopy. Two composites having different particulate fillers and one with continuous fibers were used. The particles are hollow ceramic spheres of different sizes, size distributions, and surface finishes. The fibers are woven carbon/graphite bundles (Figure 1 -- Instructor Note 2). The particulate composites have cyanate ester resin [7] matrices, while the fiber composite has an epoxy resin [8] matrix. Composites made with these thermosetting resins have widespread aerospace applications. Since the structure of the particulate composites is not expected to be orientation dependent, only one sample was prepared for each composite. Visual examination of the fiber composite revealed that it is laminated. Since this material is highly anisotropic (i.e., direction-dependent structure and properties), both longitudinal and planar sections were prepared based on the as-received composite beam geometry. These two sections provide orthogonal views, allowing the relative orientations of adjacent laminae (plies) to be determined.

A. SAMPLE PREPARATION [9] (Instructor Note 3)

1. Mount sample in Buehler EPO-KWICK epoxy using the processing procedure [10] prescribed by the manufacturer (Instructor Note 4).
2. Perform series of fine grinding steps (Instructor Notes 5 and 6) using silicon carbide papers, with successive 240, 320, 400, 600, and 2400 grit sizes, corresponding to 54, 29, 23, 17, and 10 μm , respectively. These papers are attached to separate platens of a Buehler Handimet grinder that provided a constant low velocity tap water wash. Before each grinding operation, the sample was first washed with deionized water followed by an ethanol rinse and drying with a commercial hair dryer (cool setting).
3. Perform rough polishing (Instructor Note 6) using a Buehler low speed polisher and Textmet polishing cloth with 6.0 μm diamond paste and Metadi fluid extender. After polishing, rinse and dry the sample as before.
4. Perform final polishing (Instructor Note 6) using a Buehler standard polisher and Microcloth with a 0.05 μm aluminum oxide/deionized water slurry. After polishing, rinse and dry the sample as before.

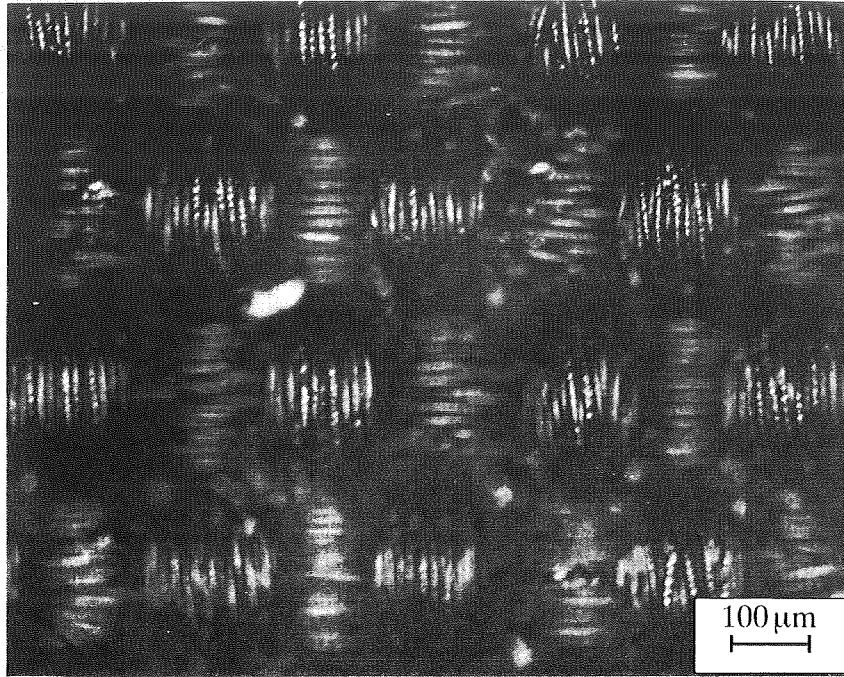


Figure 1. Reflected Light Photomicrograph Showing Woven Carbon/Graphite Bundles.

B. MICROSTRUCTURAL CHARACTERIZATION

1. Examine the resultant microstructure with a Zeiss model ICM 405 bench metallograph. Sample surface is as-polished and unetched.
2. Obtain reflected light photomicrographs using brightfield illumination [11] and Polaroid Type 57 film.

Analysis

1. Studying the photomicrographs, qualitatively characterize the following structural features of the microstructurally-prepared composite as appropriate:

particulate composite -- porosity and cracks; interfacial bonding; and particle shape, size, size distribution, and loading distribution; and

fiber composite -- porosity and cracks; interfacial bonding; and fiber orientation, packing variation, and discontinuities.

SAMPLE PHOTOMICROGRAPHS AND OBSERVATIONS: All of the experimental steps were performed on the three composite samples to verify that the sample preparation procedure was satisfactory. Figures 2 to 5 show representative photomicrographs of the samples prepared microstructurally. For each sample, the scratches were successfully removed from the polymer matrix with minimal surface relief resulting.

Porosity and Cracks: Referring to Figures 2 to 5 reveals that all three samples were well made with a virtual absence of porosity or macrocracks (Instructor Note 7). Scanning the entire surface of the sample shown in Figure 2 revealed at least one pore on the scale of the filler particles. In Figure 2, some small cracks are present in the matrix and appear to emanate from particles near to the polished surface where the matrix is very thin. This suggests that the polymer matrix is brittle. A similar occurrence, however, was not observed in Figure 3 (Instructor Note 8). One possible explanation for at least part of the cracking is the dislodgement of filler particles during sample preparation. The difference in cracking behaviors would then be attributed to a dissimilarity in interfacial bond strengths, presumably associated with the different particle surface finishes. The absence of filler particle breakage reveals that sufficiently gentle mixing conditions were used

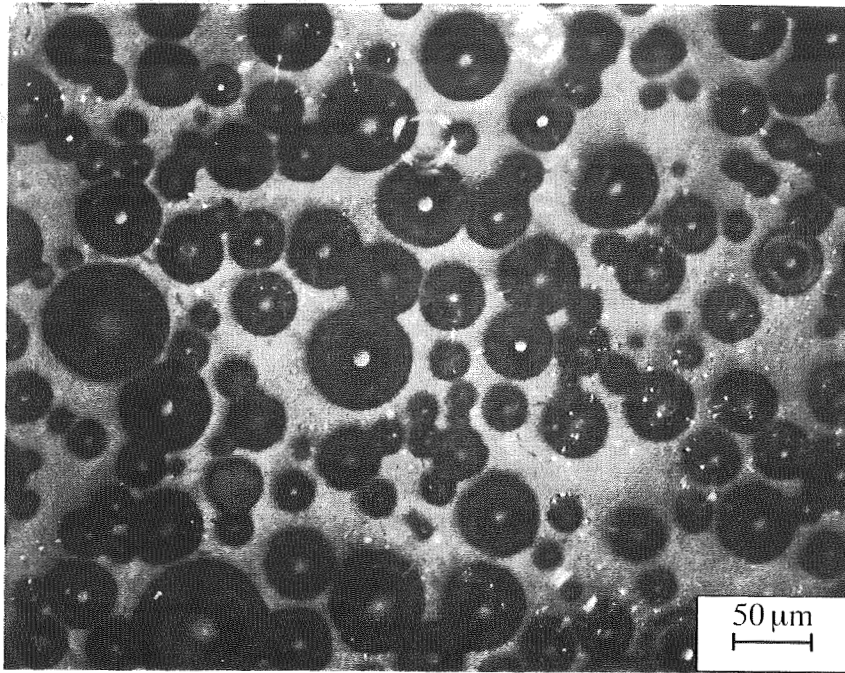


Figure 2. Reflected Light Photomicrograph of Glass Bubble - Cyanate Ester Resin Composite.

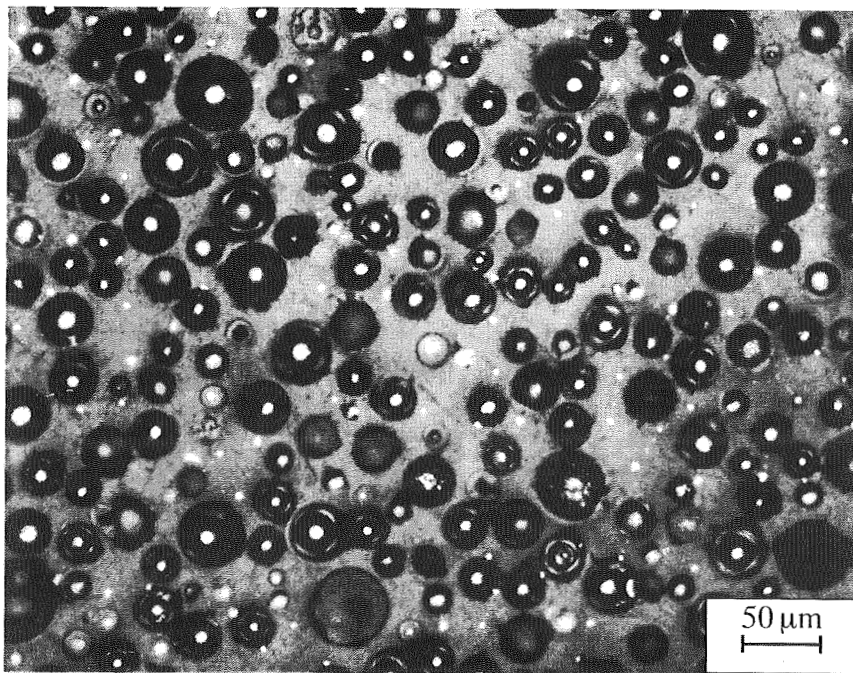


Figure 3. Reflected Light Photomicrograph of Reflective Coated Hollow Ceramic Sphere - Cyanate Ester Resin Composite.

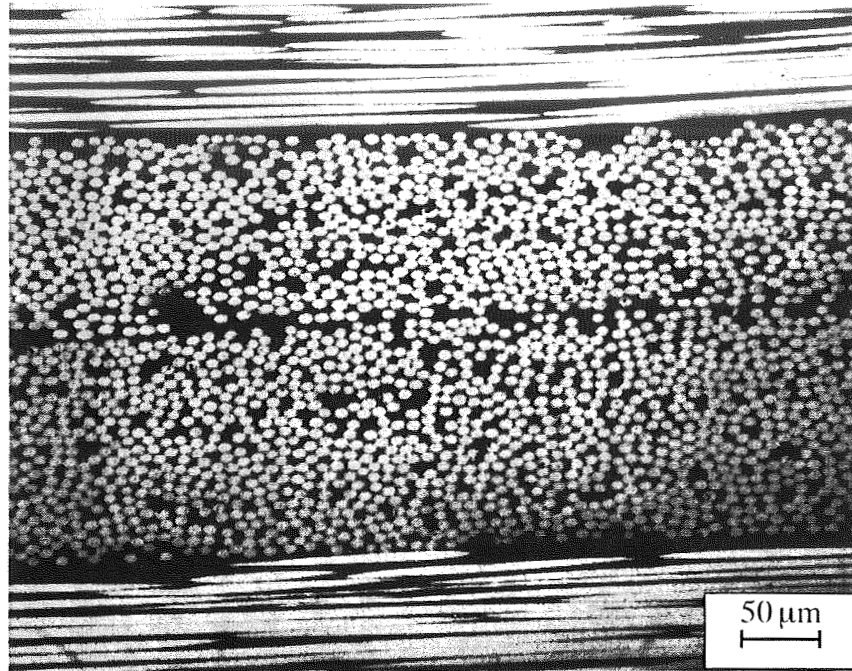


Figure 4. Reflected Light Photomicrograph of Longitudinal Section of Carbon/Graphite Fiber - Epoxy Resin Composite.

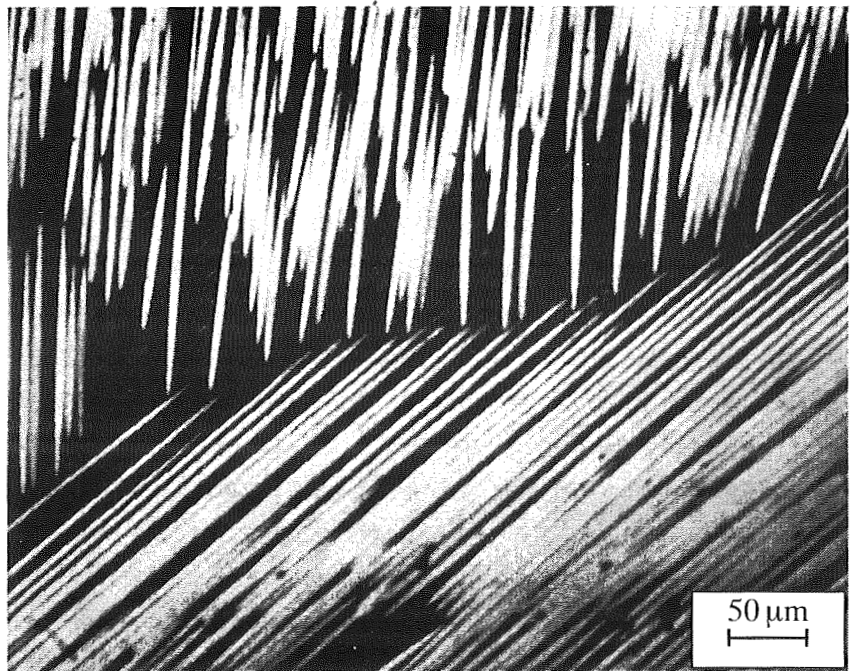


Figure 5. Reflected Light Photomicrograph of Planar Section of Carbon/Graphite Fiber - Epoxy Resin Composite.

before curing the matrix. Since the as-manufactured quality is quite good, it is probable that the particulate composites were cast under vacuum and that the fiber composite was prepared [12] under pressure (e.g., in an autoclave).

Interfacial Bonding: The photomicrographs for all three samples reveal no disruption of the interface (where it exists) between matrix and reinforcing agent. Occasionally, particles were observed to touch such that they are not completely surrounded by matrix. This indicates that these particles were not completely wetted by the polymer binder during processing. Otherwise, the interfacial region appears to be uniform. However, the absence of vacuoles or interfacial tears around or near the various reinforcing agents does not necessarily mean that good adhesion exists in this region since the samples were not deformed prior to microstructural examination. [13]

Filler Particle Characteristics: Both types of filler particles were spherically shaped except for a few oblong particles (Figure 3, in particular). The largest particles were determined to be 90 and 50 μm in Figures 2 and 3, respectively (Instructor Note 9). Although deceptive because certain particles are not observed at their diameters, it appears that both composites contain fillers having a wide range of sizes compared to the particles being unimodal. In both materials, there is no evidence that there is any preferred loading, but some particles were not completely wetted by the polymer as noted previously.

Fiber Characteristics: Figures 4 and 5 show longitudinal and planar sections, respectively, of the fiber composite. The as-photographed planar section was rotated 90° relative to the longitudinal section appearing in Figure 4. Similar to results reported by Nelson [3], the sample preparation procedure provided for good fiber retention. Figure 4 reveals portions of what appears to be four laminae (plies); the two in the center are oriented to allow the fiber cross-sections to be examined. These cross-sections are ellipsoidal indicating that the fiber axes are not orthogonal to the examined, polished surface. There are occasional binder-rich regions particularly at the laminae interfaces; otherwise, the fiber packing is reasonably uniform in the center two laminae. Assessment of discontinuities in the fibers is difficult at least in part because they are woven, but no splintered fibers were observed. Figure 5 shows portions of two laminae oriented approximately 45° to each other, also with no indication of splintering. Taken together, Figures 1, 4, and 5 reveal that the fiber composite consists of multidirectional fabric plies [14].

INSTRUCTOR NOTES:

1. This experiment relates to two previous National Educators' Workshop papers [15,16] in particular.
2. This photomicrograph is partially out of focus because the weave within the lamina is slightly inclined to the as-viewed surface and because of the depth-of-field limitation of the light optics.
3. Besides Reference [1], two comprehensive guides [17,18] have been published describing the theory of metallographic sample preparation with procedural recommendations for specific materials.
4. Compression polymer mounts processed at elevated pressure and temperature, often used for metallic samples, are not suitable in the current work. A castable polymer mounting medium that cures at room temperature was selected to avoid sample damage (chemical decomposition of polymer matrix and breakage of filler particles). The choice of mounting materials has been discussed [19] in detail.
5. Each composite sample was received with at least one surface already sectioned, probably with a diamond wheel saw. This surface was chosen for microstructural preparation with the exception of the planar section of the fiber composite. Since the polymer matrix is reasonably soft, the material removal rate is sufficiently high that the rough grinding step, normally used on metallic samples, can be eliminated.
6. A guide [20] presenting various aspects of fine grinding and polishing, specifically using Buehler equipment and consumables, has been published. Other guides describing grinding [21] and polishing [22] have also been published.
7. According to Sawyer and Grubb [23], voids or holes in fiber PMC samples appear black.
8. This photomicrograph is significantly higher quality because the filler particles have a reflective coating that reduces the amount of light transmission and scattering compared to the sample in Figure 2.

9. This is calculated using the relation

$$\text{Actual Dimension} = \text{Dimension on Film/Magnification.} \quad (1)$$

In this work, the magnification is the product of the powers of the eyepiece and objective (12.5X and 16X, respectively) since the camera lens has the same power as the eyepiece.

General: In addition to all of the instructional literature from various vendors cited in the References, two instructional video cassette tapes (VHS) entitled "Introduction to Metallographic Sample Preparation" and "Microscopes/Metallographs" have been prepared by LECO Corporation, same address as in [11].

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SOURCES OF SUPPLIES: The composite samples used in this experiment were provided by a private vendor who is no longer able to make them available. However, two alternate suppliers for similar type materials have been identified: (1) G.M. Jurscaga, Head, Polymer Technology Section, National Aeronautics and Space Administration, Langley Research Center, Mail Stop 397, Hampton, Virginia 23665 and (2) J.V. Masi, Professor, Department of Electrical Engineering, Western New England College, 1215 Wilbraham Road, Springfield, Massachusetts 01119. With one exception, the metallographic consumables are available from Buehler Ltd., 41 Waukegan Road, Lake Bluff, Illinois 60044. The 2400 grit silicon carbide waterproof paper is available from Struers, A Division of Radiometer America, Inc., 810 Sharon Drive, Westlake, Ohio 44145, in 200 mm disks that were cut to fit on the Buehler Handimet grinder.

ACKNOWLEDGEMENTS: The author is deeply indebted to W. Ahmed (See Reference 9.) for providing microstructural sample preparation recommendations and other information that allowed the current work to be accomplished. The help of W.A. Glover, Information Services, Loyola College, in using image processing software to obtain Figures 1 to 5 in final form is gratefully recognized.

**VISUALIZING INFRARED (IR) SPECTROSCOPY
WITH COMPUTER ANIMATION**

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PANEL PRESENTATION

TITLE: Visualizing Infrared (IR) Spectroscopy with Computer Animation

AUTHORS: Charles B. Abrams, McGill University, and Leonard W. Fine^{*}, Columbia University.

IR Tutor, an interactive, animated infrared (IR) spectroscopy tutorial has been developed for Macintosh and IBM-compatible computers. Using unique color animation, complicated vibrational modes can be introduced to beginning students. Rules governing the appearance of IR absorption bands become obvious because the vibrational modes can be visualized. Each peak in the IR spectrum is highlighted, and the animation of the corresponding normal mode can be shown. Students can study each spectrum stepwise, or click on any individual peak to see its assignment. Important regions of each spectrum can be expanded and spectra can be overlaid for comparison. An introduction to the theory of IR spectroscopy is included, making the program a complete instructional package. Our own success in using this software for teach and research in both academic and industrial environments will be described.

IR Tutor consists of three sections: (1) INTRODUCTION is a review of basic principles of spectroscopy. First, the absorption of light by a sample is discussed. Then, the physics of light (electromagnetic radiation) is reviewed. Finally, the operation of a grating spectrometer is explained with an animated schematic diagram. (2) THEORY begins with the classical model of a simple diatomic molecule. Quantization of energy levels is introduced, and the selection rules for the absorption of light are explained. The theory is expanded to include larger molecules by introducing normal modes and group frequencies. (3) INTERPRETATION is the heart of the tutorial. Thirteen IR spectra are analyzed in detail, covering the most important functional groups. This section features color animation of each normal mode, full interactivity... "click on any peak to see the assignment" ... overlay of related spectra, and expansion of important regions. This section can also be used as a reference.

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**POLYBUTADIENE
(Jumping Rubber)**

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POLYBUTADIENE (Jumping Rubber)

A violet suspension of an "alfin" catalyst is added to a bottle containing a solution of 1,3-butadiene in pentane. The bottle is corked and shaken for several seconds. The mixture sets to a gel, and within 2 minutes the contents erupt from the bottle [1].

MATERIALS

Jumping Rubber kit [2]. The kit includes:

- wax-sealed, screw-capped vial containing alfin catalyst
- small sealed bottle containing 1,3-butadiene dissolved in dry pentane cork for bottle
- gloves, plastic or rubber
- bottle opener
- stirring rod
- tongs

PROCEDURE

WARNING! The alfin catalyst is a fire hazard.

Perform this demonstration in a well-ventilated room and wear gloves.

Open the catalyst vial and stir its contents with the glass rod. Remove the crown seal from the bottle. Quickly add *all* the catalyst to the bottle. Immediately cork the bottle and shake. Do not point the corked bottle at anyone. The temperature increases slightly (to about 50°C), and the pressure increases (perhaps 2-3 atm) until, within 2 minutes, the cork is forced from the mouth of the bottle and a polymer "snake" shoots out. The bottle is left almost dry, and the liquid is trapped in the polymer. Use a pair of tongs to handle the polymer. During the next hour or so, the trapped pentane will evaporate and the polymer will shrink.

HAZARDS

This dramatic demonstration should be performed only by individuals who understand the fire hazard and reactivity of organosodium reagents. We have performed this demonstration over three hundred times without a single accident. Under hot or extremely humid conditions, the catalyst could ignite in air or ignite the butadiene-pentane solution. A carbon dioxide fire extinguisher must be available.

Pentane is a highly flammable and volatile liquid (boiling point: 36°C), which can explode when exposed to heat, sparks or flame. Avoid inhalation of pentane vapors since they are slightly toxic. In high concentrations pentane is a narcotic.

The compound 1,3-butadiene (boiling point: -5°C) can be irritating to skin and mucous membranes and is a narcotic in high concentrations.

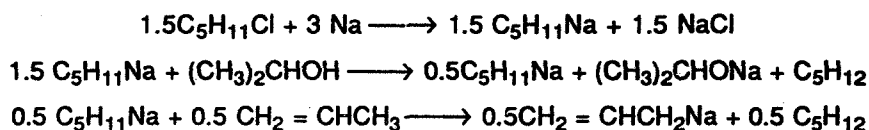
DISPOSAL

Since pentane is trapped in the product, the polymer should be kept away from flames. After several hours the pentane will evaporate, and the shrunken polymer can be discarded.

The empty screw-capped vial should be rinsed carefully with water and discarded.

DISCUSSION

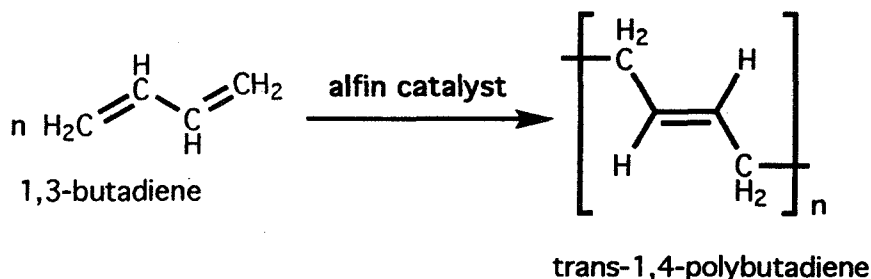
Alfin catalysts are a class of heterogeneous catalysts which cause rapid polymerization of butadiene, isoprene, and other monomers resulting in polymers with very high molecular weights (1-2 million or higher). The alfin catalyst used in this demonstration is a solid surface catalyst developed by A. A. Morton [3-5] and co-workers. It is produced by reacting amyl chloride ($C_5H_{11}Cl$) with sodium, which is then reacted with isopropyl alcohol $[(CH_3)_2CHOH]$. The resulting mixture contains amylsodium ($C_5H_{11}Na$), sodium isopropoxide $[(CH_3)_2CHONa]$ and sodium chloride. Propylene ($CH_2=CHCH_3$) is added to produce allylsodium ($CH_2=CHCH_2Na$) from amylsodium. The following sequence shows the necessary stoichiometry [6]:



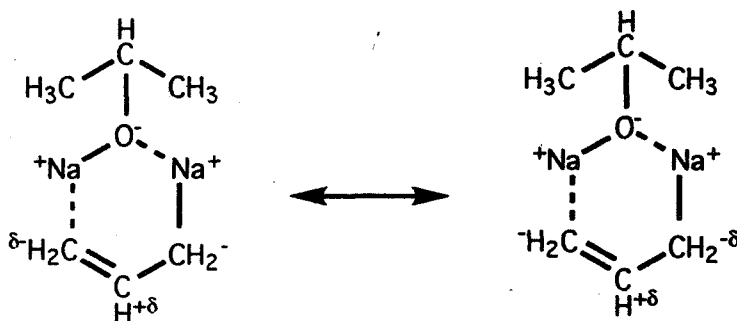
The sodium isopropoxide-allylsodium combination gives the highest polymer yield. The role of the sodium chloride is not clear, although it could be acting as a support for the catalyst.

The catalyst is the mixture of the three sodium compounds, allyl sodium, sodium isopropoxide, and sodium chloride. All are essential constituents. The name "alfin" was derived from the words "alcohol" and "olefin" because both are involved in the preparation of the reagent.

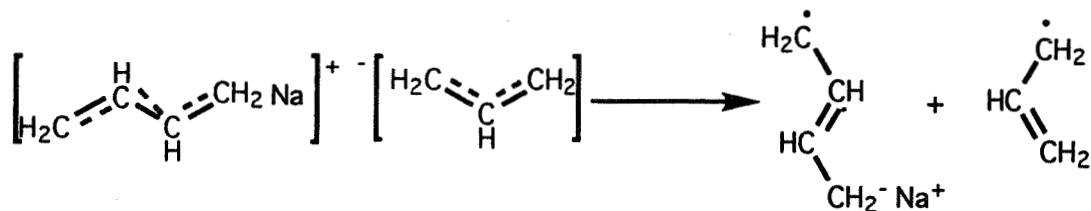
The alfin catalyst is believed [7,8] to adsorb and orient the monomer prior to the chain-growth process. Surface effects presumably influence the stereochemistry [6], and the polymer consists mainly of trans-1,4 repeating units. Since one allyl group is incorporated into each polymer chain, the process resembles Zeigler-Natta catalysis [6]:



The predominance of 1,4-polymerization has been suggested as evidence for a free radical propagation mechanism. It has been proposed [6] that complexes such as

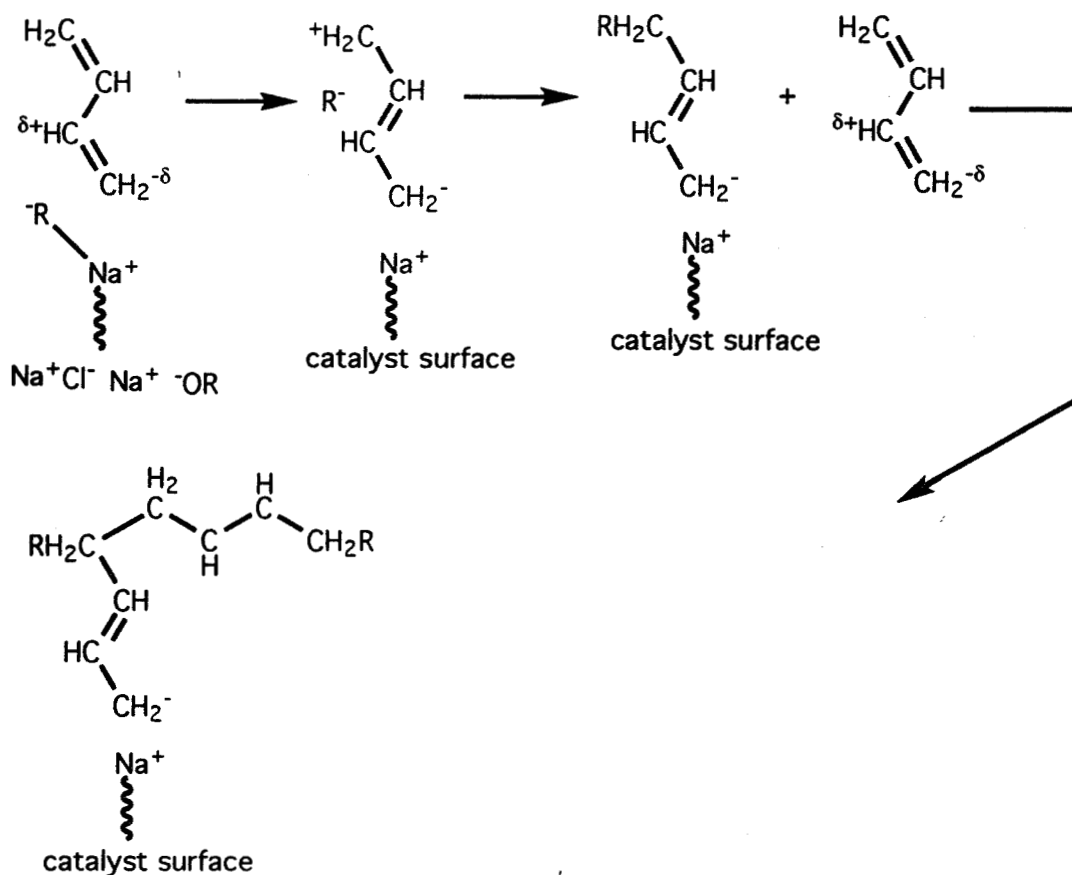


are formed and that the adsorbed monomer displaces the allyl anion from the complex to form an ion pair, which then reacts to form a radical pair:



The radical anion initiates polymerization, which continues until combination with an allyl radical occurs. This combination does not occur very readily because the allyl radical is bound to the catalyst surface [6], and hence very high molecular weights are obtained.

An anionic mechanism for polymerization with the alfin catalyst has been proposed [9]. According to this mechanism, monomer molecules are inserted into the chain:



The references cited include further discussion of these and other hypotheses.

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**EFFECTS OF CORE THICKNESS AND
FIBER ORIENTATION ON COMPOSITE
BEAM STIFFNESS**

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Effects of Core Thickness and Fiber Orientation on Composite Beam Stiffness

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Key words: composite beam, fiber orientation, foam core, beam deflection, sandwich panels

Prerequisite knowledge required: This laboratory experiment is intended for students in an introductory polymer materials and processes course or engineering materials course. Students should understand the basic concepts of beam deflection, flexural stress and modulus of elasticity. However, this experiment can also be conducted as an introduction to the hand lay-up process, with additional observations regarding the stiffness of the completed composite beams based on core thickness and fiber orientation.

Objectives: Students gain hands-on experience with the hand lay-up process by constructing glass/epoxy composite panels. Each lab group produces a panel with different core thickness or fiber orientation. The panels are then cut into strips and tested for flexural stiffness in a three-point bending fixture. Students plot deflection versus load data for composite beams with two different fiber orientations, two core thicknesses and one beam with laminate plies only (no core). The deflection plots highlight the effects of core thickness and fiber orientation on composite beam stiffness.

Equipment and supplies:

1. Core materials (polyurethane or polystyrene foam) in 10 mm and 20 mm thicknesses
2. 0⁰-90⁰ glass cloth, 6 or 7.5 oz.
3. Glass mat
4. Epoxy resin and hardener
5. Digital scales
6. Flat plates (6 mm - 10 mm aluminum) to use as mold forms
7. Mold release
8. Stir sticks, brushes, rollers, gloves
9. Bandsaw
10. Load frame with three-point bending fixture; set up to measure load and deflection

Procedure: Students work in teams assigned by the instructor; three to four students per team. Each team is given two aluminum plates to be used as mold forms. The plates are used to form smooth sides on their hand laid panels. A label, containing lab division and group number, is applied to the back (rough) side of each plate. A very thin coating of mold release is then applied to the smooth side of each plate.

Five different composite panels are constructed, one from each team, based on the core and fiber orientations shown in Table 1. The glass mat and glass cloth layers are cut using a rectangular “glass pattern” template so that all glass layers are the same size. Students must orient the template properly to cut glass cloth layers with the proper fiber orientation, as shown in Figure 1.

- Team 1: mat, 0° - 90° cloth, 3 mat layers, 0° - 90° cloth, mat
 Team 2: mat, 0° - 90° cloth, mat, 3/8" core, mat, 0° - 90° cloth, mat
 Team 3: mat, 45° - 45° cloth, mat, 3/8" core, mat, 45° - 45° cloth, mat
 Team 4: mat, 0° - 90° cloth, mat, 3/4" core, mat, 0° - 90° cloth, mat
 Team 5: mat, 45° - 45° cloth, mat, 3/4" core, mat, 45° - 45° cloth, mat

Table 1 Fiber orientations and core sizes of panels prepared by each team

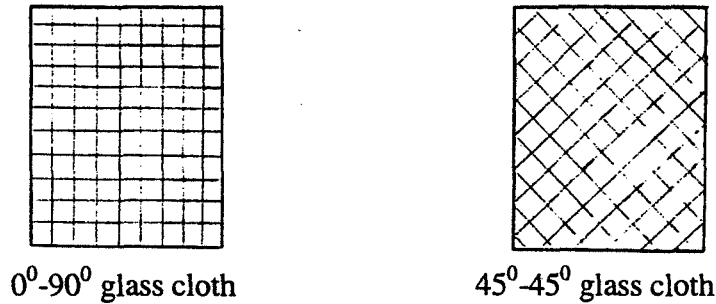


Figure 1 0° - 90° and 45° - 45° fiber orientations used for the composite panels

Students prepare a sufficient quantity of epoxy resin and hardener using a 3-1 resin/hardener ratio (by weight). Digital scales are used to measure the weights of each component, and then the resin and hardener are completely mixed using the stirring sticks. A thin layer of the resin/hardener mixture is then brushed onto one of the mold plates over an area that is slightly larger than the glass mat. The first layer (glass mat) is placed on the resin covering the mold form, and brushes and/or rollers are used to wet out all of the glass fibers. Successive layers are applied as above until all of the layers of the panel have been assembled, taking care to properly wet out all glass fibers in each layer. The second mold form is then placed on the laminated plies, mold release side facing in. All molds are then placed in a compression press, or vacuum bagged, to help remove any excess resin from the composite panel. All composite panels are allowed to cure overnight.

After sufficient cure time, the composite panels are removed from the mold forms and cut into strips 25 mm by 250 mm using a bandsaw. Each strip is then tested in three-point bending as shown in Figure 2. Students collect deflection versus load data for all of the samples of various core thicknesses and fiber orientations; this data is then averaged for each sample type, and plotted as shown in Figure 3.

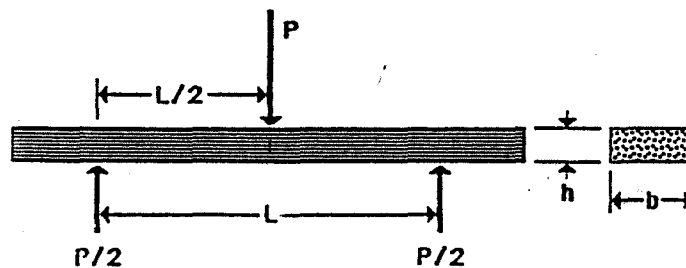


Figure 2 Three-point bending test (1)

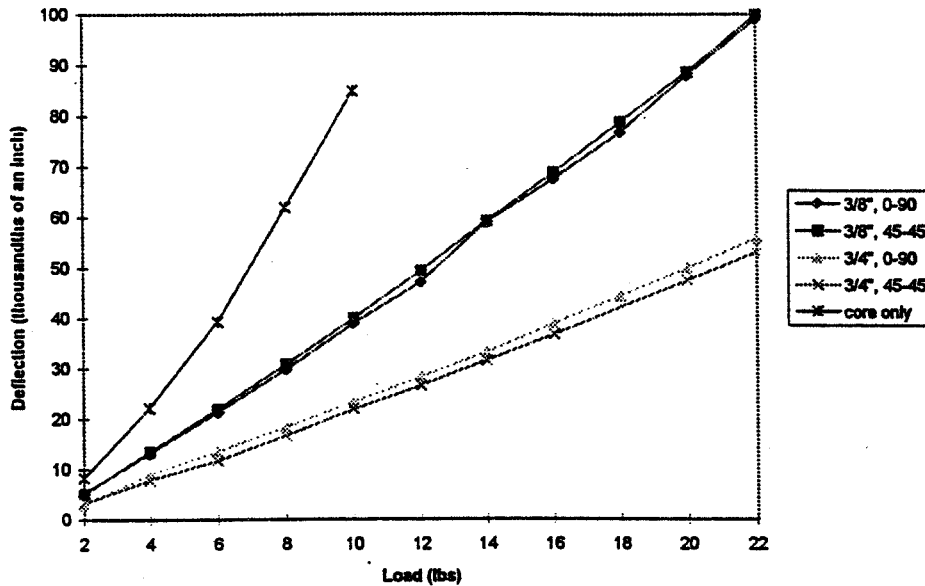


Figure 3 Deflection versus load plot for composite beam samples

Students can easily see the effect of core thickness on composite beam stiffness (2); however, it is much more difficult to see the stiffness effects of the fiber orientations used in this test. Although laminated plate theory (1) predicts that the 0° - 90° orientation should exhibit higher stiffness than the 45° - 45° orientation, the effects of fiber orientation are not readily apparent from the plots shown in Figure 3.

Sample data sheets: Self-evident

Instructor notes: Students generally have little trouble preparing acceptable composite panels; however, care must be taken to insure that the fibers in each ply are sufficiently wet out without using an excessive amount of resin. Composite beam strips of constant width can be cut on a bandsaw when using a rip fence.

If extremely low density core materials are used to construct the composite panels, some compression of the core material may occur directly under the applied load; this will be evident in the data when deflection becomes nonlinear for each identical increase in load.

If a load frame with load cell and cross-head position is not available for the three-point bending test, the composite beams could also be tested for deflection as cantilever beams, using the test equipment described in Reference 3.

The plot of the three-point bending test data (Figure 3) easily shows the effects of core thickness on beam stiffness (deflection). It should be noted that composite beams of either core thickness were stiffer than the core material itself, but the core material was stiffer than the sample laminated without any core (not shown), primarily due to the higher rectangular moment of inertia of the core material.

Unfortunately, the effects of fiber orientation are more difficult to show, perhaps because the stiffnesses of the 45° - 45° and 0° - 90° laminates were too similar for the differences to be clearly shown. The effects of fiber orientation on stiffness could be more clearly shown by comparing quasi-isotropic laminates to unidirectional laminates (4); this change will be incorporated into future versions of this experiment.

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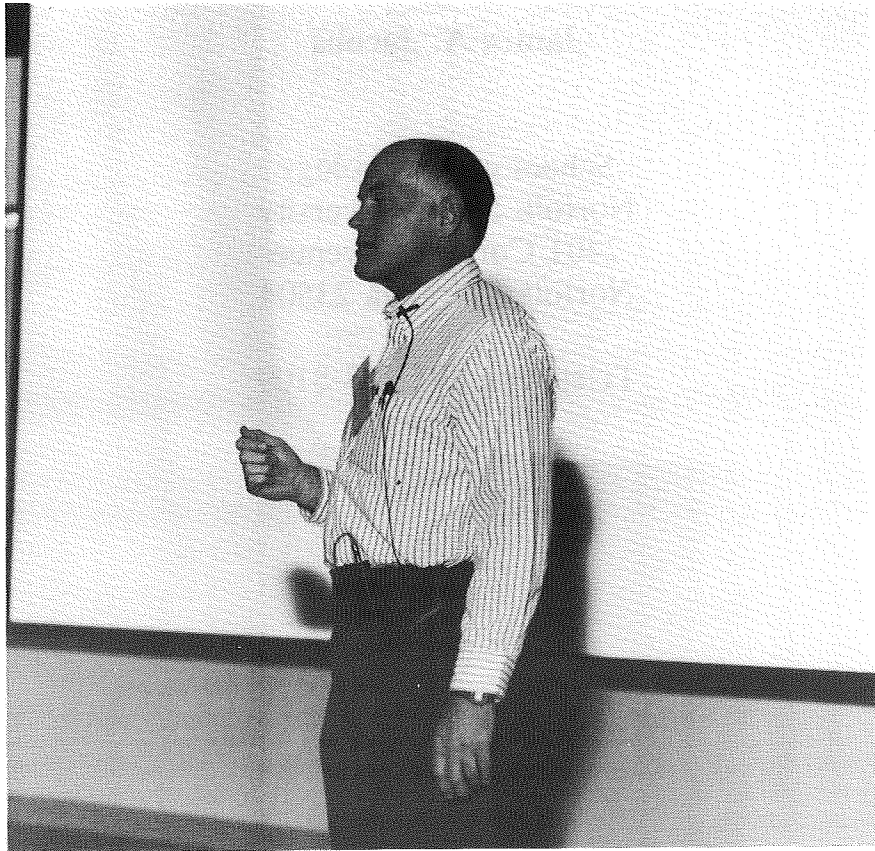
Sources of supplies: Foam core materials, epoxy resins and glass cloth and mat are normally available from plastics supply companies, or from educational supply companies such as Iasco (Minneapolis, MN). Laminating supplies (brushes, rollers stir sticks, gloves) are normally available at local hardware or automotive supply stores.

MATERIALS ALL AROUND US

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Materials All Around Us

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Key Words: Materials system, journal

Prerequisite Knowledge: Initially none, but as course progresses students must be able to connect properties to the main groups of materials to their applications. Can use at pre- college - see References below for supplements.

Objectives: To observe materials in the environment around use
To determine the properties of materials that cause their use in materials systems
To develop a strong rationale for gaining a knowledge about engineering materials

Supplies: The variety of materials we encounter daily

Students often look for a strong rationale for studying a subject. Among advantages to teaching a basic course in engineering materials is the fact that materials are all around us. While many people, including technical people, don't give much attention to materials, we can teach students to become materials observers. They will find proper and improper materials selection. They benefit from this knowledge as consumers, citizens, and in their careers.

Procedures:

1. **Journal** - Keep a journal with which regular entries about materials that include: a) applications in service, b) news reports, c) advertisements, d) candidates for usage. The journal should have entries entitled: date, observations and analysis. Sample entries are shown on the journal page below. For the sake of space, I used simplistic examples that illustrate the range of items that might be observed. Each item could involve very thorough analysis, but the goal is to make materials observers of students and let that motivate them to dig deeper into the subject.

The journal doesn't require grading but serves a point of discussion for class. Discuss these observations and analysis in class. Many analyses will be simplistic. As the course progresses, students should be able to make progressively more informed analysis as demonstrated on the sample below. Few of us possess the background to analyze all material conditions. It is difficult to simply look at an alloy or plastic and be able to make proper identification. This should not be a deterrent. Rather, it provides the opportunity for students to share their unique experiences and knowledge for which both professor and students learn. The journal idea connects with the "Writing Across the Curriculum" movement. This aims to encourage technical students to engage in free style writing in all courses. I encourage my students to use this journal (100 page spiral notebook) as a central location to keep notes, make sketches, list resources, and keep together with their engineering materials textbook for later use in other classes and on the

job.

2. Mounted Samples - Students bring to class materials and products composed of materials systems. Encourage them to look around for broken and discarded examples of materials. The examples they bring vary widely from disassembled calculators and hair dryers to shoe soles, electrical switches, and computer speakers (Figure 1). I ask the students to mount the samples on 220mm x 280mm posterboard as seen in Figure 1, and label the types of materials while providing explanations of what properties caused the selection of the materials for the system as seen on the Data Sheet below.

In our book *Engineering Materials Technology*, which we just finished the manuscript for the 3rd edition that's due out next fall, we discuss materials systems as . . .

Materials rarely exist in isolation without interacting with other materials. Rather, a combination of materials are selected to complement one another. In a successful *materials system*, each component is compatible with the others, while contributing its distinctive properties to the overall characteristics of the system of which it is a part. A state-of-the art telephone is a good example. The casing might be a tough ABS plastic, which houses a microchip (a solid-state ceramic device) that provides memory and sound-transmission capabilities. Copper leads join the circuitry together. There might be a battery and a ceramic light-emitting diode to show when the battery is low. The acid in the battery must be isolated to prevent corrosion, and the copper leads must be insulated so that they do not short out. Each component is made of materials that meet the demands of the physical and chemical environment normally encountered when using the system.
[Jacobs, p. 15.]

These specimens provide for useful discussion that help reinforce the content of the course. I include them as a part of the overall course grade. Mounting the specimens provide for interesting problem-solving. Many think a "super glue" will hold anything. This presents an opportunity to delve into adhesive bonding. Within the size restriction for the display, many approaches to mounting and labeling emerge as seen in Figure 1. The mounted specimens are also good to take to schools when I am asked to speak to students.

Conclusion: Materials are all around us. Learning about materials is easily made interesting if we remember to encourage students to be materials observers. The ideas presented here suggest many other opportunities to make materials education relevant to any audience.

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Journal Entries

Observation	Analysis
1/15/96 Garbage cans are rusted and top has blown away	Make containers out of concrete
1/25/96 Paint on the foam plastic bumper of car has faded and is cracking	Wrong type of paint selected; shouldn't paint plastic or rubber but instead mix color into polymer; sun is attacking polymer
2/13/96 News Item: A commuter plane crashed when the propeller blade fell off	Improper maintenance caused metal fatigue
2/15/96 Shopping for a bicycle, salesperson says brand x has an alloy frame with urethane shock absorbers making it stiffer and lighter than competitor's frame	9000 aluminum alloy provides light weight, corrosion resistance making it superior to steel alloy frames, urethane shocks are superior to steel springs since they cushion and avoid sudden jolts, but will they wear out quickly?

Data Sheet

MATERIALS & THEIR PROPERTIES

Type of Material: (Provide specific info. e.g. alloy or plastic name)	Reason Material Selected: Functions of the material in the system, e.g., corrosion resistance and electrical conductivity
1	
2	
3	
4	
5	
6	

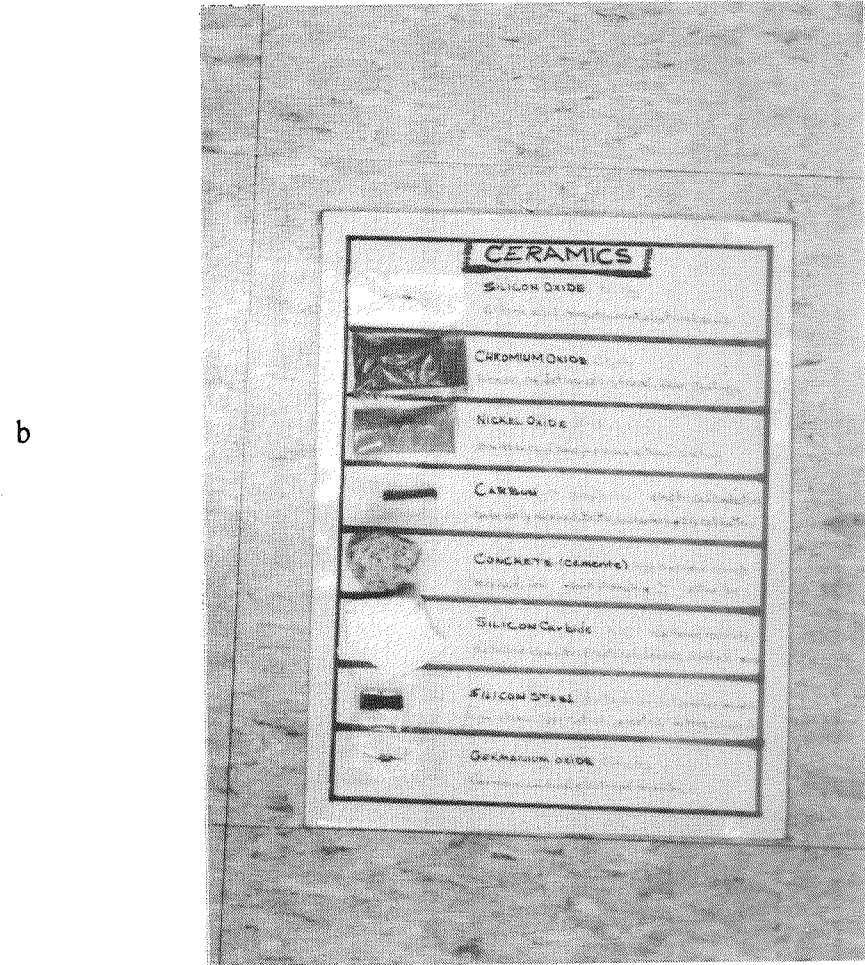


Figure 1 Examples: a) typical products readily available that consist of materials systems, b) students' samples of discarded ceramics

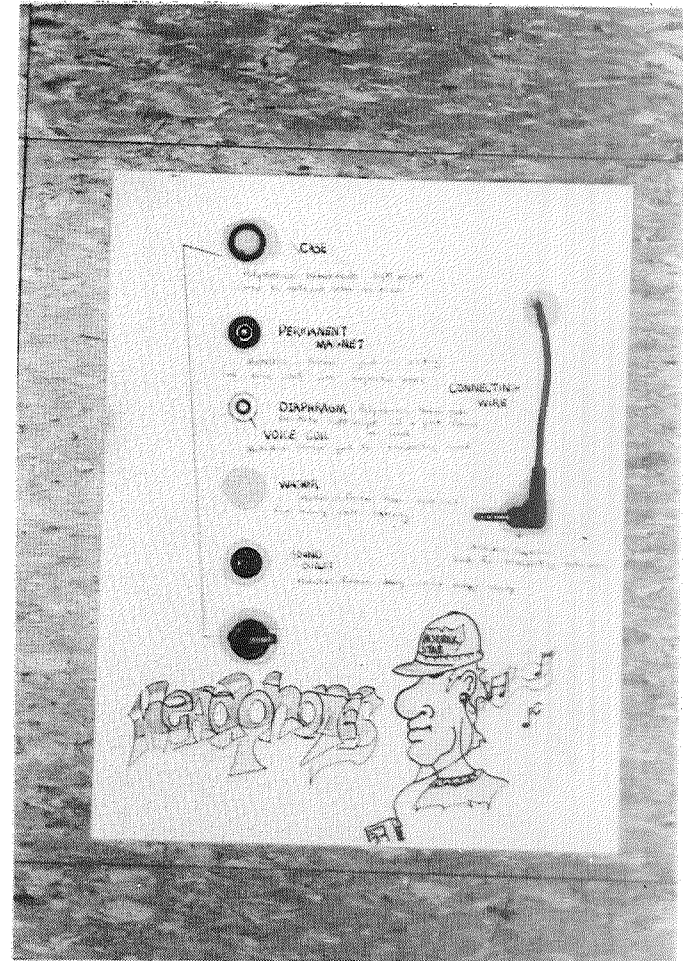
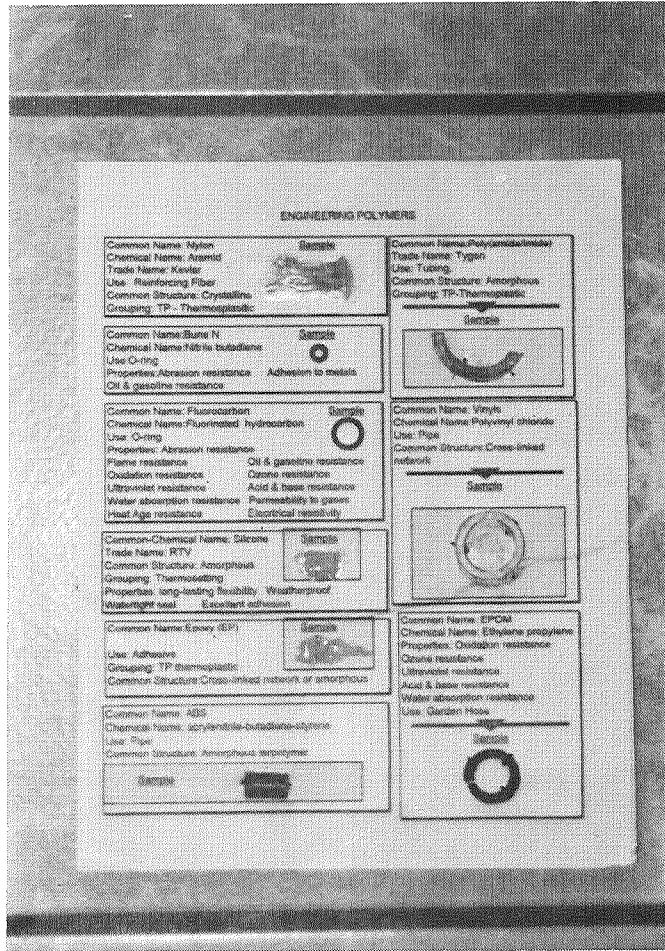


Figure 1 cont. c) students' samples of discarded polymers, and d) students' disassembled products showing materials systems.

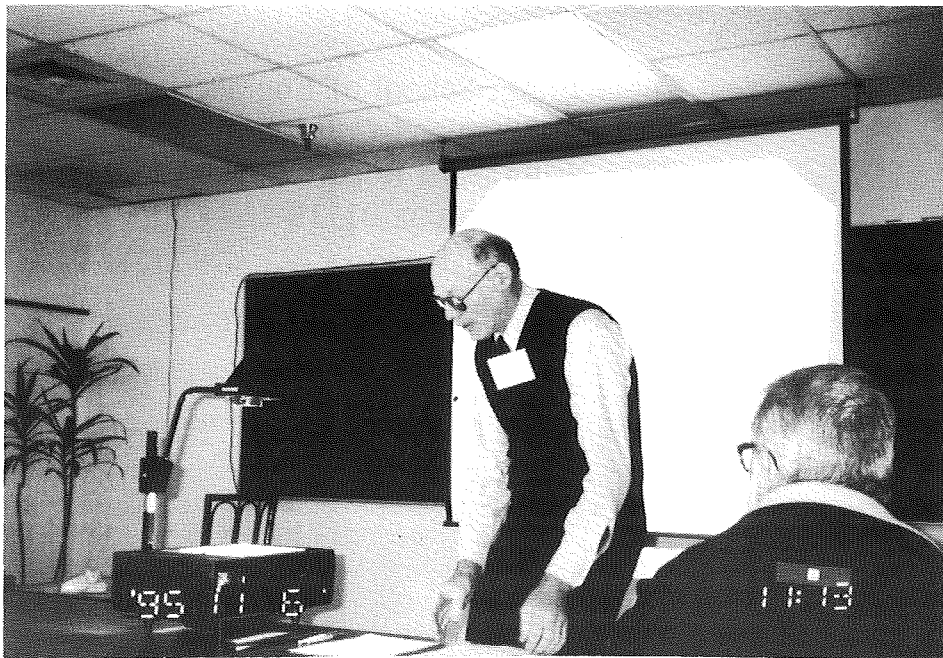
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CRAFT STICK BEAMS

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Craft Stick Beams

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Keywords:

Beams, Bend Tests, Composite Structures

Prerequisite Knowledge:

The student

1. should know what a craft or popsicle stick is and that it can be bent and broken,
2. should be familiar with fiberboard and/or cardboard and that it can be bent and torn apart, and
3. should know that sticks of wood and fiberboard can be glued together to form beams of specified dimension.

Objective:

The objective of this exercise is to provide a phenomenological “hands-on” experience that shows how geometry can affect the load carrying capacity of a material used in construction, how different materials have different failure characteristics, and how construction affects the performance of a composite material.

The student will learn to:

1. Fabricate different types of layered beams such as
 - A. Built-up beams of a single material, and
 - B. Composite beams of a mixture of materials,
2. Test these layered beams to determine how and where the beams fail,
3. Use knowledge gained from 1 and 2, to design a layered beam that will fail in a predicted manner, and
4. Capture a knowledge of the effects of lamination, adhesion, and geometry in layered beam construction on beam strength and failure location.

Equipment and Supplies:

1. Forster Craft Sticks, Forster Inc. Wilton, ME or popsicle sticks, fiberboard sheets from backs of pads of paper, Puritan Tongue Depressors, Hardwood Products Company, Guilford, ME
2. Large Size Paper Cutter
3. Micrometer or Vernier Caliper to measure sample thickness
4. Safety Glasses
5. Glue - Elmer's Glue All, Bordon, Inc., Columbus, OH, is suggested, but any other glue can be used. In fact, glue type can become a variable. Be sure to use the same glue for ALL samples in a given test.
6. Clamps for holding glued craft sticks (an anvil capable of applying load over the complete craft stick is necessary for quality results)
7. Test Apparatus with three point loading fixture: Instron Load Frame with Load versus Deflection plot output capability or Hydraulic Tester and gage to read “on-the-run” the first maximum load.
8. Data Sheet (see recommended samples below)
9. Magnifying glass
10. Computer spread sheet if desired

Test Activity Overview:

The first step is to create reference data for comparison purposes. This can be considered a “benchmark” to which all subsequent findings can be compared. The recommendation is to record failure loads in a table for one, then two, three, and four craft sticks placed together on their wide flat faces unglued (Series I), and loaded to find the first maximum failure load as the beam is loaded to failure, which occurs when the load carried by the beam decreases after reaching a maximum. Remember the load is applied at a right angle to the wide flat face of the craft stick and uniformly across the width as shown in Figure 1. In the case that a plot of load against beam deformation can be made while the test is under way, a review of the plot may show jumps which can be due to material failure or debonding of glue that indicate significant changes in the ability of the beam to carry load. A loss of load signals a failure. These kinds of observations will be seen in the glued beams such as series II.

Testing - Phase I:

Two three point type beam test units are available. One is similar to an Instron machine under position control when the load rate is specified in inches per second and a plot of load against deflection is obtained. The second is a hydraulic jack setup which could be prepared as a clamp when curing the glued beams and as a device for obtaining maximum failure load for each beam loaded to failure. When craft sticks are used each measures a length close to 4.5 inches. Prepare the three point loading apparatus so the bottom supports are 4.00 inches apart and the third load is applied in the center or 2.00 inches from each end of the bottom supports. Kundu and Wickman (1) present an approach to making a mechanical tester.

Once a three point beam test unit has been selected, place a beam in the three point test fixture - two load edges on the bottom and one on the top make three points. Be sure the load is applied perpendicular to the wide face of the craft sticks on the outside surfaces of a manufactured beam. Apply load until the beam fails. Failure is seen as the load indicator rises and then falls off as the beam is no longer able to support load. For the unglued beams sliding of the components relative to the upper stick is often noticeable, especially when noting the alignment at the end of a beam. Use of a magnifying glass will help. Check the beam under the load points, on the free ends and under the center applied load. LISTEN and you may hear a noise as the beam or glue fails, too. Place on the data sheet the maximum load found just before the FIRST failure occurs. Continue this process for all beams in a series. Please remember a useful approach is to make notes about the noises heard, the changes seen in the beam - in series IV with the three layered beam, did the fiber beam in the center layer crush?

Series I: First a single stick beam and then built-up beams made from two, three, and four craft sticks should be tested and the first maximum load prior to failure recorded in the table. Written notes on the data sheet about the response of each beam to its three point bending evaluation are recommended. For example, for the single craft stick the maximum load carried is 12 pounds; the beam broke in the middle under the applied load and the beam splintered. In addition, written comments on a visual inspection of each beam before, during and after test can be helpful. Since there are many beams under evaluation, please label each beam in a series (series I - beam 1, etc.) and make notes before the next beam is loaded. Figure 2 shows the load deformation plot for one, two, three, and four layered glued craft sticks. The jumps present failures which often can be heard as a ‘snap’ when the test is run.

Composite Beams:

All composite beams will be made with layers that are glued together. The naming of composite beams is used to specify beam stick layering. One or more fiber sticks is substituted for one or more of the wooden

Procedure:

Overview:

The first step is to make built-up beams. One, two, three, and four craft sticks are used to make a series of unglued beams and a series of glued beams. The second step is to make fiber sticks cut from the backings of pads of paper and make fiber stick built-up beams: a series of unglued fiber stick beams and a series of glued fiber stick beams. The third step is to test each beam in the four series and make a record of the results of the mechanical testing so that composite beams can be designed. The fourth step is to design series of composite beams with fiber sticks and craft sticks, and to prepare hypotheses that predict which layer in a composite beam will fail first and where in the layer the failure will occur. The last step is to test each beam in a series of composite beams to accept or reject an hypothesis.

Sample Preparation:

The craft sticks are used as they come from the package. The fiber board needs to be cut to size with a large paper cutter. A pair of scissors can be used, but the chance to twist and bend or break the fiber board is so great that scissors are not recommended. Another recommended cutter is a scroll saw, but again care in cutting is critical to assure beam integrity. The craft sticks are close to 0.088 by 0.364 by 4.488 inches in size while fiber boards from legal pads found were 0.073 inches thick. While 0.073 inches is less than 0.088 inches the thinner fiber board sticks were used due to legal pad availability.

Sample Gluing:

The task of placing glue on the beams is significant. At first there appears to be no concern, and then concern sets in. How uniform is the coating, how fast will it set up on a beam with three layers of craft sticks, and how should the beams be clamped, etc.? Perhaps the best suggestion is to select and use the same glue for all series needing glue. A good approach is to use Elmer's Glue All and a small brush to quickly lay a bead of glue which is spread with the brush, and if three craft sticks are to be joined, place glue on two craft sticks and place them together, rub them about and realign the sticks as one beam and place the composite beam into the clamp. Next apply the clamp force as soon as possible. Be sure to check alignment after clamping to be assured that all members are parallel. Make up the series of beams you plan to evaluate, select the materials needed to build them, and build them, being sure to keep notes along the way.

To assist the experimenter in keeping good records, a beam series is defined as a group of samples which have common features. Four sticks are chosen because four craft sticks have the same height as the width of one craft stick. The series of Built-Up Beams follows:

1. Wooden Craft Sticks

- a. Series I : First a craft stick alone, and then two, three, and four craft sticks stacked together, and
- b. Series II: Two, three, and four of the wooden craft sticks are glued together on their wide flat faces as built-up beams.

2. Fiber stick beams are developed when fiber board as fiber sticks of the same thickness and size of the craft stick are used in place of the wooden craft sticks. The selections are:

- a. Series III: First a fiber stick alone, and then two, three, and four fiber sticks are stacked together, and
- b. Series IV: Two, three, and four fiber sticks glued together on the wide flat faces as a built-up beam.

craft sticks when a composite beam is prepared. A scheme for designating wood sticks (W) and fiber sticks (F) components is created. If the first letter denotes the top surface and top member of the composite beam, then the following combinations may prove interesting: Series V which includes FW and WF, Series VI with members FWF, WFW, Series VII with members WFFW, FWWF, WFWF, and FWWF are suggested.

Hypothesis formation:

Each student should make an hypothesis which addresses which layer in the layered structure of a WFW composite beam will fail first and will it be crushed or splintered. The hypothesis should be formulated based on the findings from testing single material beams of wooden craft stick beams and fiber stick beams. The previously collected information can enhance your knowledge and is to be used to make an hypothesis for composite beam performance. For example, in series V, the first **hypothesis** is that the fiber stick (F) in the middle of a three layer composite beam (WFW) will be the first to fail and will it fail in the center of the beam layer beam by crushing or splintering, is made. Future hypotheses can address the expected location in the beam and the expected types of failures in WFFW , WFWF, and FWWF beams.

Testing- Phase II:

Composite beam load tests are performed to determine the effect of material arrangement for fabricated composite beams. The first hypothesis is for the WFW beam, and this hypothesis should be tested prior to testing other composite beams. Once confidence has been gained in predicting that the fiber stick will fail first and the failures will be due to separation within the fiber stick given that the glue between layers does not fail, new composite arrangements can be addressed. Sometimes failures will occur because of gluing technique and not because of materials arrangement. Remember the **hypothesis** presented above. When evaluating the series V, three layered composite beam WFW be sure to look at the data from series I-IV and see what beam configuration is the strongest. How did the hypothesis fare? Was it accepted or rejected? The fiber layer in WFW usually fails directly under the applied load and is crushed.

It is always possible to check the current hypothesis a second time. This verification activity is accomplished by preparing a second sample of the beam from this series, **but** be sure the procedure used to make, glue , and clamp the beam is the SAME as before. Variation will be present, but the trend should be clear.

The experimenters will soon discover that making composite beams from layers of sticks which are glued together needs an expertise developed for glue application and clamping. The amount of clamping force can alter the quality of end product. Often the glue is not the weakest link and the beam material will fail first. However, uniform application of glue to the surfaces to be joined is important as otherwise premature failures may occur.

As multiple layered composite beams are made careful observation of beam layer failure may show a dramatic change or jump in load on a load against deformation graph that is made while the beam is under test. In addition, astute observation by a student may catch the layer destruction action when one member of the glued composite beam fails. As the load applied to a beam increases a careful observer can see the reaction on the beam - splinters can be formed, fiber beams can be crushed and separate from their glued outer surfaces, and sometimes the composite beam separates in the glued region at one end between the wood stick and the fiber stick or maybe within the fiber itself! This information should be recorded and used when the next series of composite beams is designed and hypotheses are made for where the failure will occur.

Results Review:

To gain perspective and show the type of findings possible for first maximum load carried by the craft stick beams, the data in Table 1 is shown with notes below the table and series defined in the text.

Table 1 - Sample Data at 0.01 inches per second Loading Rate: Pounds at Failure Load

Series	I	II	III	IV	VII	S-2
Layers :1	10.1	---	1.7	---	29.5	19.5
2	18.2	37.4	2.0	6.6	44.2	58.5
3	29.3	78.8	4.5	14.0	27.1	108.9
4	35.4	90.9	4.6	21.3	28.3	197.6

Series I is craft sticks without glue

Series II is craft sticks glued with Elmer's Glue All

Series III is fiber sticks without glue

Series IV is fiber sticks glued with Elmer's Glue All

Series VII is a 4 layer composite as follows: for Layer 1 designation WFFW, Layer 2 designation FWWF, for Layer 3 designation WFWF, and Layer 4 designation FWWF

Series S-2 is solid birch cut to thickness of layers designated (see Comments below)

From Table 1 data it is seen that the unglued craft sticks in series I carry more load than the fiber sticks in series III and that gluing sticks to double the beam height in a built-up beam can triple (two layers of craft sticks or fiber sticks) load carrying capacity. Built-up fiber stick beams appear not to gain appreciable load carrying capacity after 3 layers if unglued, but that gluing makes a tremendous difference and increases the load carrying capacity over a single stick by seven or more times. The four layered unglued beams are not as good in carrying load as the two member glued beams. In series VII the combination WFWF is not as good as FWWF, and FWWF is best, but not as strong as four layers of glued craft sticks. From Figure 3, which is a plot of series II, series IV and series S-2, it can be seen that the difference between the glued stick beams and solid wood beams of thickness is similar to the layered beams. In all cases the center of the beam resists the transverse shear load on the beam which is greatest at the center of the cross-section at mid-span as presented by Hibbler (2). In all cases the solid wood samples were superior to the laminated beams.

Comments:

Extension of the concepts learned includes several initiatives which you and/or your students may want to follow:

1. A change in glue is possible. If this is done, be sure all sets of beams use this same glue so that one kind of glue can be compared to another. DAP Weldwood Carpenter's Glue, DAP, Inc., Dayton, OH, Titebond Wood Glue, Franklin Chemical Industries, Columbus, OH, and Dap Weldwood Hobby'n Craft Glue, DAP, Inc., Dayton, OH, are a few that have been tried. Ask yourself a question - Is the glue weaker or stronger than the wood and/or the fiberboard used? Usually the glue is stronger and fails when the wood and/or fiber sticks change shape under load.

2. A set of solid wood beams with thickness of one, two, three, and four craft sticks with the depth and length the same as the craft sticks could be prepared. This should be done carefully because cutting small pieces the size of craft sticks can be dangerous. Seek the help of a craftsman who knows how to do this type of work.

3. The craft sticks are white birch which was found via a call to the manufacturer. Tongue depressors (about 0.063 by 0.706 by 6.007 inches in size) are usually white birch, too. How are the white birch sticks and/or the tongue depressors made? Consider a log that has a layer of the selected thickness peeled off and then a punch is used to form craft sticks or tongue depressors. This process is compared to making tangential or transverse saw cuts for the formation of solid wood samples that you might prepare.

4. Different treatments could be given to the beams prior to testing. Painting or coating with a penetrating preservative can change attributes. Even wrapping the beams in tissue and painting with airplane dope will simulate a built-up wing type structure. You select the options!

5. An interesting approach is to use tongue depressors which are wider and thinner than craft sticks. Select tongue depressor beams of one, two, three, four, five, and six thicknesses which correspond to the width of a craft stick and compare finding for the composite structures of WFW, FWF, WFFW, FWWF, WWFW, WFFF, FWWWF, FWFWF, WWFFW, WFFFF, FFWWF, and FWWWF, for example, to those of the craft stick thickness. Commonly available fiberboard from paper pads of 0.026 inches was used because of availability. The trends observed could be that the strongest combinations are WF, WFW, FWWF, WWFW, and WWFFW. You might ask about the reasons for this, and reference to the resistance to the maximum shear stress provides an answer. At the center of the mid-span of the beam consider the cross-section that is perpendicular to the length of the beam. The maximum transverse shear stress occurs at the center of this beam cross-section while the maximum bending stress occurs at the outer-most fibers of this cross-section of the beam.

6. A comparison of recorded information for white birch by Tsoumis (3), often referred to as Paper Birch, can provide some engineering calculations. The Wood Handbook (4) presents for paper birch with 12 percent moisture content a modulus of rupture of 12300 psi and a shear strength parallel to the grain of 1210 psi. These properties can be compared to values found for loads listed in Table 1, above, under column S-2 for the solid wood beams cut to order. Equations for the calculations after Higdon (5) are available to students of engineering who have studied Mechanics of Materials. In addition, the Wood Handbook provides some reference to the "basic stresses" for structural members while reference information on the strength of glued joints is scarce.

7. A set of sample of other materials can be used. Plastic materials and appropriate bonding agents, some of which might be solvents, can be considered. A feature of this approach is that several student teams can be selected, given same size geometries and appropriate bonding agents, sent to independently build uniform material beams or composite material beams and all brought together for testing and/or data analysis.

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Acknowledgments:

The author received assistance over the 1995 summer from Robert Chhugani, a Western New England College incoming Senior Mechanical Engineering student, and from Mathew and Jeff Kolb, brothers and local Springfield, MA, high school students. Their endeavor and comments were valuable and greatly appreciated.

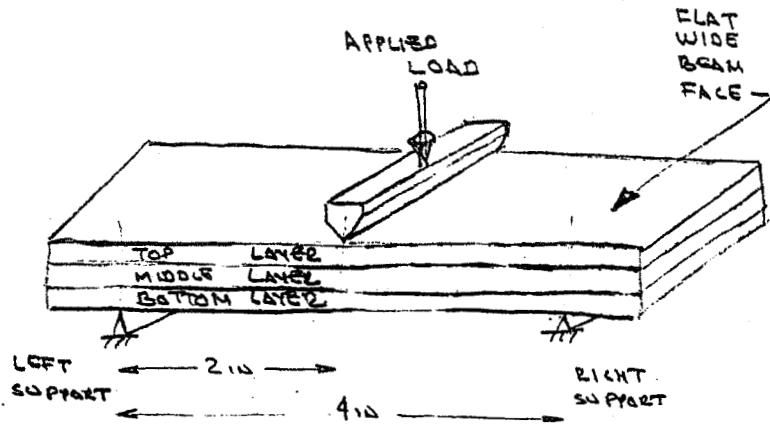
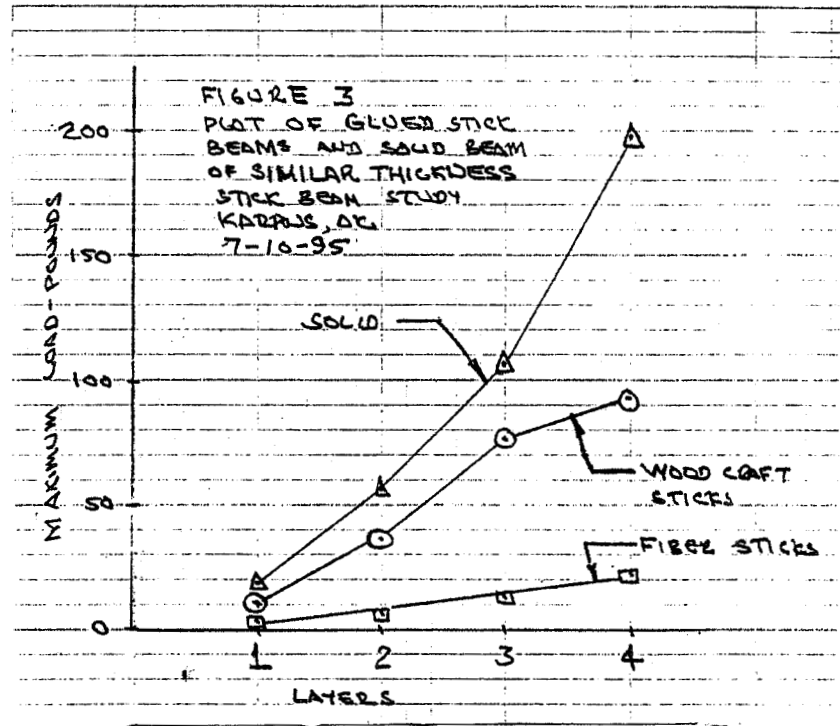
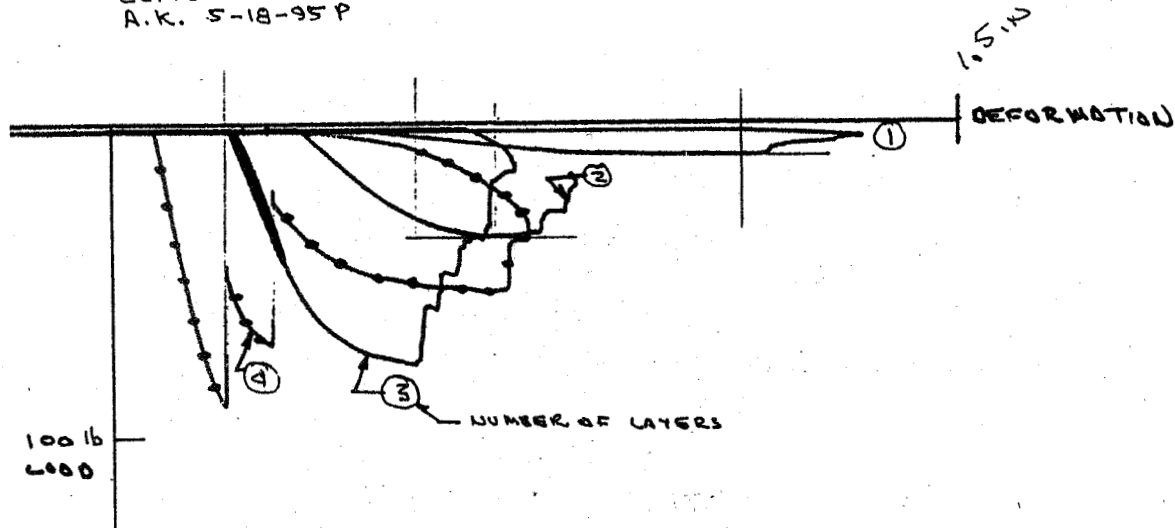


FIGURE 1. THREE-POINT LOADING FOR STICK BEAMS

FIGURE 2
LOAD AGAINST DEFORMATION
POPSICLE STICKS BUILT-UP BEAMS
ELMER'S GLUE, LOADING RATE 0.01 lb/sec.
A.K. 5-18-95 P



AN EXERCISE IN ION BEAM ANALYSIS

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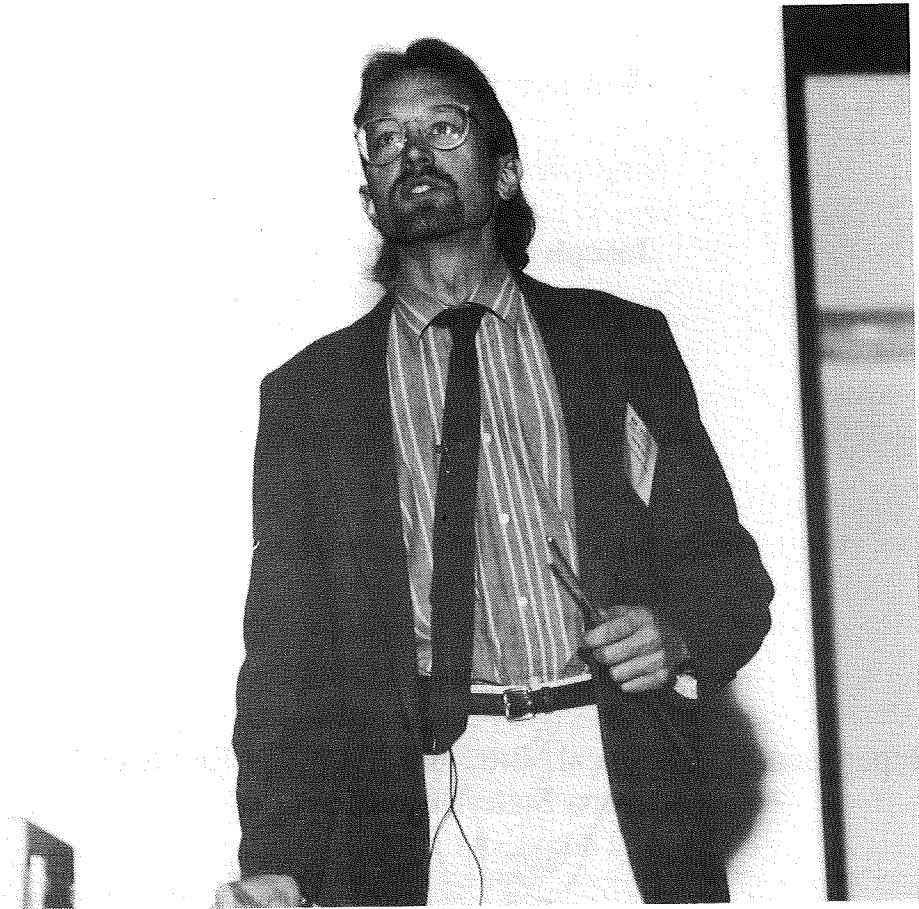
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An Exercise in Ion Beam Analysis

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Key Words: Ion Beam Analysis, Rutherford Backscattering Spectrometry

Prerequisite Knowledge: Introductory understanding of conservation of energy and momentum in collisions and Rutherford scattering is helpful.

Objective: To analyze data from Rutherford Backscattering experiments in order to determine elemental composition.

Supplies: Sample RBS spectra, including a calibration spectrum, Ruler.

Introduction:

Scattering phenomena are taught in introductory physics classes, and concepts such as conservation of energy and momentum are used at all levels of physics. However, applications of scattering are often not included as part of an education. Rutherford scattering, a topic of any modern physics course, is now used as a tool for materials science applications [1,2,3]. In the absence of laboratory equipment for students to perform such experiments, an exercise in the analysis of scattering data may accent the useful concepts given in lectures.

The fundamental picture of Rutherford scattering is shown in Figure 1. An energetic ion of mass m , shown here approaching from the left, comes into the proximity of a stationary nucleus of mass M . For the case of a positive ion approaching the nucleus of a target atom, there is mutual repulsion due to the charges on each. As a result, energy is transferred from the incident ion to the target nucleus. The direction of travel and the energy of the incident ion is changed and the target nucleus will recoil as a result of the collision. The process described here is elastic scattering. In such collisions, energy and momentum are conserved, as is expressed in three equations:

$$\begin{aligned}\frac{1}{2} m v^2 &= \frac{1}{2} m v_1^2 + \frac{1}{2} M v_2^2 \\ m v &= m v_1 \cos \Theta + M v_2 \cos \Phi \\ 0 &= m v_1 \sin \Theta - M v_2 \sin \Phi\end{aligned}\tag{Eq. 1}$$

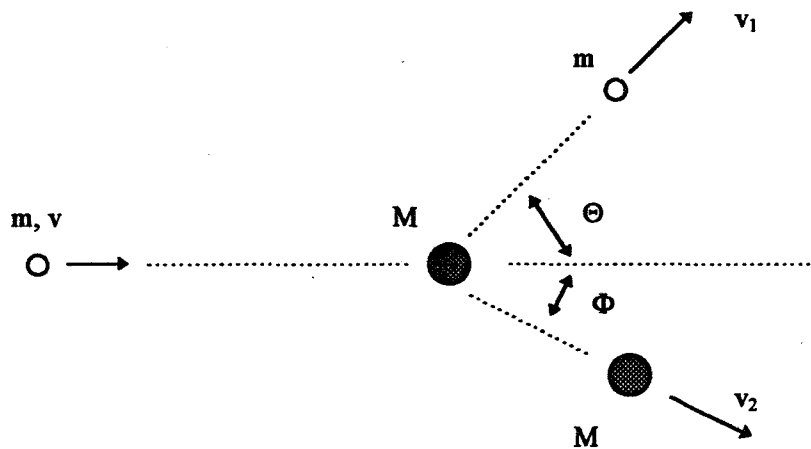


Figure 1. Rutherford Scattering.

It is common for these equations to be combined to find the ratio of the energy E_1 of the scattered ion to the energy E_0 of the incident ion, called the kinematic factor, K ,

$$K = \frac{E_1}{E_0} = \left[\frac{(M^2 - m^2 \sin^2 \Theta)^{1/2} + m \cos \Theta}{M + m} \right]^2 \quad \text{Eq. 2}$$

The kinematic factor is a function of the masses of the incident ion and target ion and the scattering angle Θ . This factor allows the identification of the target nucleus if the incident ion species is known and the angle of scattering and energy of the scattered particle are measured.

Consider the experiment shown in Figure 2. A beam of ions of known species and known energy is incident on some material. A detector, which measures the number of particles it receives and separates them into discrete energy channels, is placed to capture the ions scattered through an angle Θ . The result of such an experiment is a plot of the number of

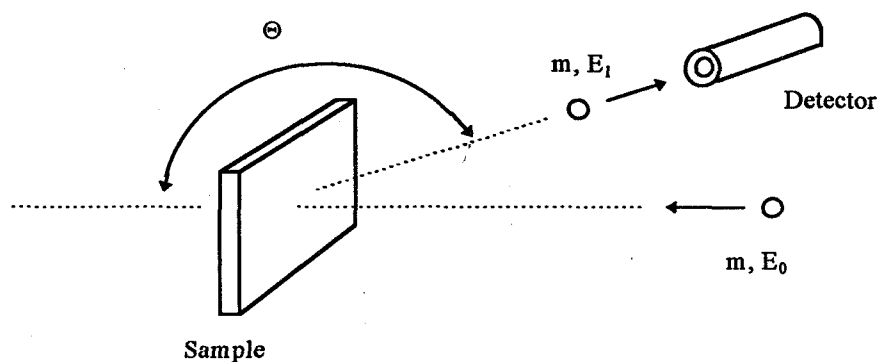


Figure 2. Experimental Arrangement for RBS.

ions received (counts) in each channel. For the case when Θ approaches 180° , the ions collected are those which are scattered back toward the ion source, and K has its smallest value resulting in the greatest mass resolution. This experimental configuration is termed Rutherford Backscattering Spectrometry (RBS) and is the most useful configuration for identification of target atoms. From the measured energy of a scattered ion, K can be calculated, and thus the mass of the nucleus from which the ion was scattered can be determined.

RBS is an analytical technique that is extensively used in materials science. The exercise being presented here involves identifying major elements within the sample only, whereas further analysis can be used to determine relative amounts of elements, depth profiles of elemental concentrations, and thickness of films. These analyses require a discussion of scattering cross sections and stopping powers. More advanced ion beam experiments can yield information on crystalline structure. These techniques are in current use in fields as diverse as materials science, archeology, geology, and anthropology [4].

Exercise:

This exercise is divided into two parts. First, the energy-channel scale must be calibrated, and second, this calibration may be used to identify elements in a spectrum.

1. Calibration:

One method for calibrating the energy-channel scale is to record the spectrum of a material that includes scattering peaks from known elements with large mass separation. A common standard material is a thin layer of Au deposited on SiO_2 . A spectrum of counts versus channel number for 2-MeV He^+ ions scattering from such a sample to a detector positioned at a scattering angle of 170° is shown in Figure 3. From knowledge of the sample structure, features in the spectrum can be identified as scattering from Au, O, and Si. Calculated values of K for each of these elements and the energy (KE_0) of the ions scattered from each are shown in Table 1. From the values of the energy, the signals from each element can be identified in the spectrum, as higher channel numbers correspond to higher energies. The signal from Au appears as a sharp peak centered at channel 700, the sharpness of the peak being indicative of the thinness of the Au layer. The Si, being much thicker than the depth the ions can penetrate, scatters ions with a maximum energy of KE_0 , which are seen at channel 424. Note that for accuracy the channel number is read as the channel for which the Si signal reaches half of its maximum below the sharp rise. See instructor's notes. Ions scattered from Si atoms below the surface of the material also reach the detector but with energy lower than KE_0 , as they lose energy as they pass through the material. Similarly, ions scattered from O appear as a broad peak with the highest energy ions appearing at channel 262. The height and width of these signals indicate the concentration and depth of the element in the material, which are topics of advanced analysis and will not be covered here. To calibrate the energy scale, the signals from Au and O can be used to calculate a linear conversion from channel number to

energy. These two signals are used as they span a greater portion of the scale than could be achieved using the Si signal. From these data we find $E = 2.55 \text{ keV/ch} \times \text{Channel} + 59.1 \text{ keV}$, and thus the energy for any channel number may be calculated. This conversion is a result of the experimental setup and may vary for different systems. The 0-channel offset (59.1 keV) in particular is extremely sensitive to experimental setup. It is expected that the student, reading channel numbers to perform this calibration, should reproduce the calibration slope accurately, but may vary somewhat in the offset value.

Table 1. RBS data for He^+ ions ($E_0=2 \text{ MeV}$) scattered from Au/SiO₂ through 170°.

Element	Mass (AMU)	K	E_1 (MeV)	Channel
Au	197.0	0.923	1.844	700
Si	28.1	0.565	1.130	424
O	16.0	0.363	0.726	262

2. Identification of Elements:

To identify elements in an RBS spectrum, first the channel number of the feature in the spectrum is determined, which is best accomplished using a ruler. Again, for the spectra discussed below, the channel number at the midpoint of the feature is selected for best accuracy. From the calibration, the energy (E_1) of the scattered ions can be calculated, and from this the kinematic factor, $K = E_1/E_0$, is calculated. The atomic mass of the target atom can then be determined by several different methods. The most obvious manner for this is by solving Equation 2 for the mass of the target atom, M . While this is an exercise in algebra, tables of kinematic factors exist in several texts [1,2], with which a kinematic factor can be matched to M . Kinematic factors for selected elements are shown in Table 2. A third method would be for the student, using a computer, to generate tables of K for all values of M .

Examples:

Figures 4-6 are example spectra that can be analyzed using the calibration performed above. These are simulated RBS spectra generated using standard analytical software entitled RUMP. See Instructor's note 1. Figure 4 shows a simulated RBS spectrum of a polymer (Polyimide - C₂₃N₂O₅H₁₀). Three steps are seen in the spectrum at channels 175, 221, and 261. These can be identified as the signals from C, N, and O, respectively. Note that while polyimide also contains H, it does not appear in this spectrum. H atoms are lighter than the He^+ ions and thus do not backscatter the incident ions. Figure 5 shows the spectrum for boron nitride. Note the two steps around channel number 150. These are due to isotopes of boron, ¹⁰B and ¹¹B, for which K is 0.186 and 0.220, giving scattered ion energies of 0.372 and 0.439 MeV. These two isotopes, although close in atomic mass, are easily distinguished. This is not the case for higher atomic mass elements. For example, W (184 AMU) and Au (197 AMU) would be separated by only 0.01 MeV for this incident ion energy, and thus cannot easily be resolved from each other. See Instructor's note 2.

Figure 6 shows the simulated RBS spectrum for Al₂O₃ and Figure 7 is that of NaCl. Note in Figure 7 that signals from ³⁵Cl and ³⁷Cl can be identified. Following the procedure above, the student should be able to identify the elements in each of these spectra.

Table 2. Kinematic Factors for Selected Elements (m = 4 AMU).

Element Mass (AMU)	Detector Angle, Θ			
	90	120	170	180
10	0.429	0.278	0.186	0.184
11	0.467	0.317	0.220	0.218
12	0.500	0.352	0.253	0.250
14	0.556	0.413	0.311	0.309
16	0.600	0.464	0.363	0.360
23	0.704	0.590	0.498	0.495
27	0.742	0.639	0.553	0.550
28	0.750	0.649	0.565	0.563
35	0.795	0.709	0.634	0.632
37	0.805	0.722	0.650	0.648
56	0.867	0.807	0.753	0.751
184	0.957	0.937	0.917	0.917
197	0.960	0.941	0.923	0.922

Instructor's Notes:

1. Spectra - While it is often not feasible to often generate spectra through actual RBS, adequate simulations serve the purposes of this exercise. Simulation software entitled RUMP is available from Computer Graphics Service, Ltd. 52 Genung Circle, Ithaca, NY 14850. Current list price is \$250 for a RUMP/GENPLOT package.
2. Limitations - As the mass of the target atom gets larger, the difference between values of K and thus E₁ for successive elements gets smaller. For example, analyzing by hand a spectrum for steel containing Cr, Fe, and Ni fails miserably as heavier elements cannot easily be resolved. Reasonable success should be achieved for elements with masses from 4 to 40. Also note that H cannot be detected as it is lighter than the incident ions and thus does not backscatter, but rather the H is scattered in the forward direction.
3. Choosing Channel Number - On the spectra included in this paper, the elements are identified by finding the channel number at which the signal drops as channel number increases. The drops do not occur at one channel due to the detector resolution. Therefore, for accuracy, the channel number at the midpoint of the drop is selected.

Acknowledgments: Many thanks to Kevin C. Walter for ideas in preparing this paper. This work was supported by Department of Energy grant DE-FG01-94EW11493.

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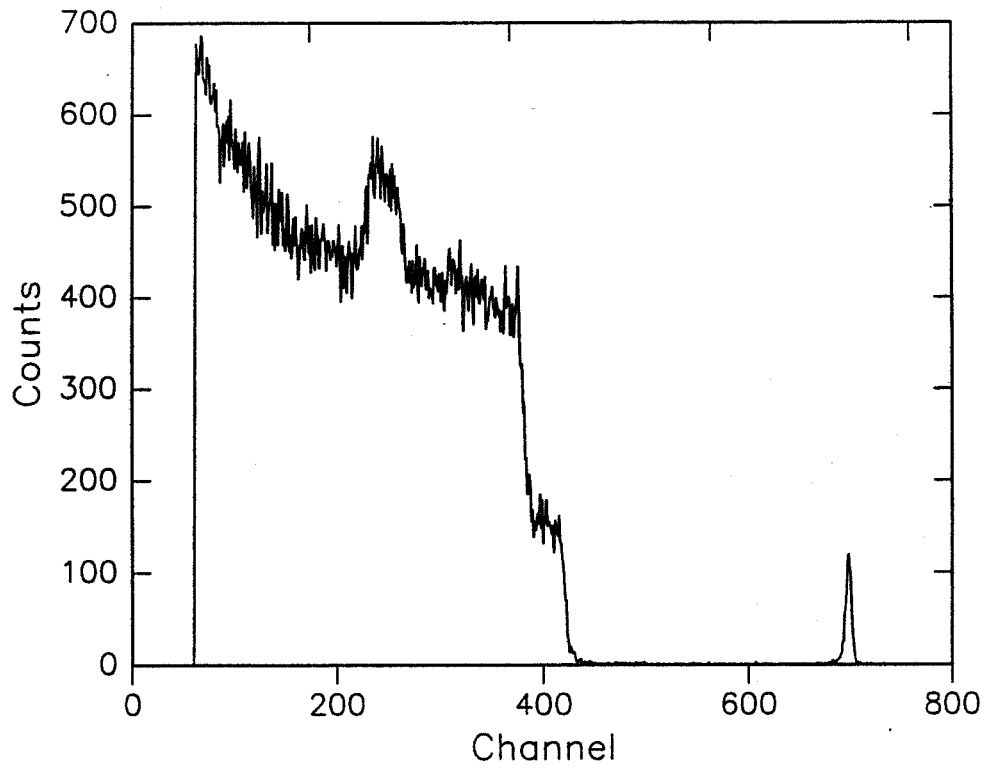


Figure 3. RBS Spectrum (2 MeV He⁺) for Au on SiO₂ for calibration.

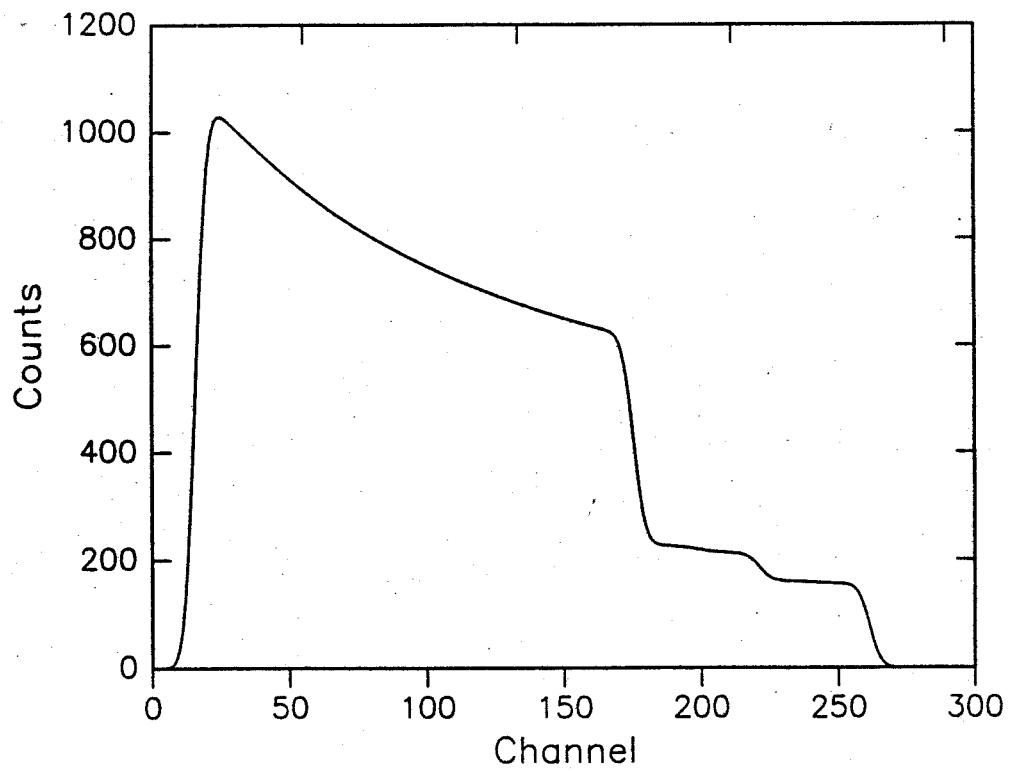


Figure 4. Simulated RBS Spectrum for Polyimide.

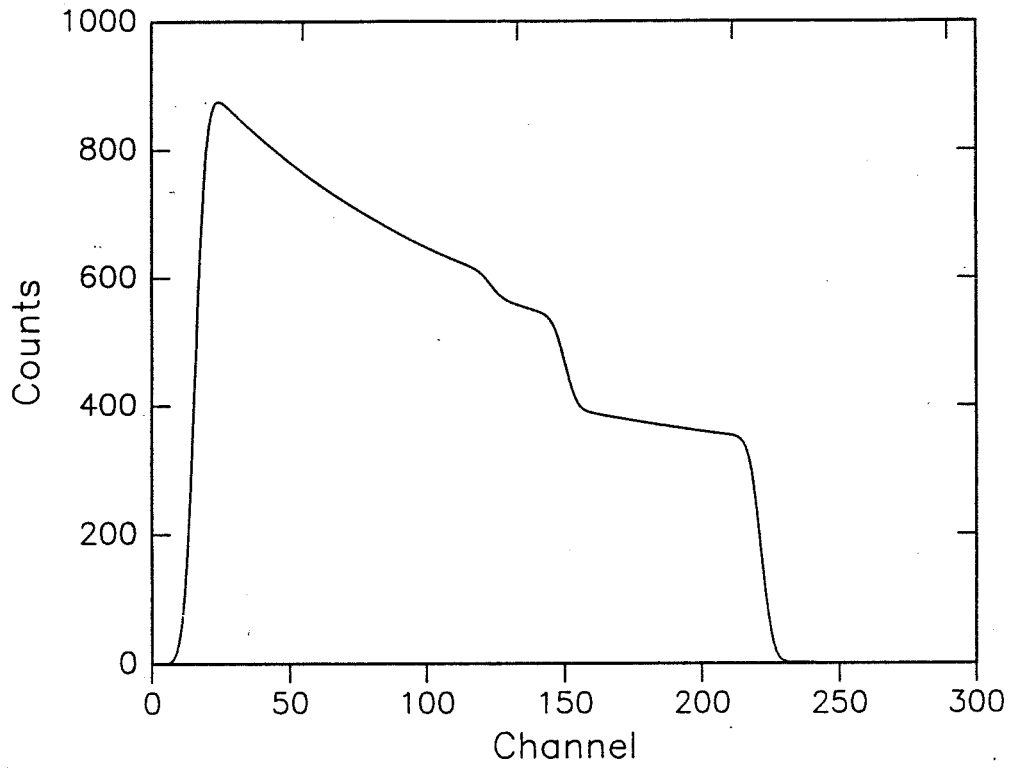


Figure 5. Simulated RBS Spectrum for BN.

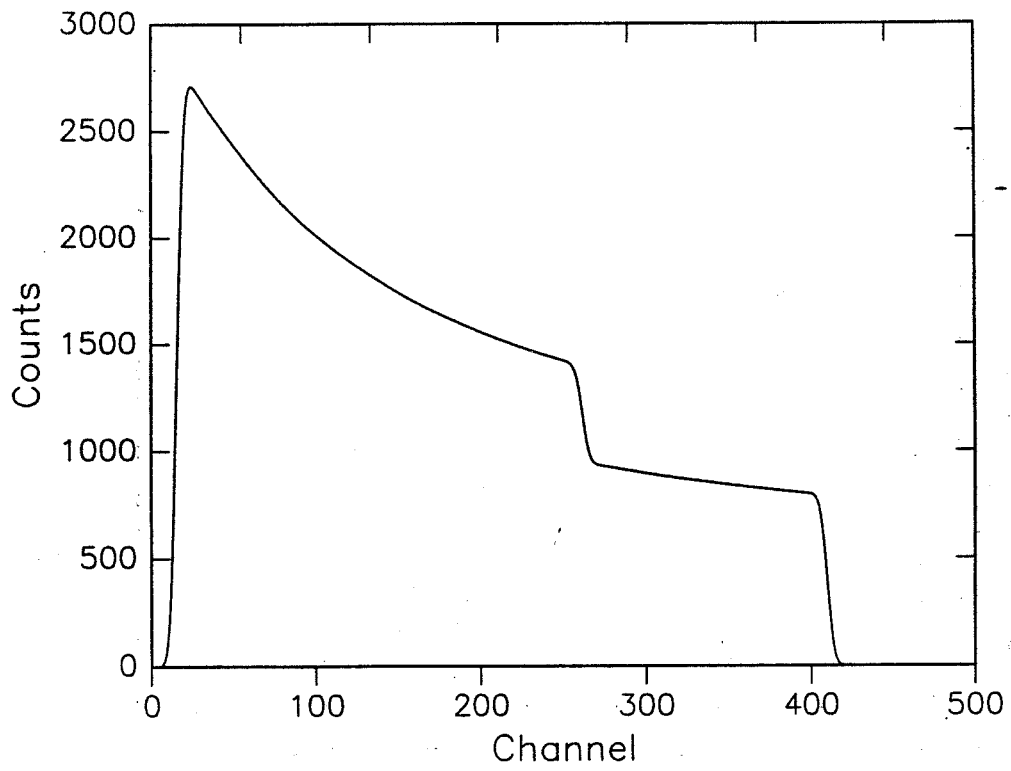


Figure 6. Simulated RBS Spectrum for Al₂O₃.

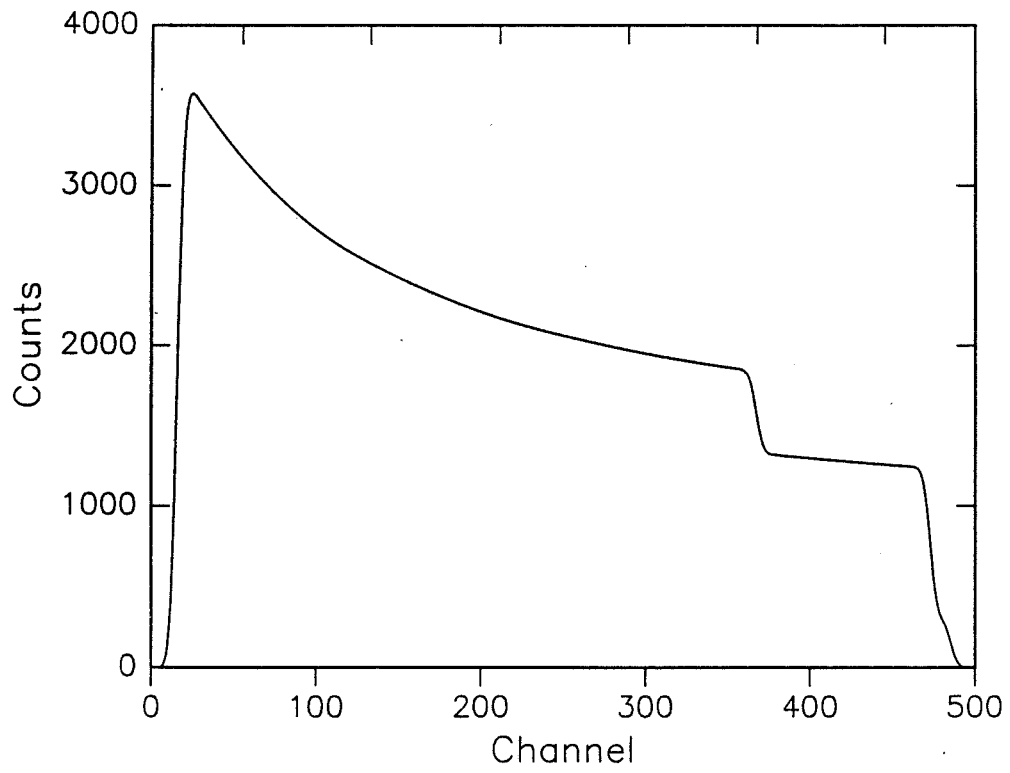


Figure 7. Simulated RBS Spectrum for NaCl.

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COMPUTER-BASED MATHEMATICS INSTRUCTIONS FOR ENGINEERING STUDENTS

Mustaq A. Khan

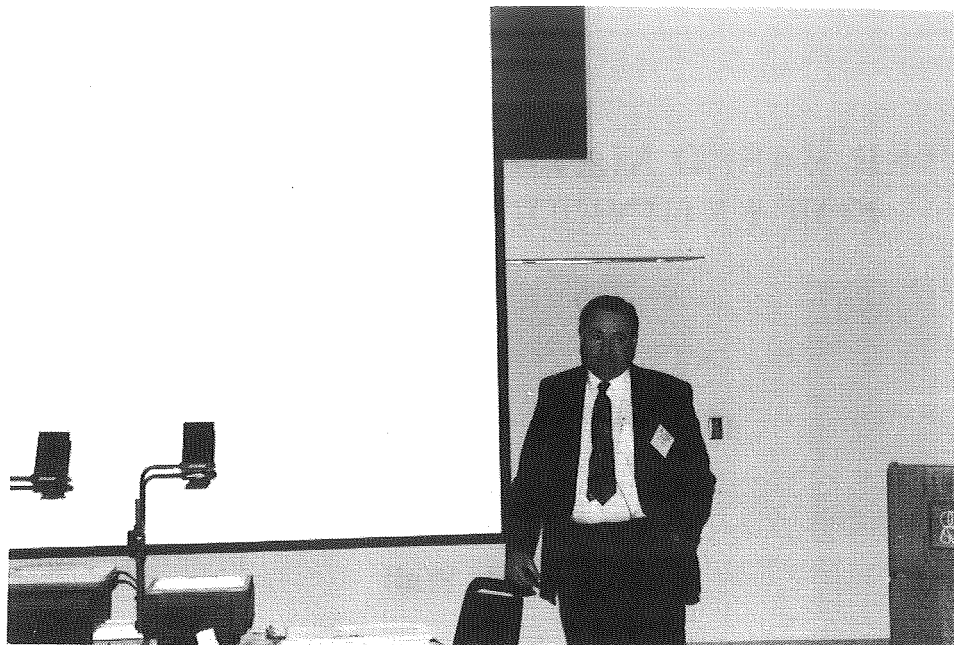
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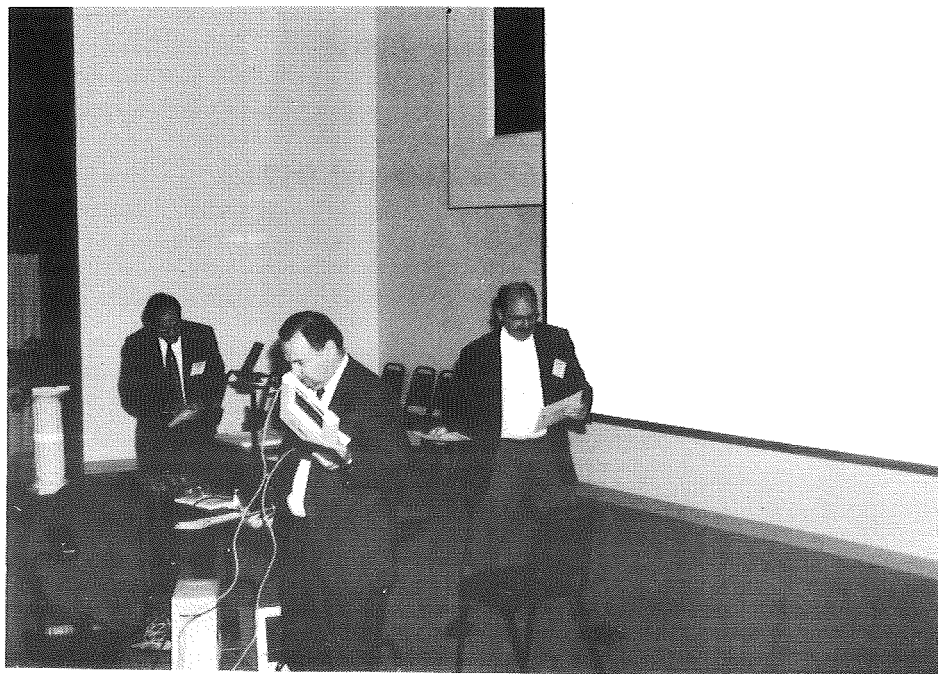
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Curtiss E. Wall



Mustaq A. Khan



**Computer-Based Mathematics Instructions
for Engineering Students**

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and
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Norfolk, Virginia

KEY WORDS: Crystals, Maple, Analysis, Random Walks, Adjacency Matrix, Differential Equations.

PREREQUISITE KNOWLEDGE: Students entering first engineering course are expected to have College Algebra and Trigonometry courses. Knowledge of the basic applications of microcomputer and DOS commands is helpful.

OBJECTIVES: To enhance the understanding of engineering problems through the integration of computer technology in classrooms.

EQUIPMENT AND SUPPLIES:

486/586 MSDOS Computer with Maple software
Overhead Projection Panel
IT-82/85 Graphing Calculator with Overhead Panel

Abstract

Almost every engineering course involves mathematics in one form or another. The analytical process of developing mathematical models is very important for engineering students. However, the computational process involved in the solution of some mathematical problems may be very tedious and time consuming. There is a significant amount of mathematical software such as Mathematica, Mathcad, and Maple designed to aid in the solution of these instructional problems. The use of these packages in classroom teaching can greatly enhance understanding, and save time. Integration of computer technology in mathematics classes, without de-emphasizing the traditional analytical aspects of teaching, has proven very successful and is becoming almost essential.

Sample computer laboratory modules are developed for presentation in the classroom setting. This is accomplished through the use of overhead projectors linked to graphing calculators and computers. Model problems are carefully selected from different areas.

INTRODUCTION:

Computers and computer aided instruction have become the norm in many of our classrooms. However, they have failed to penetrate significantly into the college level engineering and mathematics classroom. Although the analytical process of developing mathematical models is very important for engineering students, the computational process involved in the solution of some mathematical problems may be very tedious and time consuming. The use of mathematics software packages, such as Mathematica, Mathcad, Math Tool Kit, and Maple in classroom teaching can save time and greatly enhance understanding of the physical problems. Teachers have realized that the computers should be used as teaching tools to illustrate and motivate concepts which are too difficult to explain. Integration of computer technology in mathematics classes, without de-emphasizing the traditional analytical aspects of teaching, has proven very successful [1]. This has created new challenges for curriculum development in mathematics and science to take into account the availability of significant computational facilities. The introduction of these tools will mean fundamental changes in the curriculum.

Ideally, each classroom should be a computer laboratory, and each lecture should be a computer based drill project along with analytical teaching. Until that time comes, we will demonstrate how a portable computer attached to an overhead projection panel or a graphing calculator with an overhead panel can be used in a classroom to facilitate computational teaching. A live demonstration will be given by solving a few sample problems.

RANDOM WALKS IN CRYSTALS

One model of atoms in a crystal structure is that of a lattice. A mathematical model of a lattice in two dimensions is called a graph. The study of graphs is well described in Harary [5], and Chartrand and Lesniak [3]. To most people involved in mathematics, the word "graph" probably suggests a picture of x and y axes together with a curve or perhaps a collection of points. Although this is indeed a "graph", it is not the kind of graph to which we are referring. For the purposes of this article, a graph is a finite non-empty collection of objects, called vertices together with lines or curves joining certain pairs of vertices. The lines are referred to as edges. It is customary to denote a graph by G and its sets of vertices and edges by V and E , respectively. If u and v are vertices of a graph G , and G contains the edge joining u and v , then we represent this edge by uv or vu . Although in a strict sense this may not be permitted, we allow more than one edge to join the same pair of vertices, an edge to join a vertex to itself (resulting in a loop), and numbers to be assigned to edges if the situation calls for it.

As an example of a graph G , let $V = \{ u, v, w, x \}$ and $E = \{ uv, uw, vw, wx \}$. The graph G is "drawn" in figure 1.

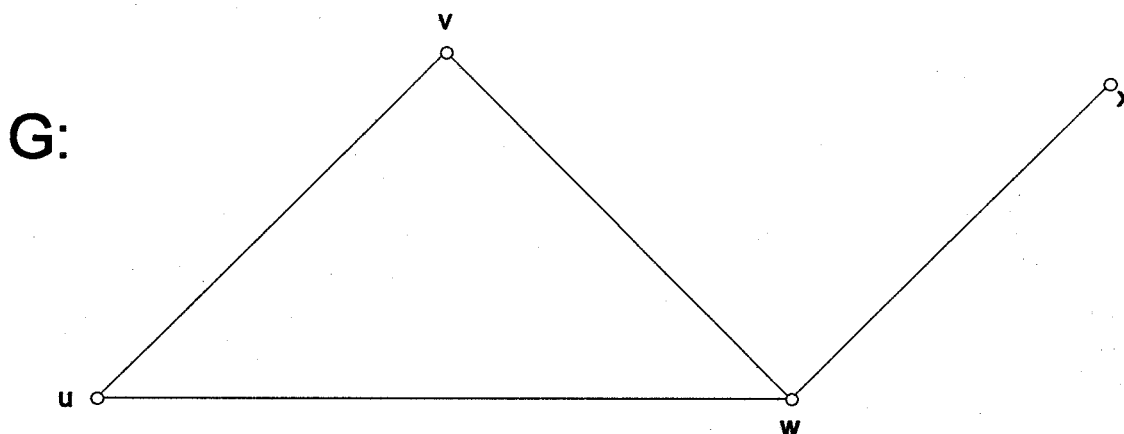
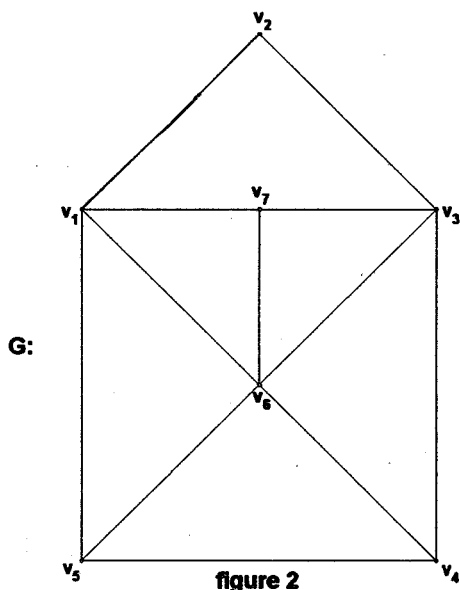


figure 1.

A crystal lattice is said to be defective if atoms can jump from an occupied node in the lattice to an adjacent unoccupied node. This process can be repeated by the same atom or a new atom jumping to a newly vacated spot. In a given time interval, each atom may move in one of several possible directions, or it may remain in its initial position. This motion of the atoms through the lattice is called a random walk and has a mathematical description in Graph Theory. Let each node on the lattice be denoted by a vertex, and two vertices will be connected by an edge if an atom can move between the locations denoted by the vertices. An atom's movement through the lattice can be described as a random walk. According to Chartrand [3], a u - v walk of a graph G is a finite alternating sequence of vertices and edges of G , beginning with u and ending with v , such that every edge is immediately preceded and succeeded by the two vertices with which it is incident. The length of the walk is the number of edges in the walk. An example of a u - v walk in figure 1 is u,v,w,x,w,u,v . This u - v walk has length six.

Let the graph in figure 2 represent the possible movements of atoms in a defective crystal. In this case, an atom at vertex v_2 would be able to jump to either location v_1 or v_3 . Suppose that we wish to ascertain the number of different u-v walks of a given length between two locations in the crystal. Two walks of the same length are different if they do not have the same sequence of



$$A = \begin{matrix} & \begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 & v_6 & v_7 \end{matrix} \\ \begin{pmatrix} 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 \end{pmatrix} & \begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \\ v_7 \end{matrix} \end{matrix}$$

labels in their respective u-v paths. If the length of the walk between the two atoms is small, we could list the walks. However, as the length of the walks increases, the difficulty of listing the walks becomes exceedingly complex. Fortunately, the following theorem provides a solution to this problem.

Theorem: Let G be a labeled graph with adjacency matrix A . Then the i,j entry of A^n is the number of walks of length n from vertex v_i to v_j .

In order to use this theorem we must be able to construct the adjacency matrix of a graph. The adjacency matrix is a square matrix with the labels of the vertices listed vertically and horizontally outside the matrix. If two vertices are adjacent, then a 1 is placed at the intersection of the row and column represented by the two labels. Otherwise, a 0 is placed at the intersection as well as along the diagonal. If we apply this method to the graph in figure 2 we have the adjacency matrix A . By applying the theorem to G we obtain the adjacency matrices below. Thus, there are two paths of length 2 between vertices v_6 and v_4 and 9 of length 3.

$$A^2 = \begin{pmatrix} 4 & 0 & 3 & 2 & 1 & 2 & 1 \\ 0 & 2 & 0 & 1 & 1 & 2 & 2 \\ 3 & 0 & 4 & 1 & 2 & 2 & 1 \\ 2 & 1 & 1 & 3 & 1 & 2 & 2 \\ 1 & 1 & 2 & 1 & 3 & 2 & 2 \\ 2 & 2 & 2 & 2 & 2 & 5 & 2 \\ 1 & 2 & 1 & 2 & 2 & 2 & 3 \end{pmatrix}$$

$$A^3 = \begin{pmatrix} 4 & 7 & 5 & 6 & 8 & 11 & 9 \\ 7 & 0 & 7 & 3 & 3 & 4 & 2 \\ 5 & 7 & 4 & 8 & 6 & 11 & 9 \\ 6 & 3 & 8 & 4 & 7 & 9 & 5 \\ 8 & 3 & 6 & 7 & 4 & 9 & 5 \\ 11 & 4 & 11 & 9 & 9 & 10 & 9 \\ 9 & 2 & 9 & 5 & 5 & 9 & 4 \end{pmatrix}$$

COUPLED SPRING

The motion of a mass attached to a spring serves as a relatively simple example of the vibrations that occur in more complex mechanical systems. In an example below, we consider the system of two masses and two springs, which is an elementary application involving systems of differential equations. Two masses m_1 and m_2 are connected to two springs A and B of negligible mass having spring constants k_1 and k_2 , respectively. The two springs are attached as shown in figure 3 below.

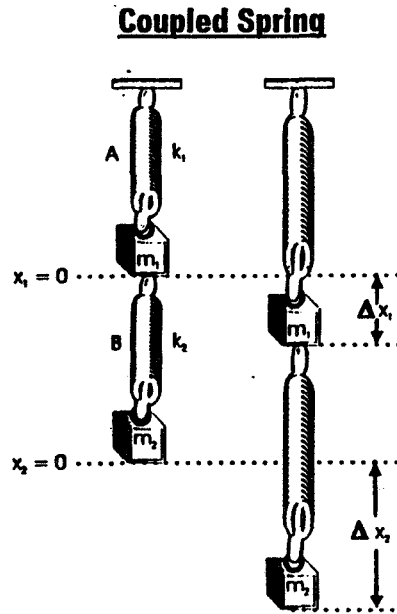


Figure 3

We denote by $x_1(t)$ and $x_2(t)$ the vertical displacements of the masses from their equilibrium positions. Thus the two springs are neither stretched nor compressed when x_1 and x_2 are zero. When the system is in motion, spring A is stretched x_1 units and spring B is stretched $x_2 - x_1$ units. Hence by Hook's Law, the force exerted on mass m_1 is $-k_1x_1 + k_2(x_2 - x_1)$ and the net force exerted on mass m_2 is due solely to the net elongation of spring B, that is, $-k_2(x_2 - x_1)$. Applying Newton's second law of motion, the motion of the coupled system is represented by the following system of simultaneous second-order differential equations:

$$m_1 \frac{d^2x_1}{dt^2} = -k_1x_1 + k_2(x_2 - x_1).$$

$$m_2 \frac{d^2x_2}{dt^2} = -k_2(x_2 - x_1).$$

Example 1:

Solve the above system if $k_1 = 6$, $k_2 = 4$, $m_1 = 1$, $m_2 = 1$ and that the masses start from their equilibrium positions with opposite unit velocities. In other words, solve

$$x_1'' + 10x_1 - 4x_2 = 0$$

$$-4x_1 + x_2'' + 4x_2 = 0$$

subject to

$$x_1(0) = 0, x_1'(0) = 1, x_2(0) = 0, x_2'(0) = -1$$

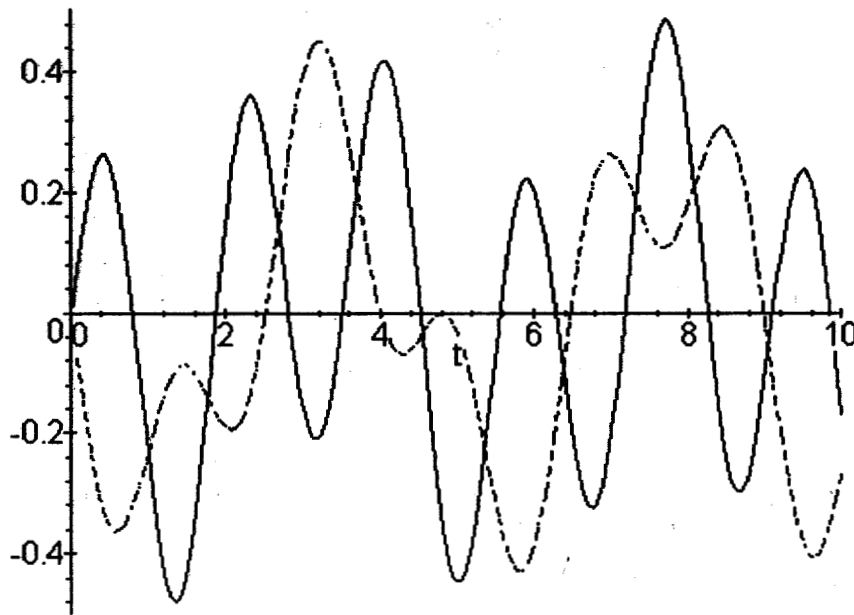
At this point, the teacher has two options: spend another thirty minutes to solve this system manually in class step by step or use the computer and any suitable mathematics package and get the result in a few minutes, and use the remaining time in interpreting and explaining the output. In engineering courses, where differential equations courses are a prerequisite, it seems to be a waste of valuable classroom time to go through a step by step solution of this problem

$$x_1(t) = -\frac{\sqrt{2}}{10} \sin \sqrt{2}t + \frac{\sqrt{3}}{5} \sin 2\sqrt{3}t$$

$$x_2(t) = -\frac{\sqrt{2}}{5} \sin \sqrt{2}t - \frac{\sqrt{3}}{10} \sin 2\sqrt{3}t$$

manually. The second option is strongly recommended. Hence, using Maple, we find the following solution to the above problem.

This solution can be further analyzed graphically and the position of the masses m_1 and m_2 can be determined instantly at different times.



Furthermore, the same problem can be solved for a different set of initial conditions and the results can be shown for comparison. The Maple commands used to solve the above system are given below.

$$de1 := \text{diff}(x1(t), t\$2) + 10 * x1(t) - 4 * x2(t) = 0;$$

$$de2 := -4 * x1(t) + \text{diff}(x2(t), t\$2) + 4 * x2(t) = 0;$$

$sys := de1, de2 : fcns := \{x1(t), x2(t)\}$

$dsolve(\{sys, x1(0) = 0, D(x1)(0) = 1, x2(0) = 0, D(x2)(0) = -1\}, fcns, laplace);$

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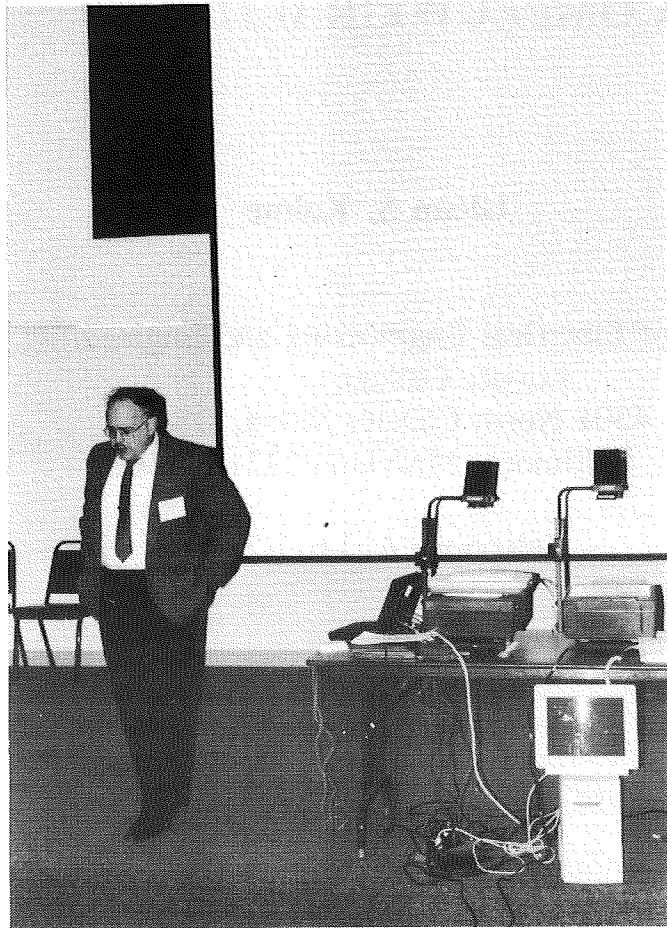
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**AN AUTOGRADING (STUDENT) PROBLEM
MANAGEMENT SYSTEM FOR THE
COMPEUWTIR ILITTUR8**

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An Autograding (Student) Problem Management System for the Compuwtr IIittur8

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Abstract:

In order to develop analysis skills necessary in engineering disciplines, students need practice solving problems using specified analytical techniques. Unless homework is collected and graded, students tend not to spend much time or effort in performing it. Teachers do not, realistically, have the time to grade large numbers of homework problems on a regular basis. This paper presents and makes available a miracle cure. The Autograding Problem Management System (APMS) provides a discipline-independent mechanism for teachers to create (quickly and easily) sets of homework problems. The APMS system provides CRT and/or printed summaries of the graded student responses. This presentation will demonstrate both the speed and the drag-and-drop simplicity of using the APMS to create self-grading homework problem sets comprised of traditional types of problems and of problems which would not be possible without the use of computers.

Introduction:

In order to develop analysis skills necessary in engineering disciplines, students need practice solving problems using specified analytical techniques. Traditionally, instructors assign homework problems to provide students with the necessary problem-solving practice and give examinations to evaluate their skill.

Two things have changed over the last thirty years. First, a much larger percentage of high school graduates is attending college. This has broadened the range of academic skill and motivation in the student body. Second, faculty salary has been linked to student opinion. The combination of these two factors has led to a dilution of performance required of the students and to (well-documented) grade inflation. The challenge to instructors is to motivate the students to do the necessary work to learn without incurring their wrath.

We have found that assigning, collecting, and grading homework will motivate the students sufficiently and they will do well on examinations. We have also found that assigning but not collecting and grading homework is not sufficient motivation and that students tend not to spend much time or effort in performing it. This results in poorer performance on examinations and student unhappiness. Teachers do not, realistically, have the time to grade large numbers of homework problems on a regular basis.

The Autograding Problem Management System (APMS) was designed and developed to accomplish several very distinct goals. The goals were to provide a mechanism:

for assigning homework that would be graded by computer; and,

that would spark student interest by presenting more interesting problems in a more interesting fashion; and,

that instructors could learn to use in one or two hours; and,

to use colors and graphics which were previously unpractical.

The APMS is not presented as an earth-shattering breakthrough in the pedagogic use of computers. Rather, it is presented as a unique and simple-to-use packaging of those tools an instructor needs to create homework (or exam) question sets which the students can administer to themselves outside of the classroom.

The APMS System:

The APMS system consists of two Windows 3.1 programs. Hardware requirements are modest by today's standards. The minimum configuration requires Windows 3.1 and about 2MB of hard disk space. Both performance and versatility are enhanced with more modern hardware. The recommended minimum hardware configuration for the Student Program is a 33 MHz 486 processor with a 1024x768 1MB video display. The recommended minimum hardware for the Teacher Program includes a 100 MHz 486 or 75 MHz Pentium, a 1024x768 2MB video display, a color scanner, and a printer.

In the paragraphs that follow, the Teacher Program and the Student Program will be discussed. Following that, several implementation issues and observations will be given.

The Teacher Program:

The Teacher Program provides two basic functions. It allows the instructor to create and edit individual problems (exercises) and it provides a means to assemble new and existing problems into coherent sets of student assignments.

Creation of new problems is accomplished through "button clicking" and "drag-and-drop" operations. Initially, a new problem is presented as a blank work area. An array of "buttons" allows the instructor to "drop" any one of a variety of "objects" into the problem. These "objects" are: windows to display pictures; text boxes to contain problem statements; number boxes to receive and automatically grade numerical answers; word boxes to receive and automatically grade true/false and short-answer answers; multiple choice boxes to receive and automatically grade multiple choice answers; essay boxes to receive essay type answers (up to 32,000 characters each); and graphics boxes to receive drawings made by the student.

Once the “object” is dropped into the problem, the instructor can move its position, change its size and shape, and fill it with the correct answer (where appropriate). Each autograded box will spawn a self-descriptive dialog window to collect the correct answer.

After creation, each problem can be saved individually as a DOS-type file (recommended). That problem can then be copied, edited to become a slightly different problem, and saved. Homework sets are generated by collecting a group of individual problems and creating student assignment diskettes.

The Student Program:

The Student Program administers the homework set. It presents the individual problems and collects the student’s answers. Depending on choices made by the instructor, various types of grading will be available.

After the student opens an assignment set, he/she can work on individual problems in any order. The answer boxes spawn dialog windows to collect the answers. The answers can be saved and work continued or answers changed at any time.

Problems for Drill:

As instructors in engineering, we want students to accomplish at least two levels of understanding. Initially, we want the students to learn about and to understand some fundamental theoretical concept or characteristic behavior. To achieve this, we explain, demonstrate, present examples, ask questions, draw pictures, discuss analogs and do all sorts of other things to help the student to understand. Secondly, we want the students to be able to use this understanding to solve problems. To this end, we can employ a two-step process. The first step is to give the students a variety of drill-type problems. By completing the drills, the students achieve competence in using analytic tools and convince themselves that they understand the underlying concept or behavior. The second step is to give students problems which are “fresh” and which require the student to consider how a problem should be solved and to select the proper analytic tools to solve it.

While most instructors have no difficulty in conceiving good drill problems, posing the problems has generally been tedious and time consuming. A large variety of basic engineering problems require some sort of picture or graphic to pose the problem adequately. This requirement has tended to keep us “married” to the textbook problems, with their printed graphics. Newer texts are using color printing of the problem graphics. Color can be used very effectively to help the student understand the problem, but it kills the instructor’s ability to generate drill problems based on the graphic which cannot be faithfully photocopied.

With the APMS, it becomes quite easy to modify existing pictures or graphics so as to quickly build large sets of drill-type exercises. I believe that students relate better to problems which are presented as clean originals than they do to marked up photocopies.

Grading Options:

There are a variety of points-of-view among instructors as to how and when students should have access to correct answers. Some feel that the students should know the correct answer before starting the problem solution; some believe that the student should have instant feedback, either incrementally as they solve the problem or immediately upon completion; and some believe that part of learning to solve problems requires the student to have enough confidence in his/her technique to defend the work without being given the correct answer. The APMS was designed to accommodate each of these points of view. When the instructor creates the assignment disk for the student, he/she has the option of specifying how and when the student can access the correct answers.

Networks/ Large Graphics Sets:

One of the major advantages of the APMS is its ability to present photographic quality color graphics to the students. In the default configuration, the APMS includes a copy of each graphics image referenced within the problem set on the assignment diskette given to the student. Graphics files can be very large. There may be occasions where it is desirable to install the graphics images on the computers available to the students or on a network server, and not include them on the student assignment disk. The APMS provides an easy to use mechanism that allows you to specify on the student assignment disk, the location of the graphics images referenced within the set. The images themselves can then be installed on your network server or on computers available to the students. This option allows you to transfer "compressed" files or to use more than one diskette to distribute an assignment set.

Textbook Editions:

It is common for authors/publishers to produce a new edition for a given text every three or four years. This practice tends to keep commerce in the used book market relatively low. It also creates work for instructors. Frequently, the content of a newer edition (for basic engineering courses) will present little or no new information, although the material might be slightly rearranged. The problem sets given for homework do tend to change. This means that instructors must commit considerable time evaluating the new problems and preparing solutions for those problems selected. With the APMS, it becomes quite easy for the instructor to maintain his/her own sets of homework exercises (collected over time). In this manner, the instructor can move to later editions with relatively little "busy-work".

Conclusion:

The APMS seems to meet all of the design goals. What remains to be evaluated is student acceptance. There is little doubt that our students will have a lot to say about the APMS. We hope that their input can be used to make this system a better tool for both the teacher and the student.

**FACTORIAL DESIGN:
AN EIGHT FACTOR EXPERIMENT
USING PAPER HELICOPTERS**

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***Factorial Design:
An Eight Factor Experiment Using Paper Helicopters***

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April 25, 1995

Concise Statement of Purpose, Goals:

The goal of this paper is to present the analysis of the multi-factor experiment (factorial design) conducted in EG 490, Junior Design. The discussion of this paper concludes the experimental analysis and ties the individual class papers together. The analysis described and used in this paper was substantially derived from the paper by Larry Panchula and John W. Patterson of the Department of Materials Science and Engineering of Iowa State University.¹

Procedure:

There are several design possibilities for paper helicopters. This experiment consists of the variables listed in Table IV. These variables can be considered to be "on" or "off" (i.e. does the paper helicopter contain a paper wing?). Construction of

¹Larry Panchula and John W. Patterson. Department of Materials Science and Engineering. Iowa State University - Ames, IA 50010.

paper helicopters using every combination of design possibilities would be both tedious and, utilizing factorial design, not necessary. Factorial design allows the experimenter to construct only a small portion of these possibilities, yet be able to determine the individual effects of each variable. In the paper helicopter experiment, only sixteen (16) helicopters were constructed per group. The settings for each variable were randomly chosen.

I was presented data of various formats by the six groups of two students participating in the experiment. In every case, I was given the characteristics (i.e. ~~Wing~~ length, etc., *please refer to later discussion and Table IV*) of each of the sixteen (16) helicopters along with five (5) trial times and a subsequent average drop time.

Since we are dealing with sixteen (16) "sample" helicopters (of the possible maximum number of 256 combinations) and two (2) possibilities for each variable (either a 0 or 1, *please refer to later discussion*), we must have eight (8) "+" and eight (8) "-" helicopters for each variable. If this condition is not met, we are not performing a true factorial design as the difference factor (effect) will be influenced by the fact that some variables are "weighted more" than others. At the time of writing of this paper only four (4) of the six (6) groups met the above conditions and therefore only four (4) groups are considered in the analysis.

Once the data appears to be in accordance with the rules

governing factorial design, the computation of difference factors can be done. Basically, this is the "effect" the variable has on the overall effect of the event under consideration. In this particular instance, we are concerned with the overall flight time of the paper helicopters. We are interested in determining how each condition (variable, factor) affects the flight time. Through a partial factorial design, as opposed to a full scale design test consisting of 256 helicopter tests per group, we can gain a very good sense of how each of these variables affects the flying time.

The above described difference effect is computed one variable at a time, one experiment at a time. "High" (or +) values of the first variable of the design (in our situation, P, the type of paper used) are marked and distinguished between "Low" (or -) values. As described earlier, there should be eight (8) "High" and eight (8) "Low" values. Next, the values of the average times of the helicopters whose design parameters match a "High" condition for the variable we are currently dealing with (P) are averaged and recorded as the "high times". Similarly, a "low time" is obtained by averaging the average flight times of the eight (8) "low" valued helicopters that are identified by the "0" or "-" for the particular variable being analyzed. The difference factor, effect, is simply the absolute value of the difference between the average of the "high times" and the average of the "low times".

$$\text{Effect} = \text{ABS} \left\{ \Sigma \text{Average Times}_{\text{High}}/8 - \Sigma \text{Average Times}_{\text{Low}}/8 \right\}$$

This process is repeated for each variable and for each of the four (4) groups. The results are presented in table form beginning on the next page. In addition, a statistical analysis of each variable is shown. The importance of this analysis will be discussed later. Table I lists the groups and participants of the experiment. Table II displays all the experimental data including a statistical analysis of each variable.

Table I

Randomly Selected Group number associations:

Group 1 - > Michelle Davis, Derek Klinedinst
Group 3 - > Brian Marinari, Nadeem Kureishy
Group 4 - > Joseph South, John Ward
Group 5 - > Ann Nickle, Brandon Quick

*BECAUSE OF INCONSISTENT DATA AT THE TIME THIS REPORT WAS COMPILED, GROUPS 2 AND 6 ARE NOT INCLUDED IN THE ANALYSIS.

Table II

Variable => P

Group #	Effect
1.	.026
3.	.02125
4.	.1765
5.	.03375

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.02125
Maximum	.1765
Mean	.064375
Median	.029875
Var. (σ^2)	.005614
S.D. (σ)	.0749

Variable => B

Group #	Effect
1.	.11225
3.	.074
4.	.0885
5.	.1487

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.074
Maximum	.1487
Mean	.1058625
Median	.100375
Var. (σ^2)	.001064
S.D. (σ)	.0326217

Variable => L

Group #	Effect
1.	.1115
3.	.02475
4.	.1435
5.	.1312

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.02475
Maximum	.1435
Mean	.1027375
Median	.12135
Var. (σ^2)	.0028768
S.D. (σ)	.0536362

Variable => W

Group #	Effect
1.	.341
3.	.28325
4.	.2305
5.	.179

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.179
Maximum	.341
Mean	.2584375
Median	.256875
Var. (σ^2)	.004841
S.D. (σ)	.0695774

Variable => C

Group #	Effect
1.	.085
3.	.2803
4.	.0715
5.	.14125

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.0715
Maximum	.2803
Mean	.1445125
Median	.113125
Var. (σ^2)	.009107
S.D. (σ)	.0954313

Variable => F

Group #	Effect
1.	.1165
3.	.07275
4.	.118
5.	.16125

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.07275
Maximum	.16125
Mean	.117125
Median	.11725
Var. (σ^2)	.00130577
S.D. (σ)	.036135

Variable => T (X)

Group #	Effect
1.	.1335
3.	.05825
4.	.1775
5.	.02625

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.02625
Maximum	.1775
Mean	.098875
Median	.095875
Var. (σ^2)	.0047685
S.D. (σ)	.06905

Variable => M (Y)

Group #	Effect
1.	.283
3.	.41025
4.	.3255
5.	.20125

Statistical Analysis of Effects with respect to all 6 groups

Minimum	.20125
Maximum	.41025
Mean	.305
Median	.30425
Var. (σ^2)	.007582
S.D. (σ)	.08707

Table III

Summary of Variable Effects (means)

Variable	Effect	S.D.
P	.064375	.0749
B	.1058625	.032617
L	.1027375	.0536362
W	.2584375	.0695774
C	.1445125	.0954313
F	.117125	.036135
T (X)	.098875	.06905
M (Y)	.305	.08707

Table III represents the best picture of the collective data. From this data, we can easily see the effect of each

variable. Consulting the above table, we can rank the importance of each variable according to the data of the experiment. Table IV presents this information with α being the importance factor of each variable; an alpha value of 1.0 represents the most important variable. Every other value of alpha represents the fractional importance with respect to the most important variable ($\alpha=1.0$).

Table IV

#	Var	Physical Representation	Value	α Value
1	M	Taped Wing (Y/N)	.305	1.000
2	W	Wing Length (2"/4")	.2584	0.847
3	C	Paper Clip (Y/N)	.144	0.472
4	F	Fold (Y/N)	.117	0.384
5	B	Body Width (1"/1.5")	.1058	0.347
6	L	Body Length (1.5"/3")	.1027	0.337
7	T	Taped Body (Y/N)	.0988	0.324
8	P	Paper (Regular/Construction)	.0644	0.211

This data is shown in different forms in figures 1, 2, and 3. In figure 1, the individual difference effects for each variable and each group (1, 3, 4 and 5) are displayed in addition to the mean effect for each variable. Figure 2 presents a clearer picture of just the means of the effects (with respect to all four groups). Figure 3 contains data of three different types. The first type is the mean (as used above) of all four groups. The second portion is a group of three randomly selected groups (the random

groups selected were 1, 3 and 5). The final portion was a random sample group (group number 4). This analysis provides a broader picture in terms of error reduction and visualization.

The next step in the analysis involves selecting how the variables should be set (either high or low) to maximize the flight time of a paper helicopter. This is accomplished by computing the average of the high and low times for each variable. These can be easily compared to determine which setting yielded a longer flight time. Table V shows the values of the high and low settings for each variable.

Perhaps the biggest advantage of factorial design is that the experimenter can easily detect an error in the data such as a miscalculated average run time. In this experiment, one group was disqualified from the analysis because the data provided by that group was not consistent at all with the data provided by the other groups of the experiment. This was discovered by simply viewing the data in graphical format. This yielded the conclusion that the group had not made eight (8) "high" and eight (8) "low" settings for each variable. Another group made a simple mathematical error. This fact was easily verified by performing the calculations again.

Table V

	Paper P	Body Wid. B	Body Len. L	Wing Len. W	Paper Clip C	Fold F	Taped Body T	Taped Wing M
Low	Reg	1"	1.5"	2"	No	No	No	No
High	Const	1.5"	3"	4"	Yes	Yes	Yes	Yes

The data is presented in table form as Table VI.

Table VI

Variable/Setting	Average Time
P High	1.0984
P Low	1.1494
B High	1.0867
B Low	1.1624
L High	1.11175
L Low	1.13645
W High	1.203
W Low	1.034
C High	1.0698
C Low	1.1785
F High	1.105875
F Low	1.1423
T High	1.1226
T Low	1.1256
M High	1.053
M Low	1.19525

This data is shown in graphical format as figure 4. From this data, we can see that in order to maximize flight time, the

design parameters presented in table VII should be adhered to in the construction of paper helicopters:

Table VII

- Regular Paper
- 1" Body Width
- 1.5" Body Length
- 4" Wing Length
- No Paper Clip
- No Fold
- No Taped Body
- No Taped Wing

However, it should be noted that there is not a large deviation in the values; perhaps the addition of more data sets would shift the design parameter decision(s) in the other direction.

Future Work, Closing Remarks

The addition of the other two groups would provide us with a more meaningful analysis. However, a fairly clear picture is obtained by the existing sets of data. The main goal of the paper has thus been accomplished. We have seen how every variable affects the overall design and how to set each variable in order to obtain the maximum flight time.

References, Assistance Provided

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Department of Materials Science and Engineering
Iowa State University - Ames, IA 50010

The students participating in the experiment as previously named:
EG490, Spring 1995
Loyola College in Maryland

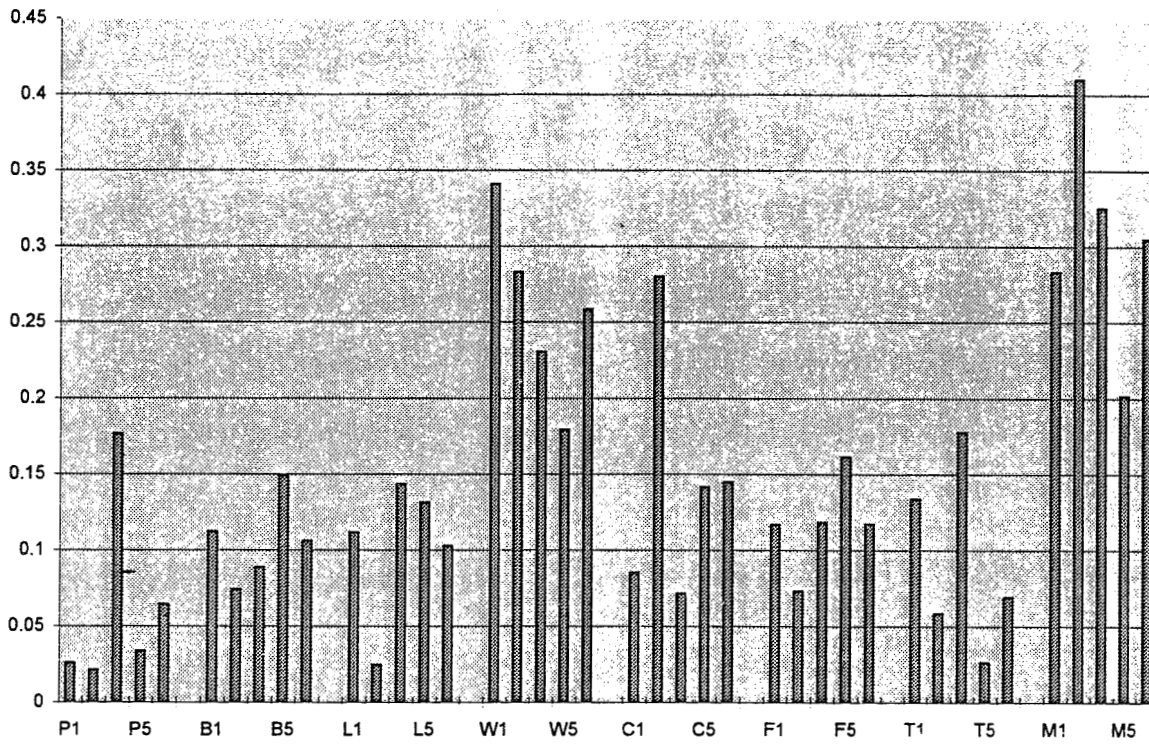


Figure 1 - Individual Group Effects and Mean Effects of Each Variable

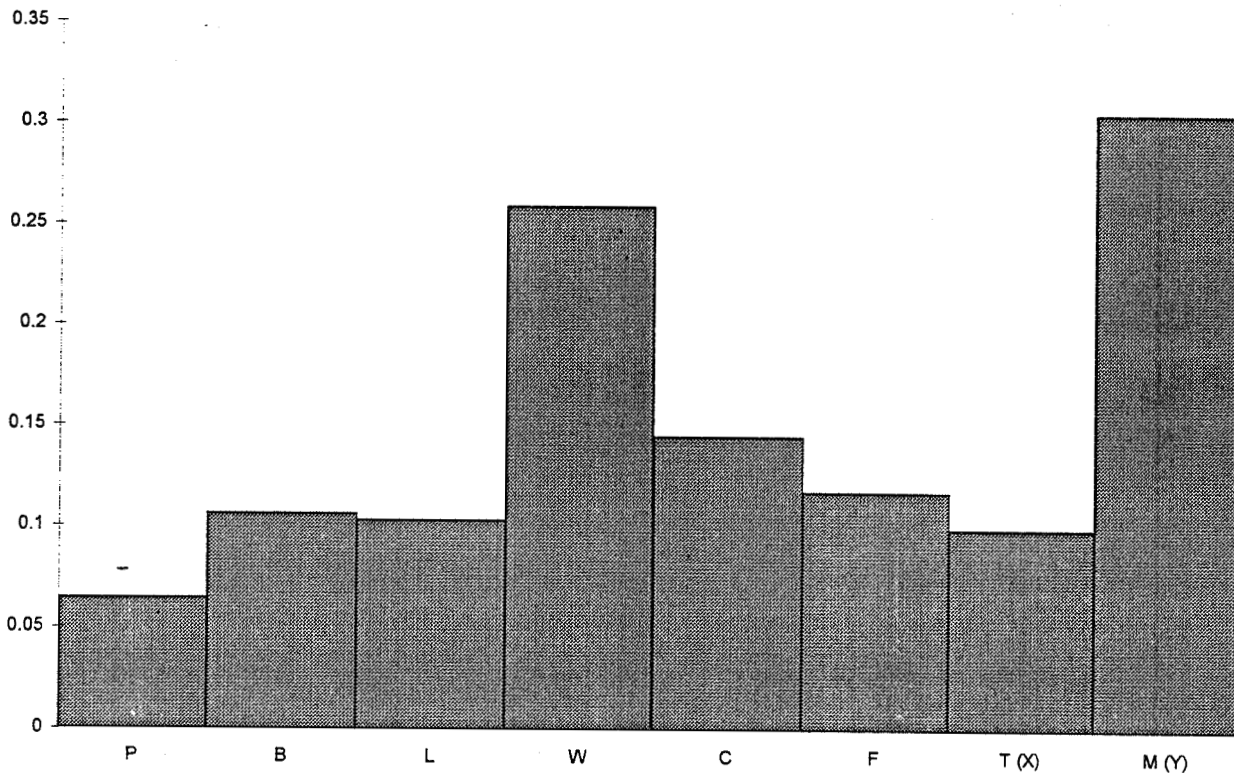


Figure 2 - Mean Effects of Each Variable

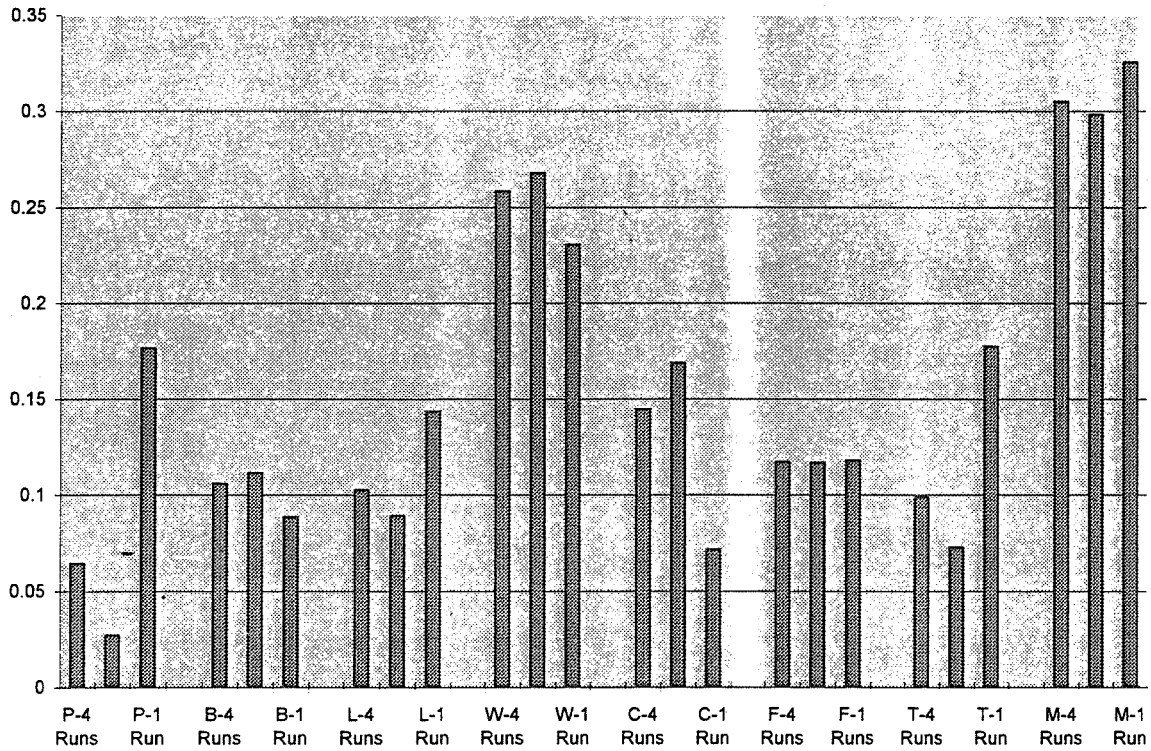


Figure 3 - Effects - Random Samples (Groups of 4, 3 and 1)

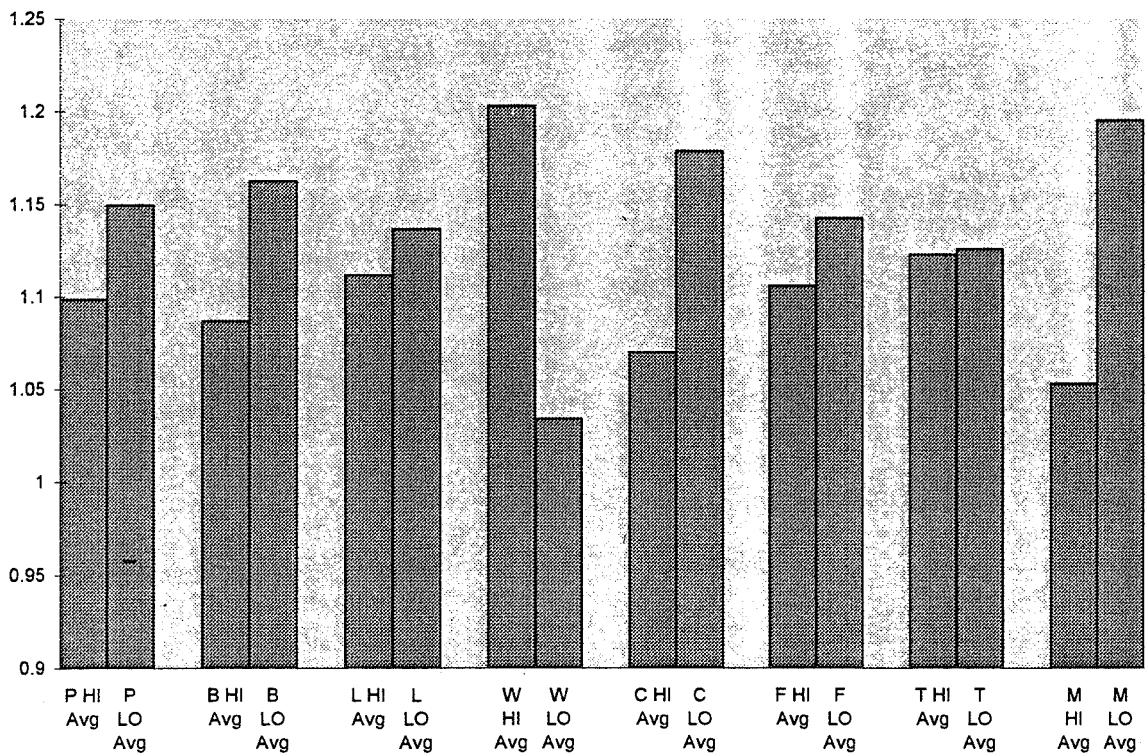


Figure 4 - Averages of "HIGH" and "LOW" Times for Each Variable

**PLASTIC RECYCLING EXPERIMENTS IN
MATERIALS EDUCATION**

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Plastic Recycling Experiments in Materials Education

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Key Words: Plastic recycling, collection, granulating, extrusion compounding, pelletizing.

Prerequisite Knowledge: Thermoplastics properties and extrusion processing.

Objective: The objective of this project was to introduce a series of plastic recycling experiments to students in materials-related courses such as materials science, material technology and materials testing. With the plastic recycling experiments, students not only can learn the fundamentals of plastic processing and properties as in conventional materials courses, but also can be exposed to the issue of materials life cycle and the impact on society and environment.

Equipment:

1. Plastic granulator
2. Extrusion machine
3. Pelletizer
4. Universal testing machine
5. Durometer hardness tester
6. Optical microscope

Introduction:

Reducing the volume of solid waste disposal in landfills has drawn considerable public attention due to the decreasing number and size of landfills in the nation. It is estimated that 179.6 million tons of municipal solid waste are generated each year [1]. This figure represents an equivalent of four pounds of trash produced daily by every man, woman and child in the United States. At this rate major cities including New York and Los Angeles will exhaust landfill space in just a few years — Philadelphia and other cities are already out of space [2]. Because of the nature and application of packaging materials, plastics occupy about 20 percent in volume of the landfill space [3]. However, less than one percent of the plastics in the United States was recycled in 1990 [4, 5]. Thus, recycling and reusing plastics will play a significant role in reducing the amount of solid waste disposal to landfills. Researchers are attempting to find different ways to recycle plastics [6, 7] and more industrial companies are becoming involved in plastic recycling activities [8, 9]. There is an urgent need to expose undergraduate students in technical and non-science majors to materials recycling for environmental protection.

The objective of this project was to introduce a series of plastic recycling experiments to students in materials-related courses such as materials science, material technology and materials

testing. With the plastic recycling experiments, students not only learned the fundamentals of plastic processing and properties as in conventional materials courses, but also dealt with the issue of materials life cycle and the impact on society and environment. Many students became more environmental conscious and more knowledgeable of environmental protection.

Experiments:

Figure 1 shows the flow chart of a series of plastic recycling activities, including collection, cleaning, granulating, extrusion-pelletizing, property-testing and structural analysis. Prior to the laboratory activities, students were introduced to the fundamentals of materials structure, processing and behavior.

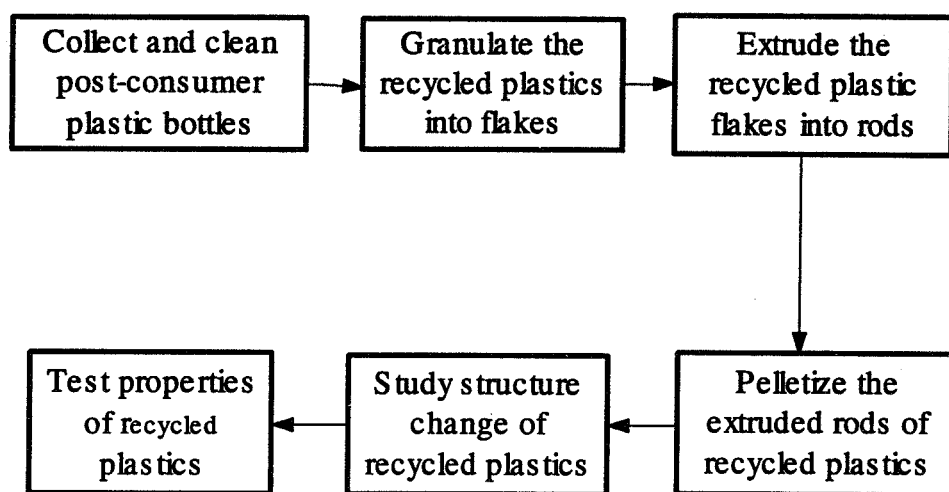


Figure 1. Flow chart of a series of plastic recycling activities.

1. Collecting and Cleaning Post-Consumer Plastic Products

To begin the plastic recycling experiments, students were exposed to some practical aspects of recycling post-consumer plastic products. These issues included mechanisms of collection, separation, transportation and storage, economics and community involvement for a successful recycling program. Recycling bins were established at Eastern Illinois University to collect plastics by faculty, staff and students. At this stage only high density polyethylene was collected for the laboratory activities.

The blending of various types of plastics will result in different properties of the final products made from recycled materials, which makes the control of product quality difficult. Therefore, separation of plastics has been a critical issue for plastic recycling and reuse. To facilitate the separation effort, the Society for Plastic Industries (SPI) has recommended a series

of voluntary codes to be placed on plastic containers. For example, high density polyethylene is coded #2 on the bottom of plastic milk jugs. This is an excellent way to introduce students to the plastics codes for practical recycling.

2. Granulating Recycled Plastic Products

Ideally, thermoplastics can be reprocessed into new products by various thermoprocessing methods such as extrusion and injection molding. Usually the plastics are fed into processing machines in pellet form. A granulator was used to cut the post consumer plastic containers into small flakes for processing. Flakes of recycled plastics obtained from grinding were used for subsequent extrusion processing.

3. Extruding and Pelletizing Recycled Plastic Flakes

Plastic flakes are not directly used for producing products because their bulk density is very low. The low bulk density of recycled plastics would hinder the material feeding efficiency and impose a serious problem of process stability in manufacturing. The recycled plastic flakes must be pelletized into dense particles before being processed into new products.

An extrusion machine was used to form the recycled plastic flakes into rods of 6.35 mm (1/4") diameter. In this experiment, students were introduced to the principle of extrusion, the effects of processing parameters on the material integrity and properties. The processing variables included heating temperature profile on the extrusion barrel, melt temperature, extrusion pressure, extrusion speed and cooling on the extruded rods.

A downstream pelletizer was employed to cut the extruded rods into small pellets. The pellets can be used for subsequent processing such as injection and blow molding for new products. The pellet form of recycled plastics provides a high feed efficiency for stable production of quality products. With this process the recycled plastics can be effectively reused or reprocessed into new products.

Another benefit of the extrusion system is that certain additives or reinforcements can be incorporated into the recycled plastics to make new composite materials. Due to contaminations, recycled plastics usually have inferior properties or undesirable color. Thus, it is beneficial to compound the plastics with certain additives or reinforcement so that the composite will possess improved material performance and physical appearance. The extruder can provide effective mixing of constituents and therefore promote uniform distribution of the reinforcements or additives. With this system, students can investigate the role of various reinforcements in improving material properties so that effective reinforcement of recycled plastics can be identified.

4. Studying the Morphology of Recycled Plastics

Since the material properties are related to material structure, it is essential to understand the plastic structure to control properties. An optical microscopic system was used to investigate the morphology of recycled plastics. This system has image analysis capability with a display

monitor allowing several students to view the microstructure of the recycled plastic simultaneously. The displayed image helps students perform investigative study and promotes active discussion among students on the material morphology.

5. Testing Mechanical Properties of the Plastics

To control the properties and quality of products made of recycled plastics, students needed to understand the methods of evaluating material properties. For this purpose, a tension test was selected to measure the mechanical strength and rigidity of plastics. The extruded rods were tested according to the standards set forth by American Society for Testing and Materials (ASTM) for ultimate tensile strength. Material rigidity is measured by percent elongation after rupture.

Another mechanical test introduced for the experiments was a Durometer hardness test. Using a fully automated Durometer test system, hardness was measured conveniently and quickly to monitor and control the product quality. Hardness can also be used to predict or estimate other mechanical properties of the material. For plastics and rubber, Durometer hardness is often appropriate. Two types of testing scales, type A and type D, were selected for soft and rigid plastics, respectively.

Conclusions:

This project introduced a series of plastic recycling experiments to undergraduate materials laboratories in materials science, materials technology and materials testing courses. With an integrative review at various stages, students participated in the entire recycling process, including collecting, granulating, extrusion-compounding, testing and structure analyzing.

In this project, students were exposed to some practical issues of material life cycles including the impacts on environment. By conducting plastic recycling experiments in the laboratory, students can learn the basic techniques for recycling plastic materials. Students can also gain an understanding of basic plastics properties, processing characteristics, structure and property control methods.

Industrial technology and non-science students with environment concerns have exhibited an interest in the courses. With exposure to plastic recycling activities and practical techniques of material recycling, students have become more aware of individual responsibility for environmental protection and the need for recycling research and development.

Acknowledgment:

The material is based on work supported by the National Science Foundation under Grant No. DUE-9350629. Another part of the support was from Illinois Department of Energy and Natural Resources through Office of Solid Waste Research at University of Illinois at Urbana-Champaign.

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**COMPRESSION MOLDING OF COMPOSITE OF
RECYCLED HDPE AND RECYCLED TIRE
PARTICLES**

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Compression Molding of Composite of Recycled HDPE and Recycled Tire Particles

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Key Words: Recycled plastics, high density polyethylene (HDPE), recycled rubber, composites, compression molding, design of experiment (DOE).

Prerequisite Knowledge: Behavior and processing of thermoplastics and rubber, compression molding of plastics, thermoplastic elastomers, design of experiments.

Objective: To introduce students to compression molding of composite from recycled high density polyethylene (HDPE) and recycled automobile tire particles. To optimize the process parameters using design of experiments (DOE) techniques.

Equipment:

1. Compression molding machine (A metallurgical specimen press can be good enough.)
2. Compression molds
3. Cutoff wheel or other cutting tools

Introduction:

Plastic and rubber recycling is an effective means of reducing solid waste to the environment and preserving natural resources. A project aimed at developing a new composite material from recycled high density polyethylene (HDPE) and recycled rubber is currently being conducted at Eastern Illinois University. The recycled plastic pellets with recycled rubber particles are extruded into some HDPE/rubber composite strands. The strand can be further cut into pellets that can be used to fabricate other material forms or products.

This experiment was inspired by the above-mentioned research activity. In order to measure Durometer hardness of the extruded composite, a specimen with relatively large dimensions was needed. Thus, compression molding was used to form a cylindrical specimen of 1" diameter and 1" thickness. The initial poor quality of the molded specimen prompted a need to optimize the processing parameters such as temperature, holding time and pressure. Design of experiment (DOE) was used to obtain optimum combination of the parameters.

Experiment:

The composite of 95%HDPE - 5%rubber was pelletized into small particles before being used for compression molding. A metallurgical specimen press was used as a compression molder for making a composite cylindrical block of 1" diameter and 1" thickness.

To improve the quality of molded specimen, parameters such as holding time (min.), temperature (°C), and pressure (psi) are identified as controllable variables to be optimized. Heating rate, environment, quality of composite pellets and distribution of rubber in pellets are identified as uncontrolled variables.

A two level full factorial (2^3) design was used for the experiment. Appropriate levels of the controllable variables are determined by fundamental understanding of materials properties, practical knowledge and limits of the press. For example, a heating temperature was chosen between 130 and 150 °C, holding time at the experimental temperature would not exceed twenty minutes, and highest pressure and temperature that can be obtained in the apparatus are 10,000 psi and 150 °C respectively. The design matrix (coded test conditions), actual test condition matrix and experimental results are shown in Table I.

Table I. Coded test conditions, actual test conditions and results of compression molding.

Coded Test Conditions				Actual Test Conditions				Results	
Test	x_1	x_2	x_3	Test Order	Time (min)	Temperature (°C)	Pressure (psi)	Formability	Appearance
1	-	-	-	6	5	130	2000	22%	Fair
2	+	-	-	8	15	130	2000	25%	Good
3	-	+	-	1	5	150	2000	54.5%	Excellent
4	+	+	-	2	15	150	2000	100%	Excellent
5	-	-	+	5	5	130	6000	10%	Bad
6	+	-	+	3	15	130	6000	25.5%	Good
7	-	+	+	4	5	150	6000	42%	Excellent
8	+	+	+	7	15	150	6000	100%	Excellent

Before tests, a random testing order was determined, as listed in Table I. Nine grams of HDPE/rubber composite pellets were used for the molding. Pressure was maintained at the designed level during the whole period of processing. After temperature reached the set value, the holding time was counted. When holding time was up, pressure was released and electrical power for heating was turned off. All eight samples were made in the same procedure.

The surface appearances of samples were first examined with naked eyes. Four qualitative scales were used to describe the surface quality of the specimen, *i.e.*, excellent, good, fair and bad. Then, samples were cut in the middle of height, as shown in Fig. 1 (a).

Formability was defined as a percentage of melted diameter in cross-section in relation to the diameter of the specimen, which is calculated according to the following equation.

$$\text{Formability} = \left[1 - \frac{\text{Average Unmelted Diameter } (\bar{d})}{\text{Diameter of Sample } (D)} \right] \times 100 \%$$

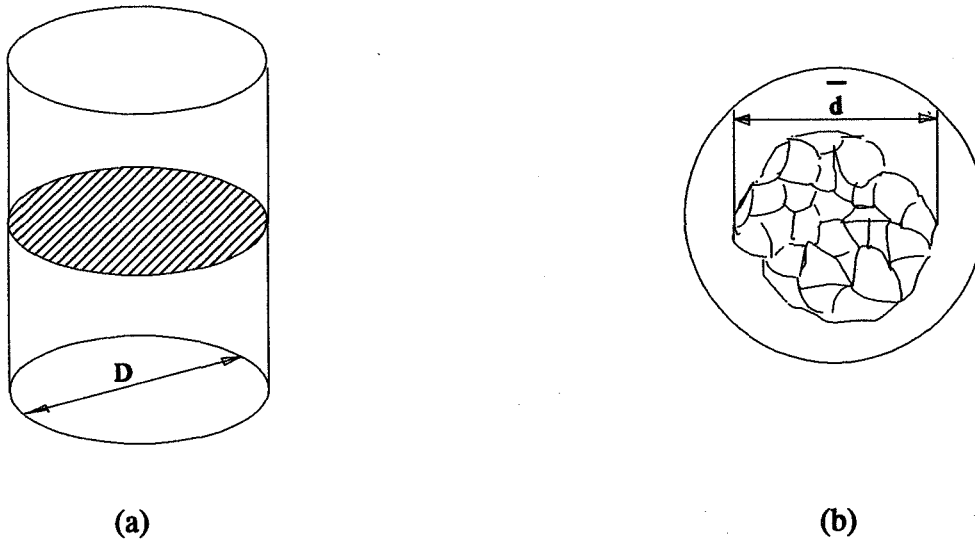


Figure 1. Schematic of compression-molded specimen: (a) Cross-section position in the specimen, (b) average unmelted diameter \bar{d} .

Results and Analysis:

The experimental results are shown in right columns of Table I. Surface appearance was used to evaluate the quality of specimens before cross-sectioning was made. The experimental results could be rearranged according to the level of surface quality of specimens, as shown in Table II. It is noted that the surface appearance was excellent when temperature was 150 °C regardless of holding time and pressure. At low temperature level, the surface quality of specimen was good when holding time was 15 min. When a shorter holding time was chosen, the surface quality was fair at lower pressure and bad at high pressure level. In other words, temperature is a significant factor in the compression molding.

For the formability, the data analysis is presented in Table III. Among the three factors, temperature showed the largest effect on the formability, which increased formability from 20.625% at lower level to 74.125% at higher level, *i.e.*, a net increase of 53.5%. The second effective factor was time, showing 30.5% net increase from lower level to higher level. Pressure showed a negative effect on the formability, which is consistent with the thermodynamic principle that the melting point of a substance will increase with increasing pressure. Moreover, pressure had the least effect on the formability in the testing range among the three factors.

Table II. Rearrangement of actual test conditions and the results

Test Order	Time (min)	Temperature (°C)	Pressure (psi)	Result	
				Appearance	Formability
5	5	130	6000	Bad	10%
6	5	130	2000	Fair	22%
8	15	130	2000	Good	25%
3	15	130	6000	Good	25.5%
4	5	150	6000	Excellent	42%
1	5	150	2000	Excellent	54.5%
2	15	150	2000	Excellent	100%
7	15	150	6000	Excellent	100%

Table III Main effects and interactions of factors

Test	Main Effects			Interactions				Formability
	Time x_1	Temp. x_2	Press. x_3	x_1x_2	x_2x_3	x_1x_3	$x_1x_2x_3$	
1	-1	-1	-1	+1	+1	+1	-1	22%
2	+1	-1	-1	-1	+1	-1	+1	25%
3	-1	+1	-1	-1	-1	+1	+1	54.5%
4	+1	+1	-1	+1	-1	-1	-1	100%
5	-1	-1	+1	+1	-1	-1	+1	10%
6	+1	-1	+1	-1	-1	+1	-1	25.5%
7	-1	+1	+1	-1	+1	-1	-1	42%
8	+1	+1	+1	+1	+1	+1	+1	100%
Sum +	250.5	296.5	177.5	232	189	202	189.5	
Sum -	128.5	82.5	201.5	147	190	177	189.5	
E_i	30.5%	53.5%	-6%	21.25%	-0.25%	6.25%	0%	47.375% (Average)

The interaction between time and temperature was very strong. That implies that the two factors have to be controlled synergetically to optimize the compression molding quality. There was less significant interaction between holding time and pressure, which can be neglected for practical purpose. There was no significant interaction between temperature and pressure.

In summary, a good compression specimen can be obtained using a higher temperature (150 °C), a longer holding time (15 min.) and a lower pressure (2000 psi).

Conclusions:

The following conclusions can be made from the analysis of 2³ factorial experiments.

(1) HDPE/rubber composite pellets can be compression-molded as a thermoplastic elastomer. The experiment can be performed by a simple metallurgical specimen press if a compression molding machine is not available.

(2) In compression molding, temperature is the most significant factor to control so that a good surface quality can be achieved.

(3) The interaction between time and temperature is very strong. Other interactions can be neglected for practical purpose.

(4) The optimum parameters for the compression molding of the HDPE/rubber composite are higher temperature (150 °C), longer holding time (15 min.) and lower pressure (2000 psi).

References:

R. J. Ehrig, *Plastics Recycling*, Hanser Publishers, New York, 1992.

Richard E. DeVor, Tsong-how Chang and John W. Sutherland, *Statistical Quality Design and Control*, Macmillan Publishing Company, New York, 1992.

Michael L. Berins, *SPI Plastics Engineering Handbook*, Van Nostrand Reinhold, New York, 1991.

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TESTING AND CHARACTERIZING OF CONTINUOUS FIBER CERAMIC COMPOSITES

Richard A. Lowden

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Edgar Lara-Curzio

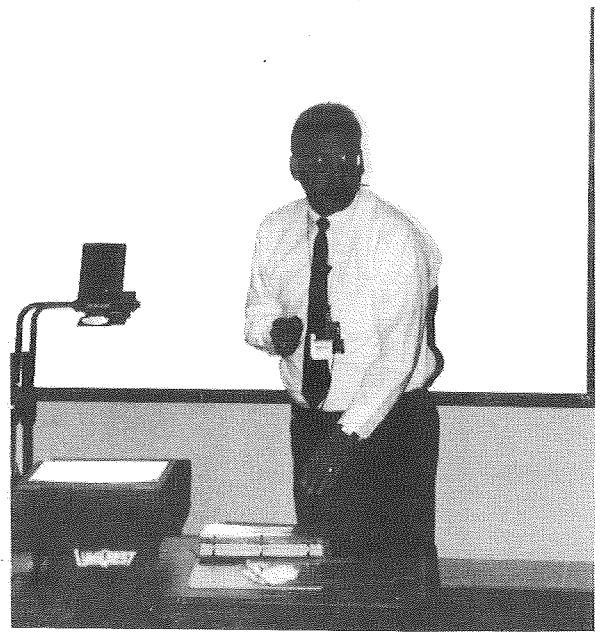
**CFCC
MS 6087, Bldg. 4508
Oak Ridge, Tennessee 37831**

Telephone 615-576-2769

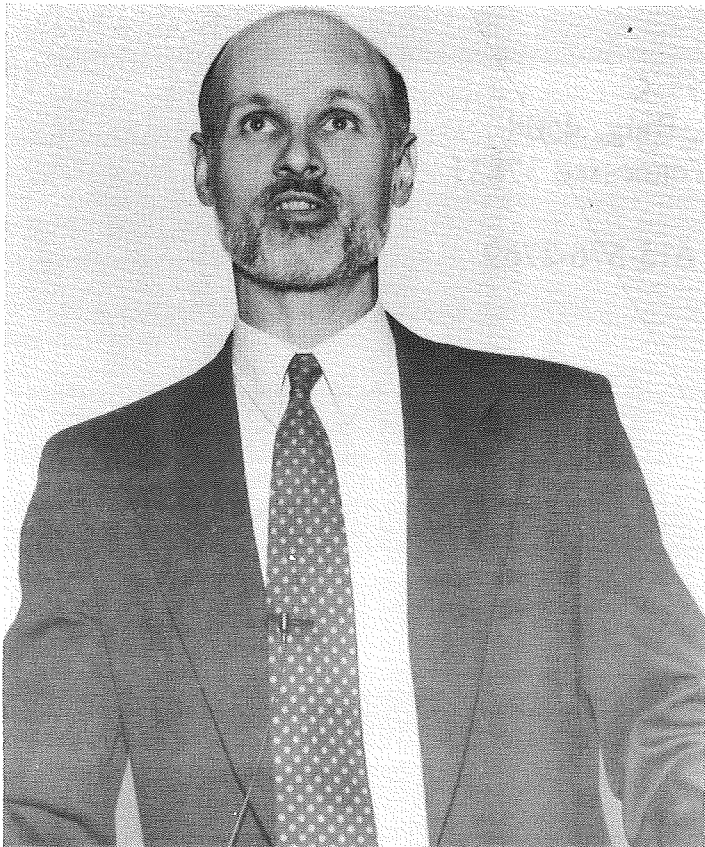
Richard A. Lowden



Edgar Lara-Curzio



Pete F. Tortorelli



Karren L. Moore



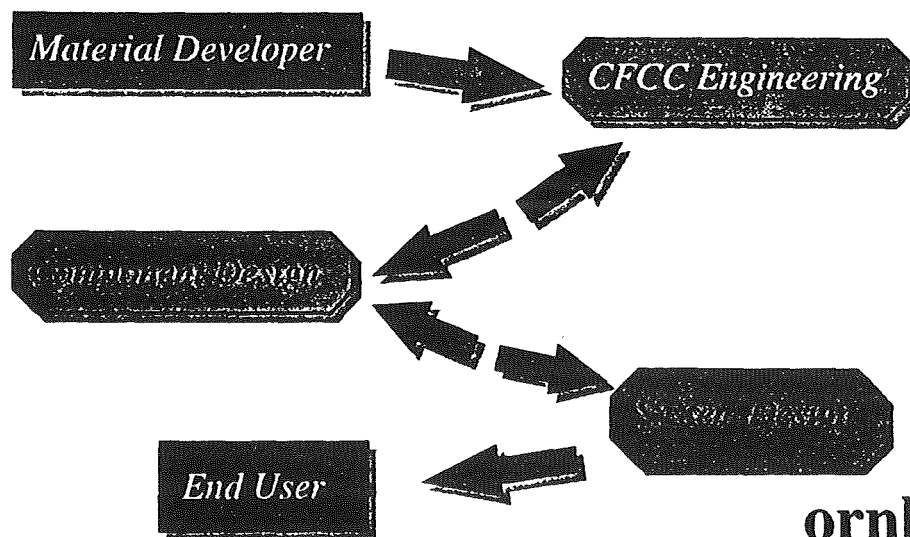
Characterization of Continuous Fiber Ceramic Composites

**Richard M. Lowden, Karren L. More,
Pete F. Tortorelli and Edgar Lara-Curzio**
Metals and Ceramics Division
Oak Ridge National Laboratory

Research sponsored by the U. S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Industrial Technologies, Industrial Energy Efficiency Division and Continuous Fiber Ceramic Composites Program, under contract DE-AC05-84OR21400 with Lockheed Martin Energy Systems, Inc.

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Design Flow



Fibers
Fiber Coatings
Matrix
Matrix Coatings

Interfaces
Fiber Architecture
sub-structure

Performance
Requirements

Design

Design Requirements



- *Constituent properties*
- *Interfacial properties*

- *Stiffness*
- *Strength*
- *Work of Fracture*
- *Fatigue resistance*
- *Creep resistance*

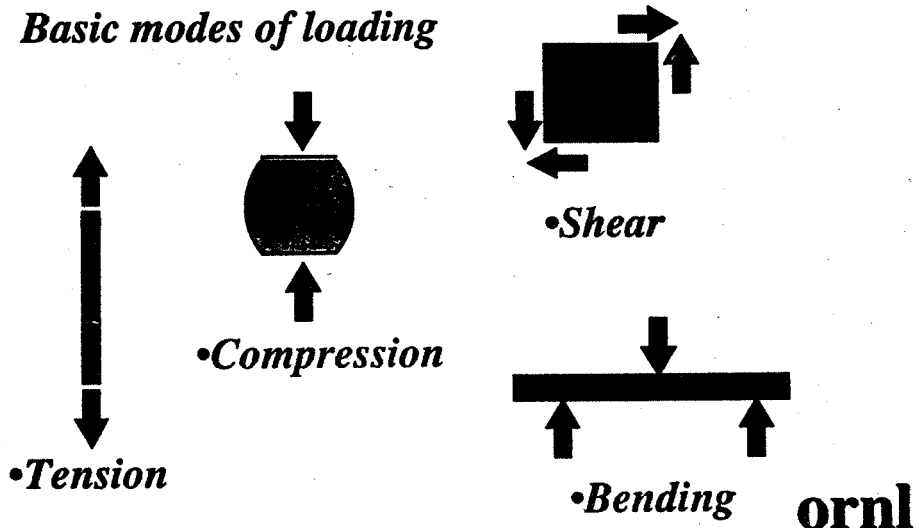
*Complex state
of stress
and service
environment*

- *Environmentally assisted
degradation of properties and
performance*

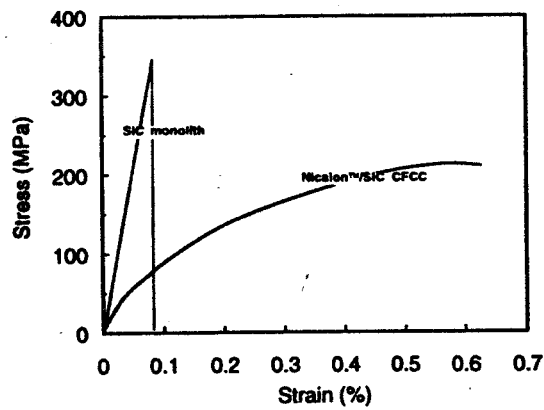
ornl

Mechanical Evaluation

Basic modes of loading

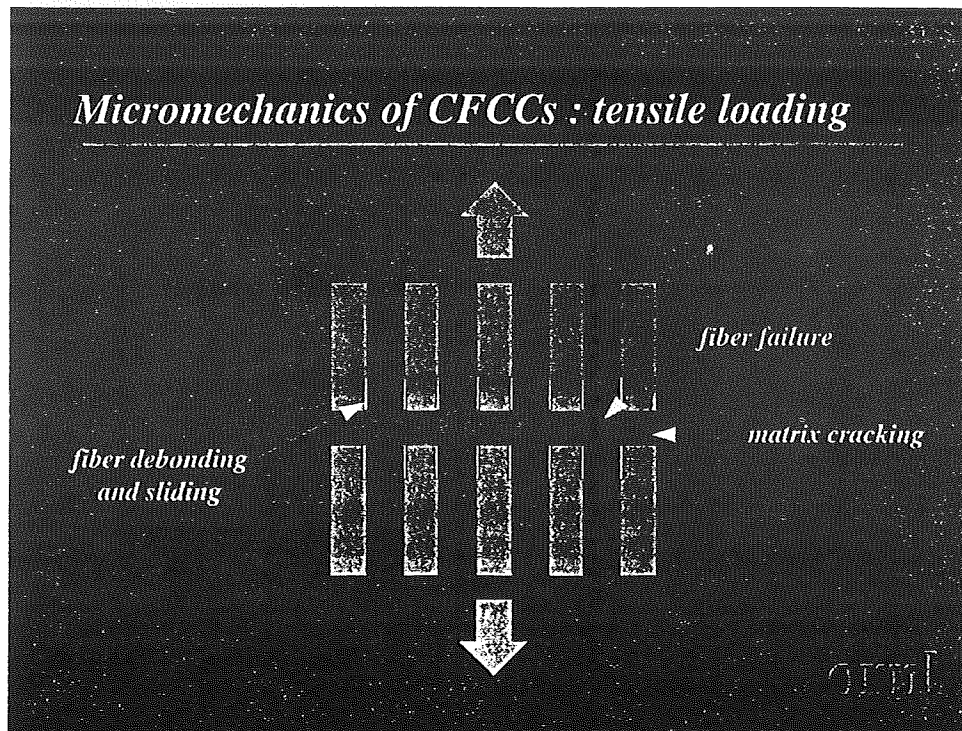


Behavior of CFCCs under tensile loading



ornl

Micromechanics of CFCCs : tensile loading



Role of Interfaces

- The fiber-matrix interface has become synonymous of the region between the fiber and the matrix, including the fiber coatings.
- The interface controls
 - stress transfer.
 - crack deflection to promote fiber debonding and sliding.


strength
wof ornl

Interfacial Evaluation

- *bond strength*

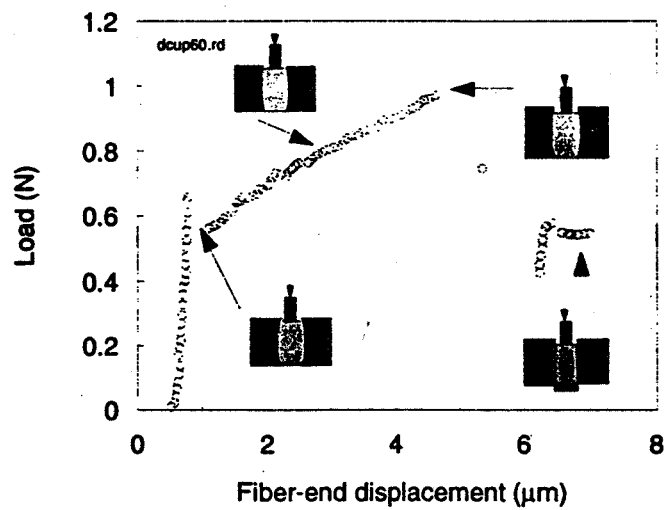
- *state of stress*

- *coefficient of friction*


$$\tau = \mu \sigma_c$$

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Single-fiber Push-out test



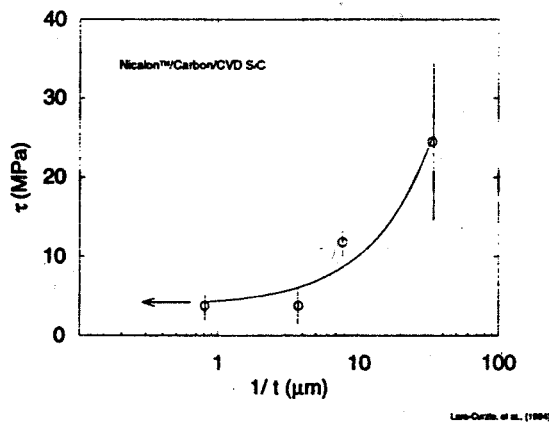
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Interfacial requirements

- *chemical compatibility between fiber, fiber coating(s) and matrix.*
- *low fracture toughness and “optimum” adhesion*
- *“optimum” roughness.*
- *mechanically compliant.*

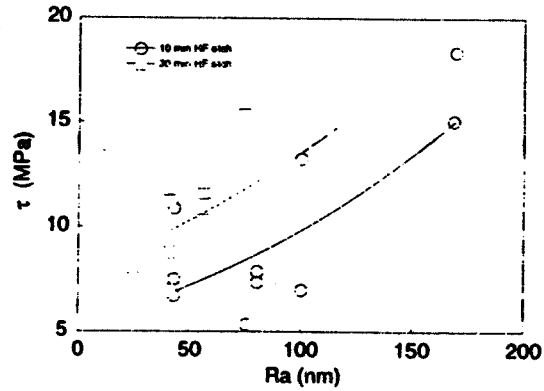
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Effect of fiber coating thickness on ISS



ornl

Effect of fiber surface topography on ISS



Brittle Fibers
+
Brittle Matrix

Brittle Composite

Brittle Fibers
+
Engineered Interfaces
+
Brittle Matrix

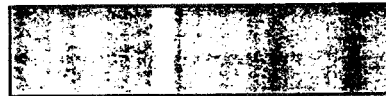
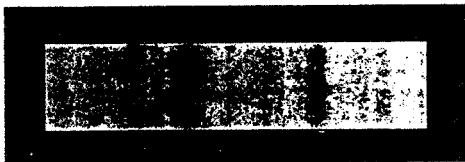
Tough Composite

Environmental Effects On Properties Of CFCCs

“CHEMISTRY MEETS MECHANICS”

In General, How Can The Environment Affect Properties?

- Wastage



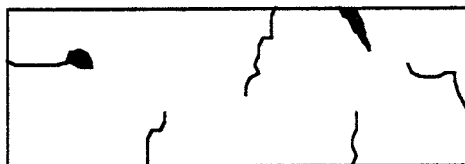
reduction in area

- Surface Modification



- *protection*
- or
- *stress riser, failure initiator*

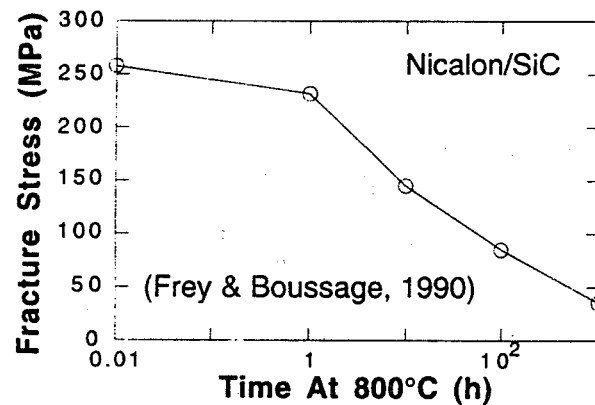
- Ingress



- *modify microstructure, comp'n.*
- *embrittle material*

Environmental Effects Are Of Particular Concern For CFCCs

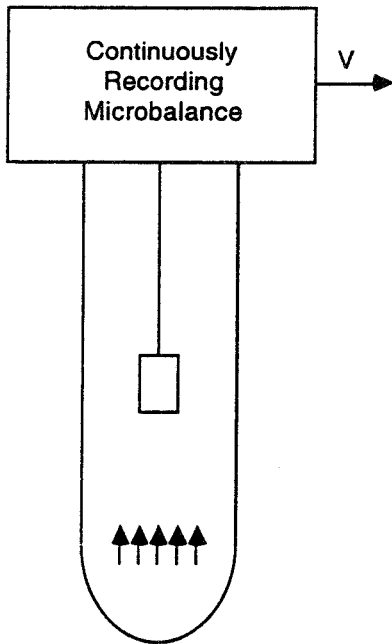
- Presence of fibers can result in greater susceptibility to environmental interactions
 - direct attack of fibers and their coatings
 - chemical instabilities
 - mass transport along extended fiber-matrix interfaces
- Environmental reactions can lead to degradation of strength, damage tolerance, and fracture



Approaches To Characterization Of Environmental Effects

- Vary environment
- Examine reactions

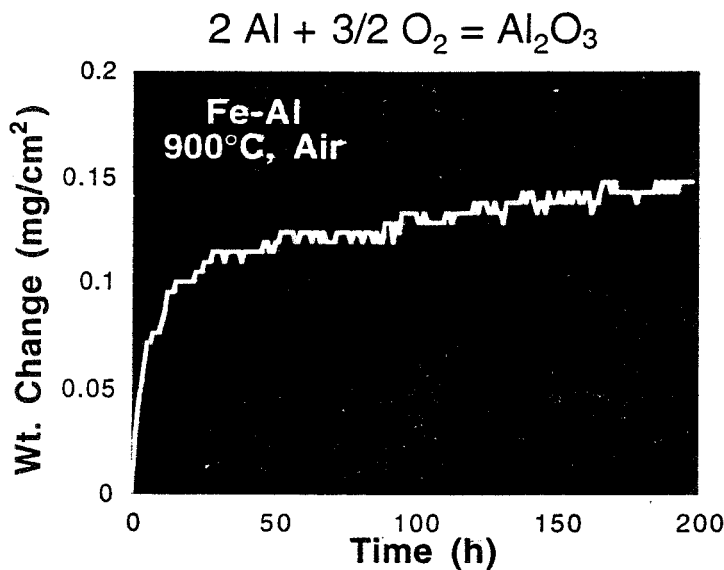
Sensitive Microbalances Can Be Used To Monitor Reactions



- Wt. changes on order of μg 's
- Flowing (or static) gases
- High temperatures

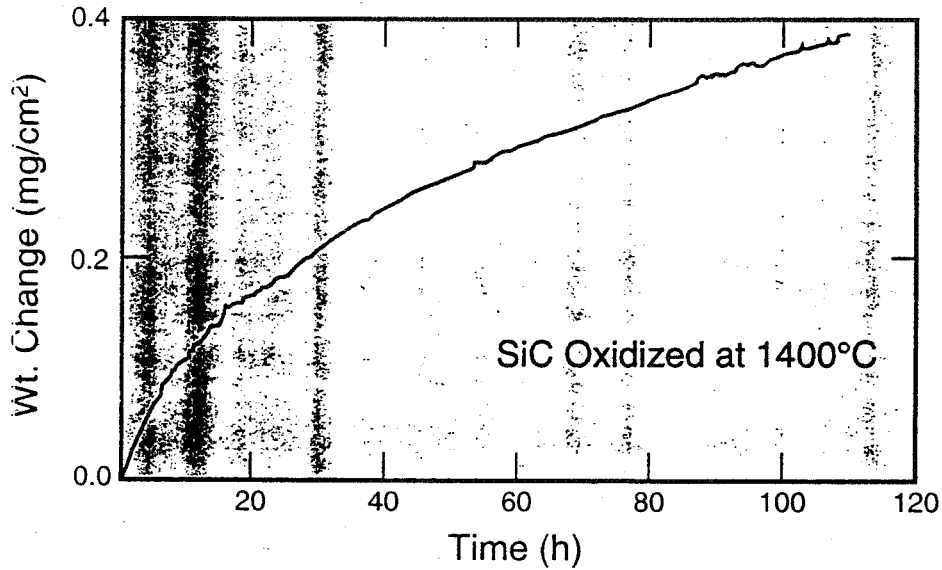
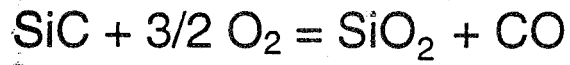
- * Track reactions in real time
- * Determine reaction kinetics, mechanisms

Reaction Of Metal With Oxygen To Form Solid Product



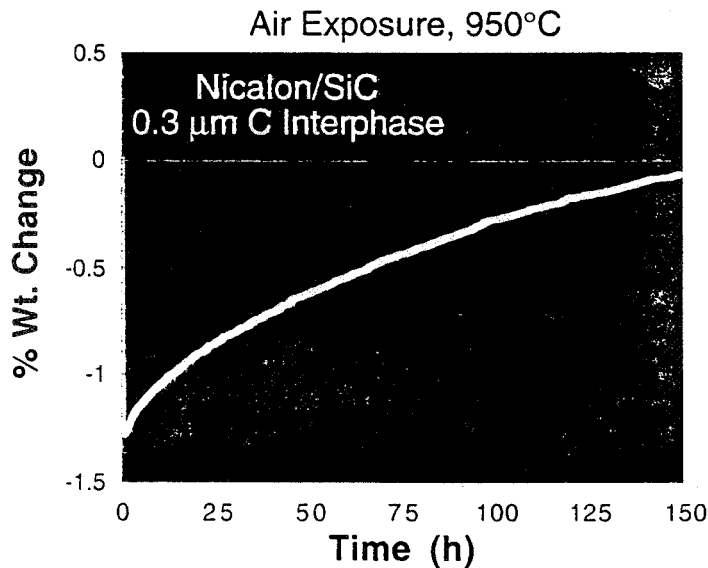
corresponds to Al_2O_3 surface layer ~ 250 nm thick

Reaction Of SiC With Oxygen

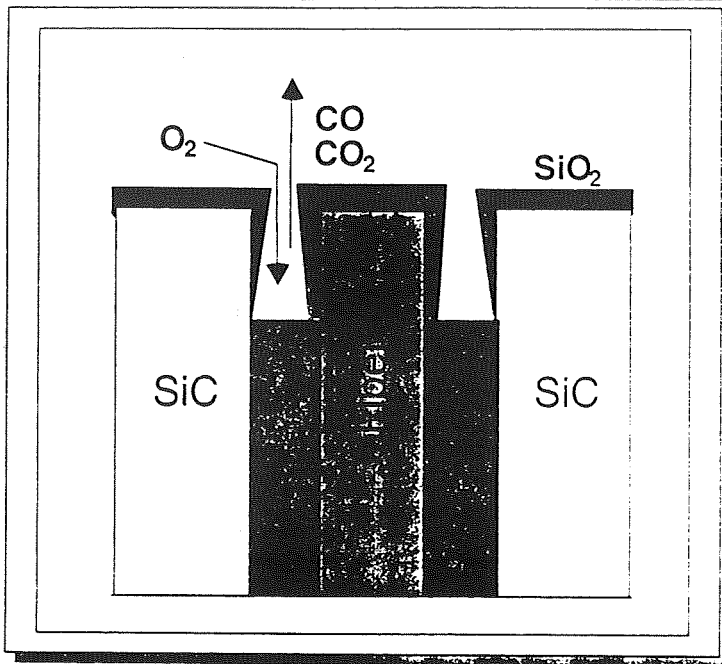


(N. S. Jacobson)

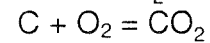
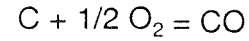
Oxidation Of SiC With C-Coated SiC Fibers Results In Complex Gravimetric Behavior



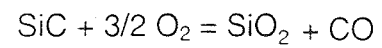
Relatively Simple Model Can Explain Oxidation Behavior Of This Composite



Loss of C Interphase:

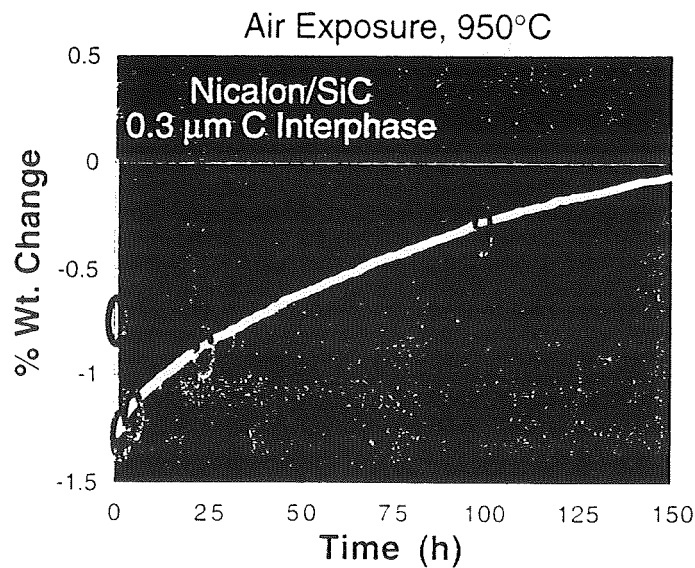


Growth of Silica:

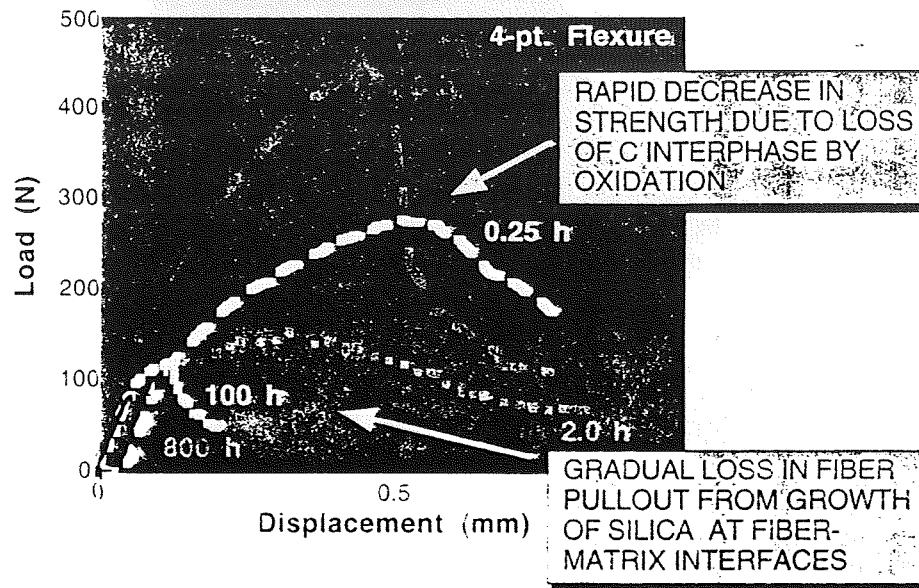


(Filipuzzi et al.)

Microbalance Data Can Be Used To Determine Test Times For Properties Measurements



Flexure Curves For Nicalon/C/SiC Preoxidized At 950°C For Various Times

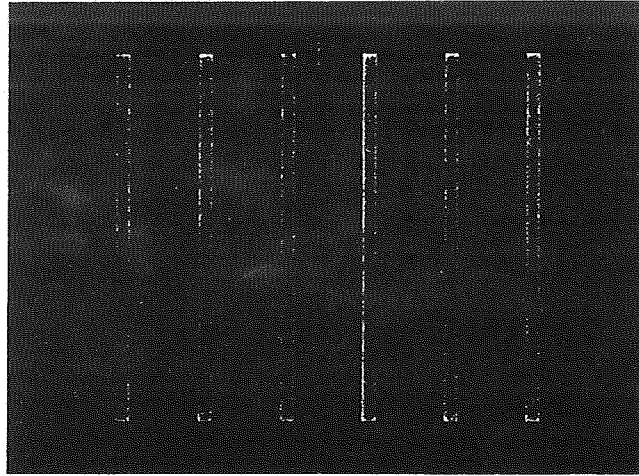


The Great Interphase Challenge

Carbon: good mechanical behavior of composite, but reacts with oxygen at high temperature

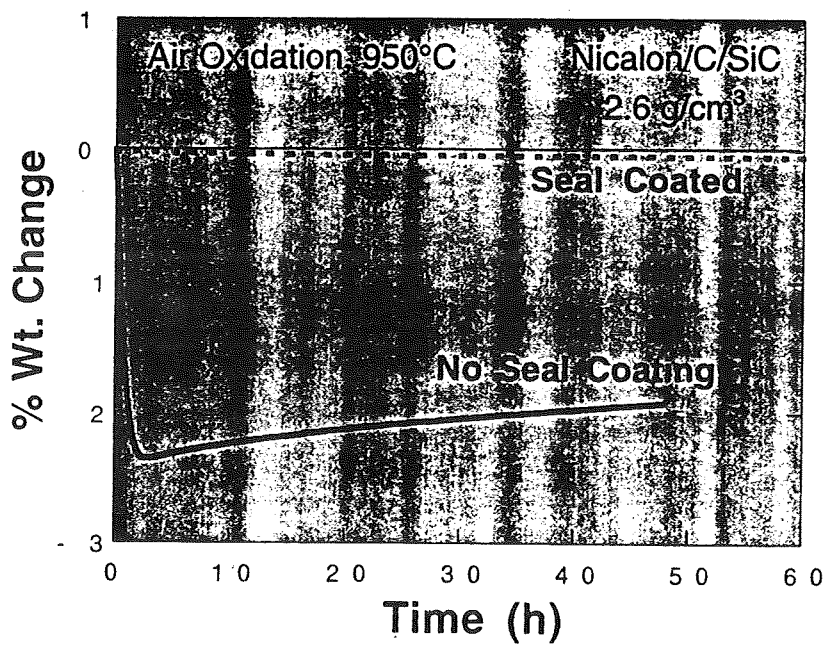
Can we find an alternative to carbon that has oxidative stability but retains good mechanical characteristics as an interphase?

Protective Coatings



Example: SiC seal coat on SiC matrix composite

SiC Seal Coats Can Be Effective



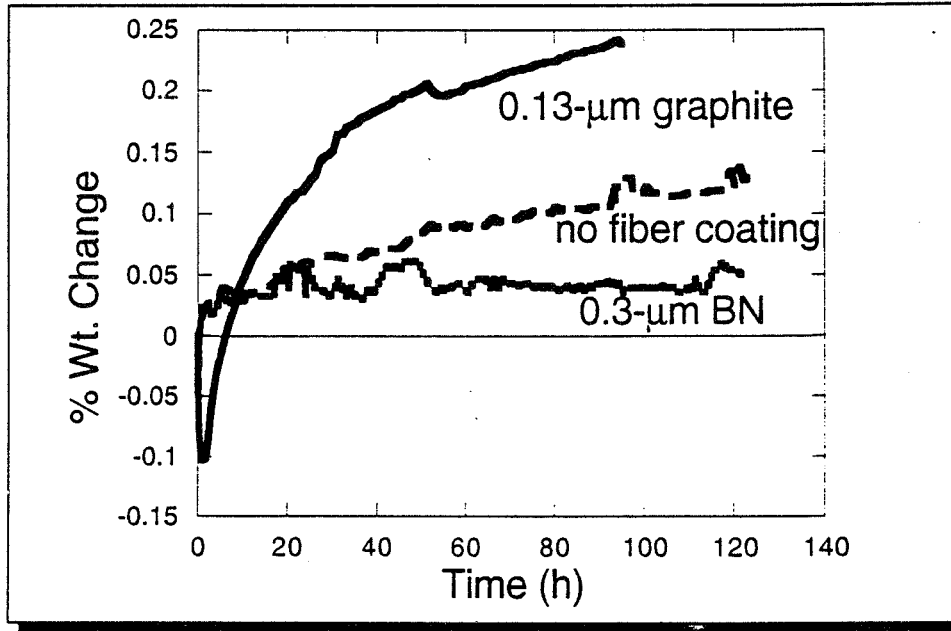
Other Compounds, Compositions For Fiber Coating/Interphase

- appropriate mechanical/physical properties
- oxidation resistance
- compatible with fiber and matrix

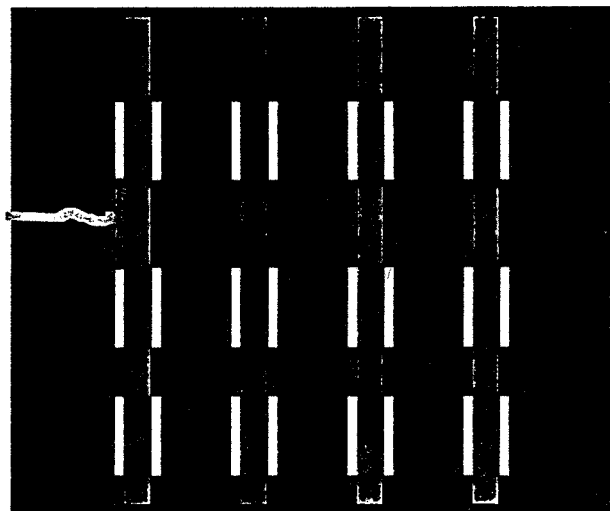
Possible Alternatives For Interphase

- Boron-doped carbon
- Boron nitride
- Oxides
- SiC
- Nothing

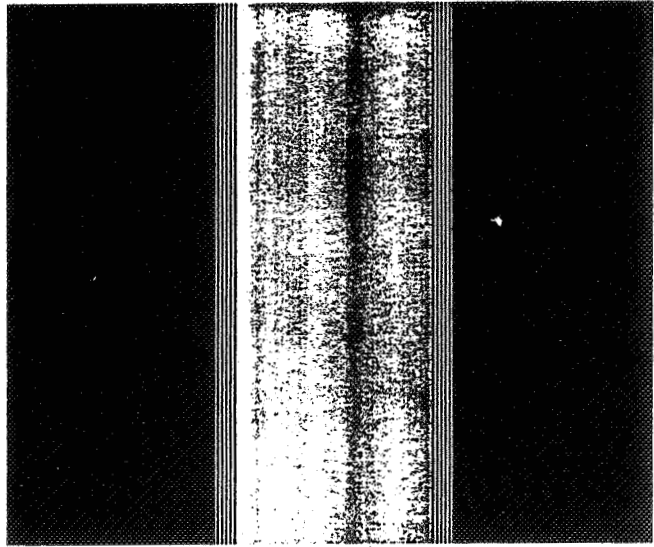
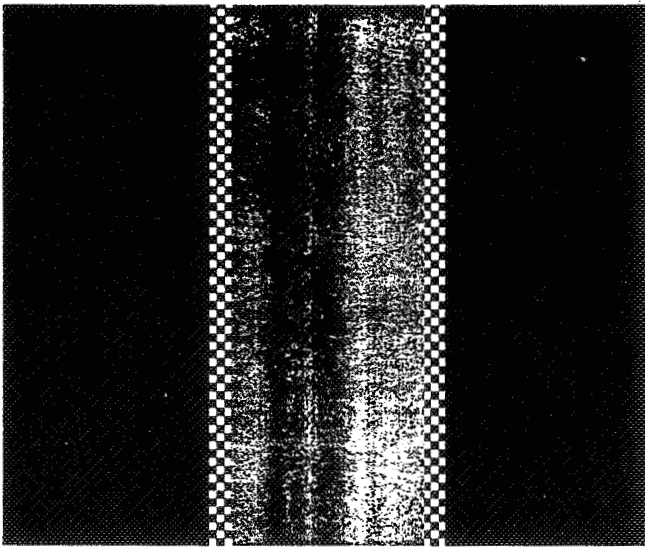
BN Interphase Gives Improved Oxidation Resistance Relative To Carbon



Interrupted Carbon Interface



Porous or Layered Interphases Of Matrix Material



MICROSTRUCTURAL CHARACTERIZATION OF CFCCS

**KARREN L. MORE
NATIONAL EDUCATORS WORKSHOP
NOVEMBER 7, 1995**

What Exactly do we “characterize” in CFCCs?

- **Matrix**
- **Fibers**
- **Fiber/Matrix Interface**

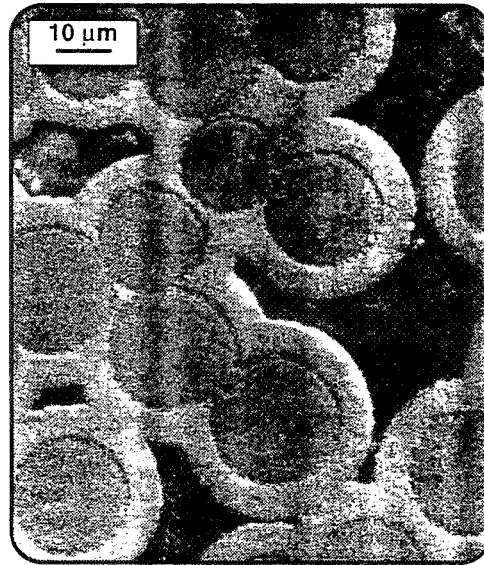
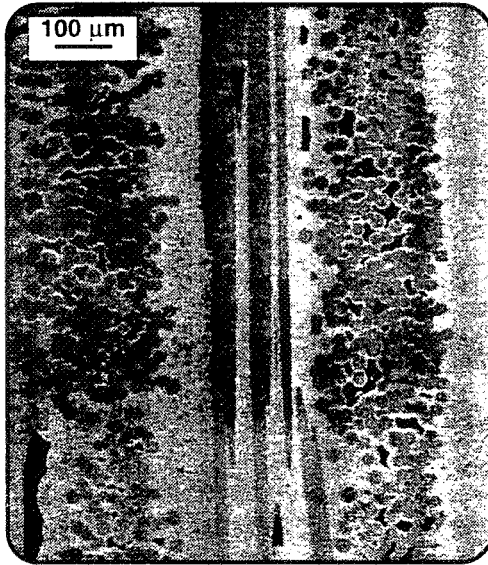
Development of Interfacial Coatings is Important in Composite Materials:

- **Protection of Fiber Reinforcement During Processing**
- **Modification of Interfacial Bonding and Frictional Stresses**
- **Enhancement of the Overall Oxidation Resistance of the Composite**

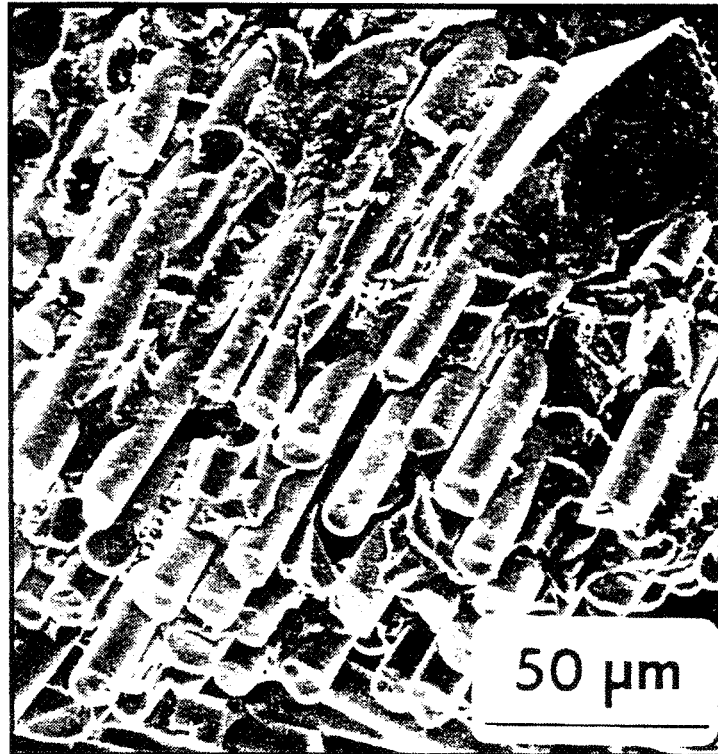
There are MANY Techniques Available for the Microstructural Characterization of CFCCs

- **Optical Microscopy for Bulk Evaluation**
- **Scanning Electron Microscopy for Bulk and Topographic Characterization**
- **Transmission Electron Microscopy for Interface Characterization**

Evaluation Using Optical Microscopy is Limited



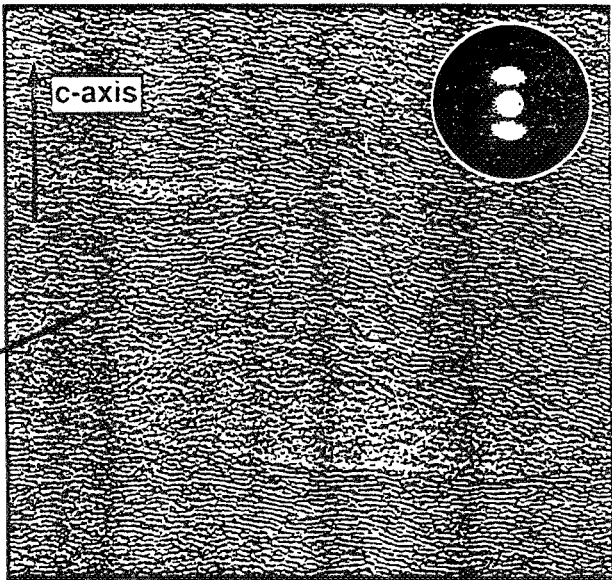
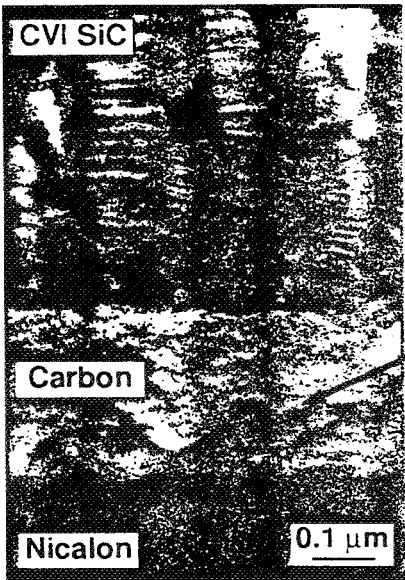
Extensive Fiber Pull-out is Generally Observed for Toughened CFCCs



Poor Interfacial Design in CFCCs Will Result in Brittle Ceramic

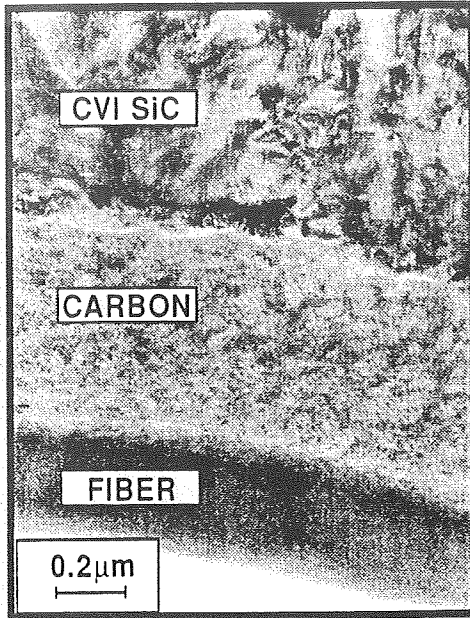


The basal planes in Propylene-derived Carbon interfaces were well aligned with respect to the Nicalon surface

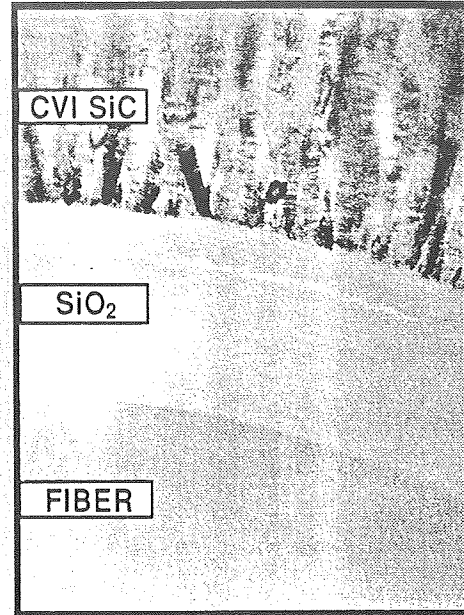


An Amorphous Silica Layer Replaces The Carbon Interlayer During Oxidation

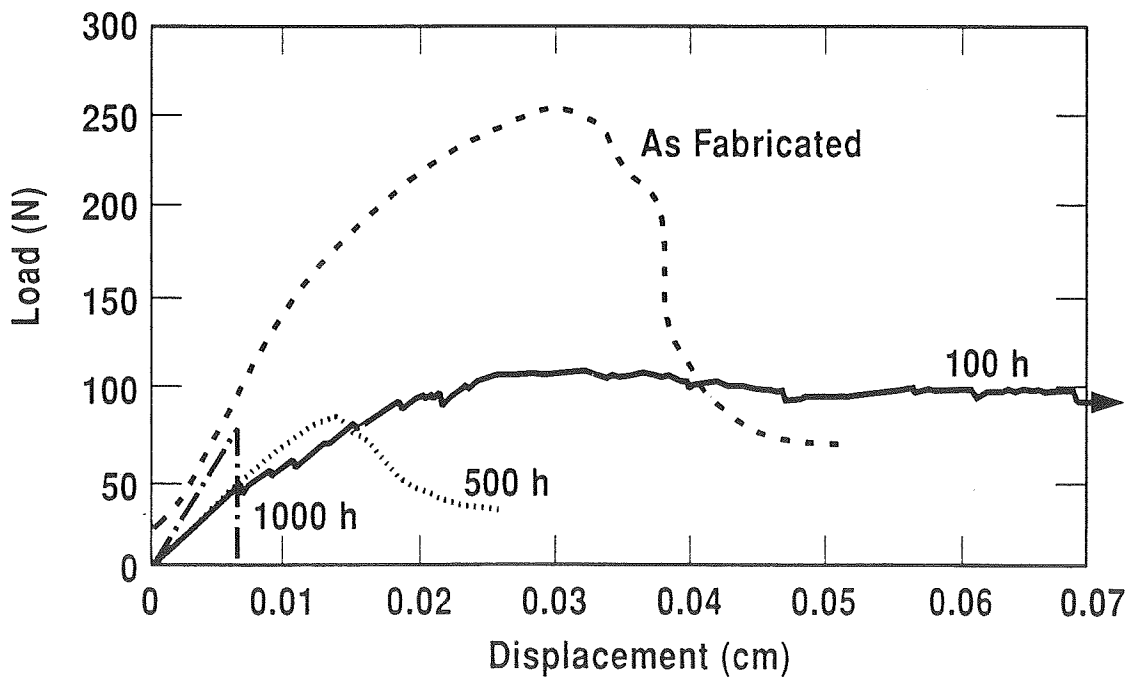
As-Fabricated



Oxidized 1000° C/1000h



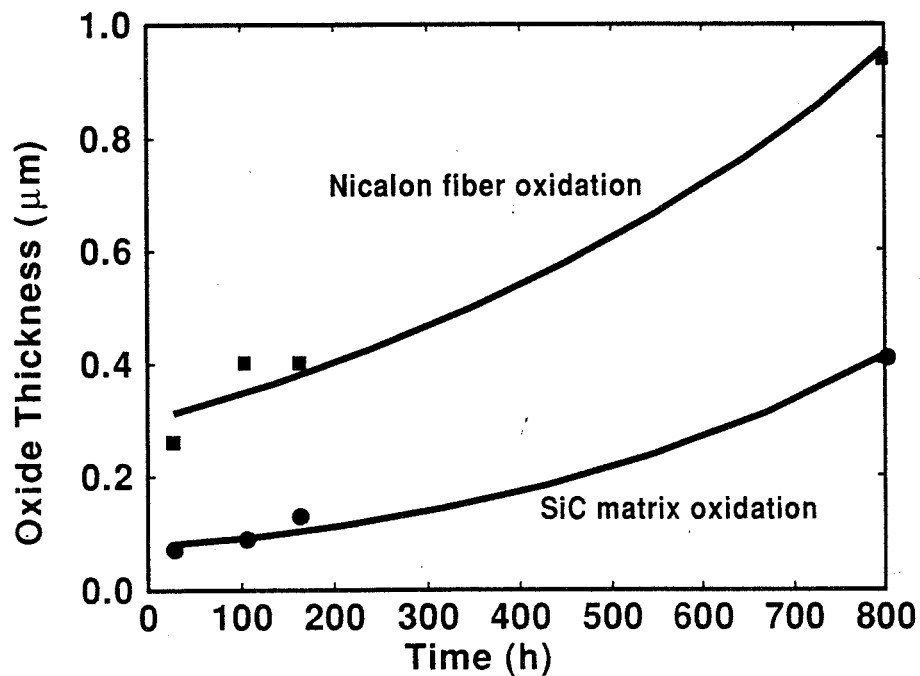
The Effects Of Oxidation On Mechanical Properties Were Progressive As A Function Of Exposure Time



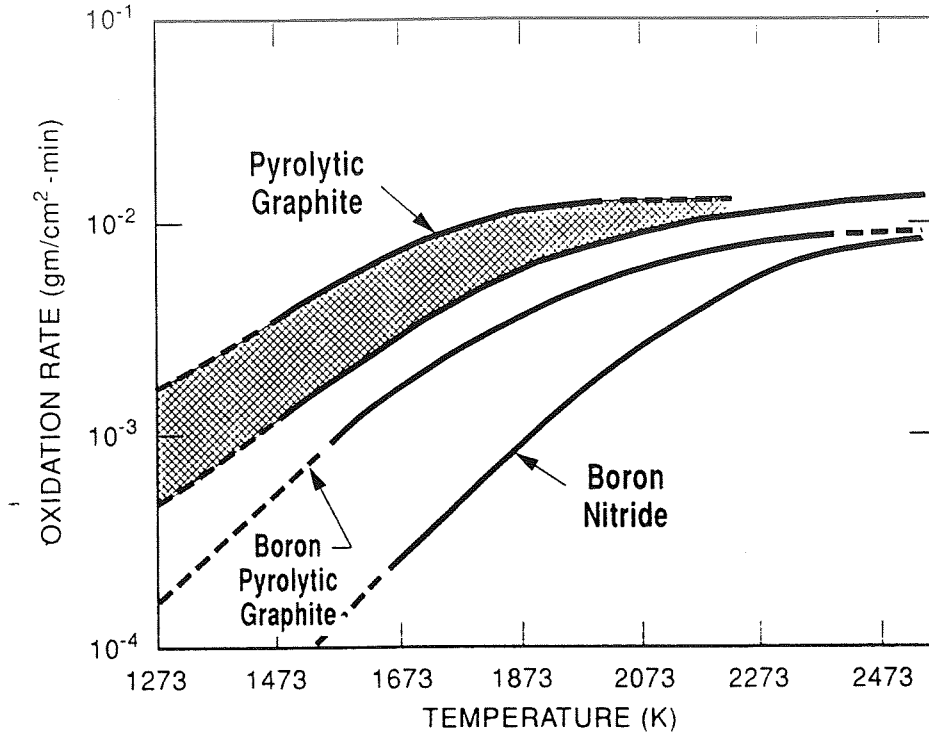
Microstructural Changes Occurring at the Interface During Oxidation Can be Fully Characterized

- Individual Oxidation Kinetics for Matrix and Fibers can be Determined
- Oxidation Effects as a Function of Depth Below the Surface can be Evaluated

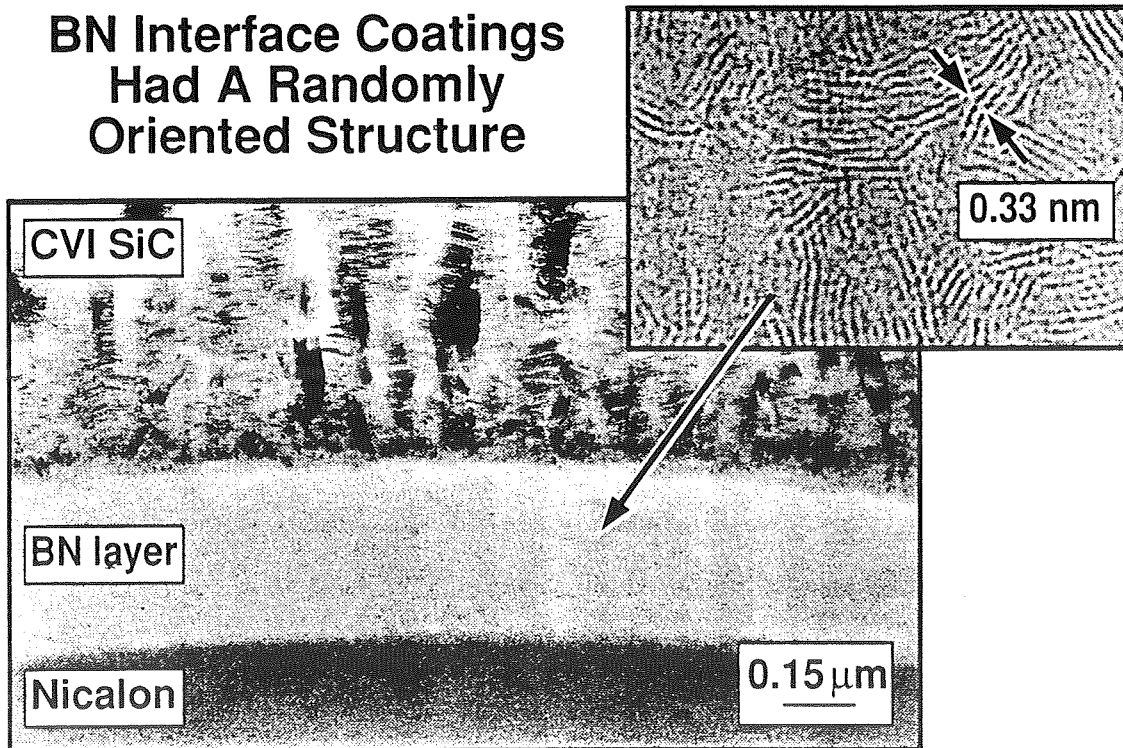
Change In Oxide Thickness As A Function Of Time At 950°C In Nicalon/C/SiC



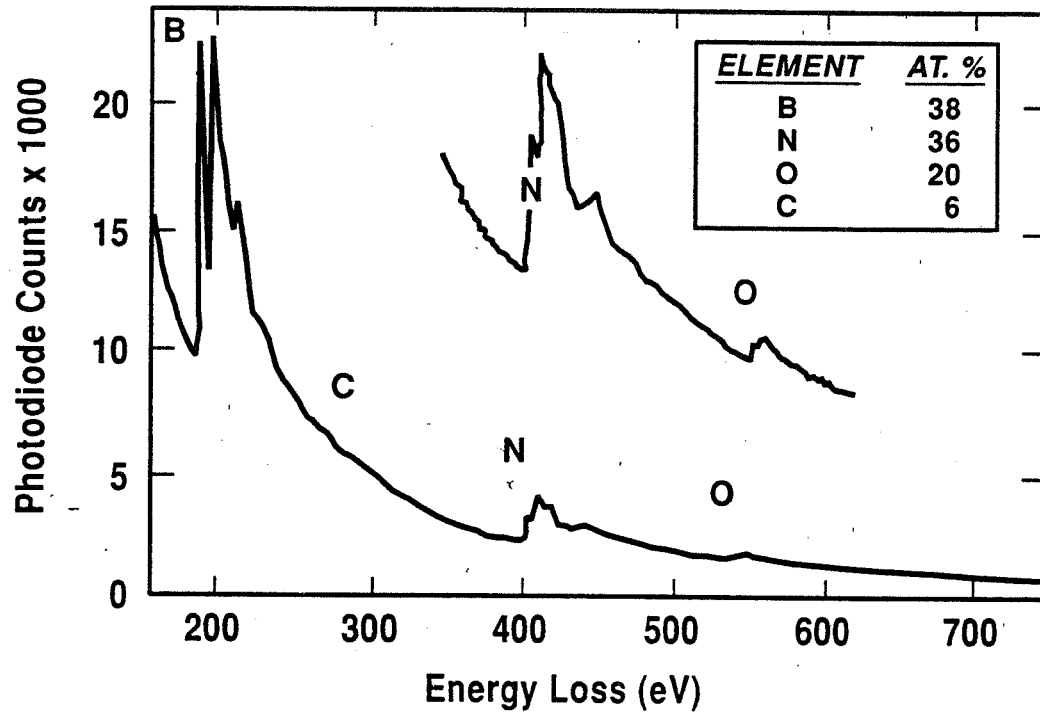
Boron-Containing Materials Offer Improved Oxidation Resistance As Compared To Carbon



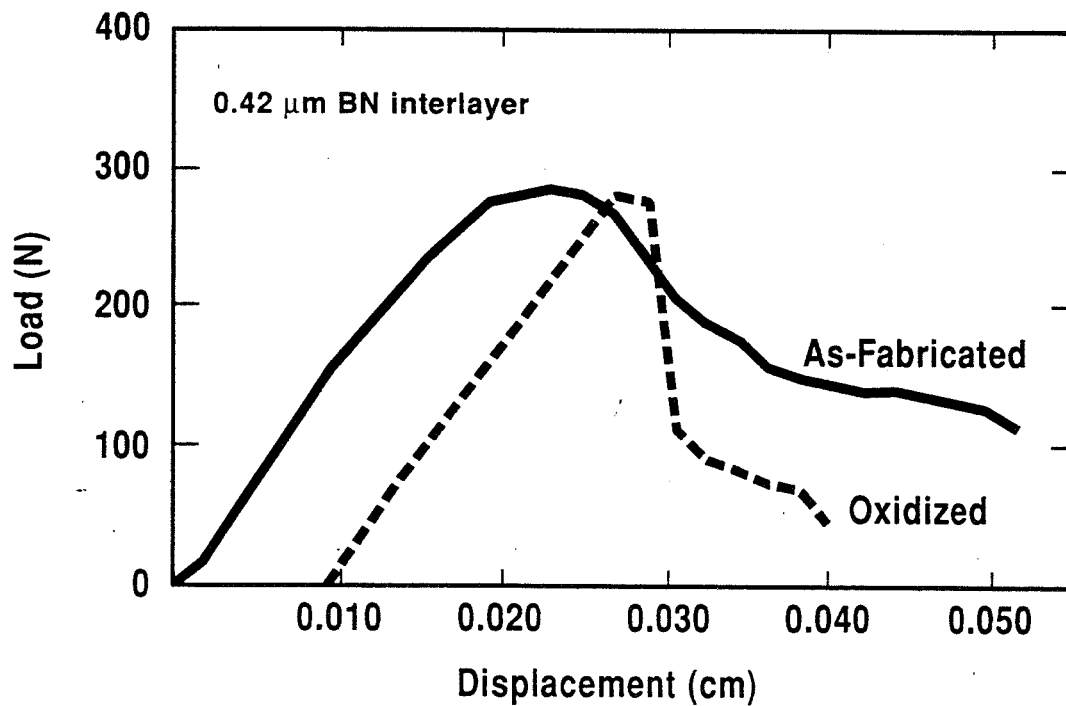
BN Interface Coatings Had A Randomly Oriented Structure



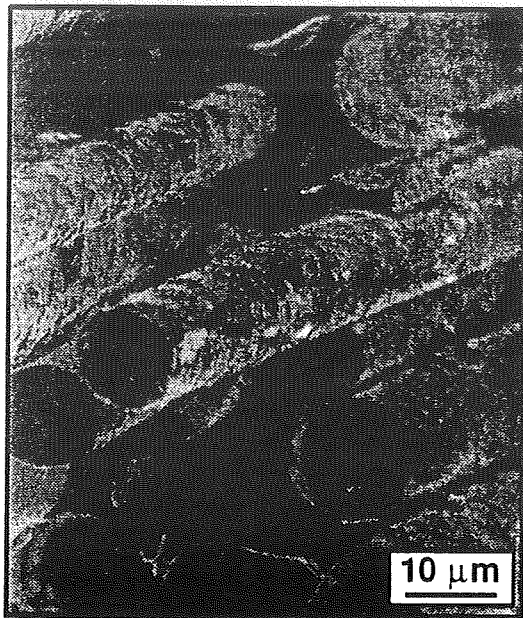
As-Deposited BN Coatings Contained Oxygen



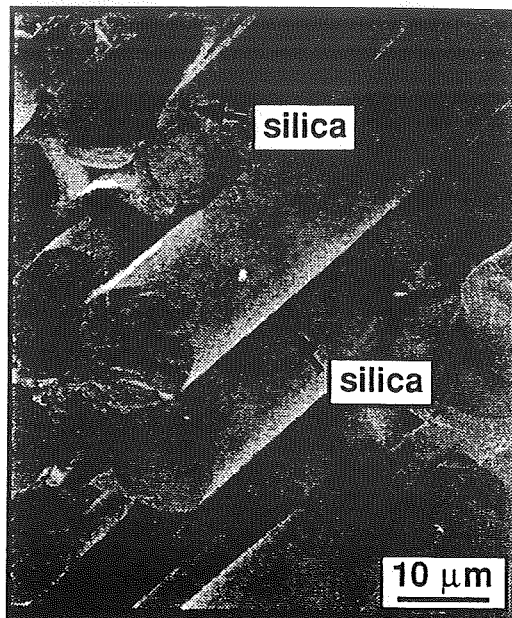
Composites With Boron Nitride Interlayers Were Embrittled By Short-Term Oxidation



Oxidation Of The Composite Changed The Fracture Behavior

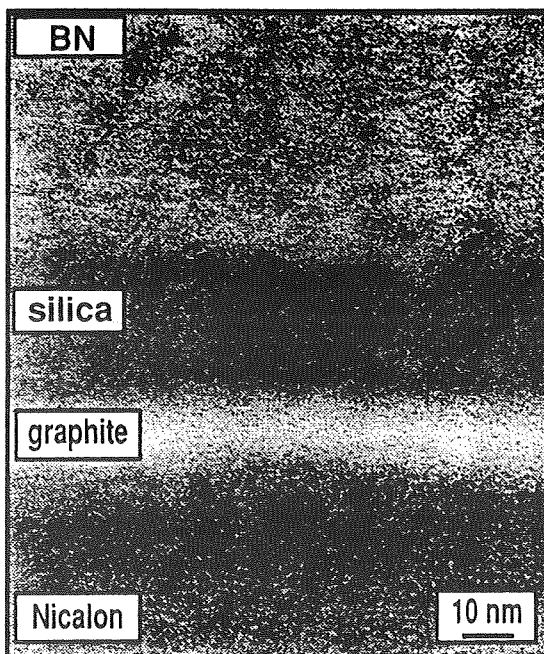


not oxidized

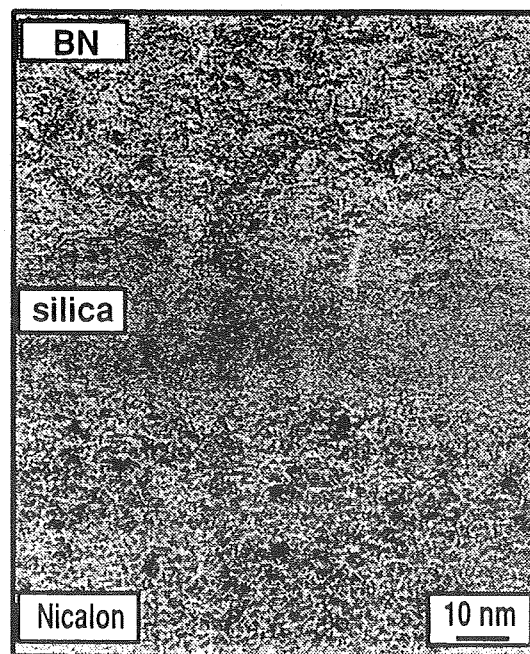


oxidized 1000 h at 1000°C

Microstructural Changes Were Observed At the BN/Nicalon Interface

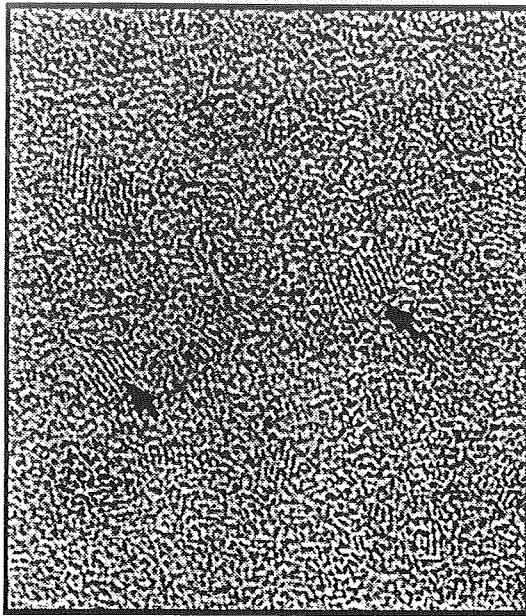


oxidized 24 h at 1000°C

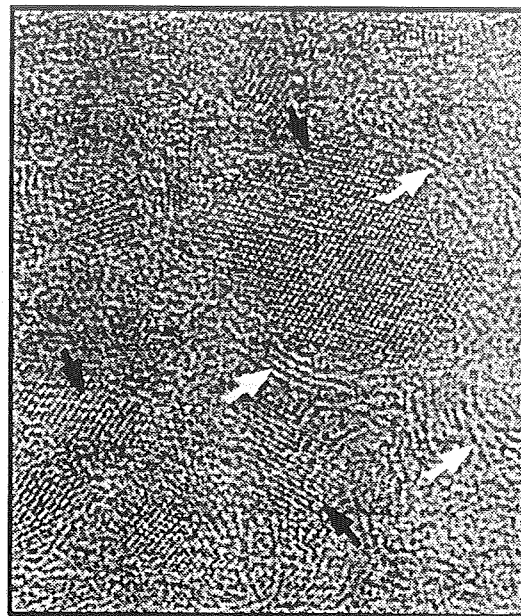


oxidized 1000 h at 1000°C

Decomposition Of The Nicalon Fibers Occurred During Oxidation

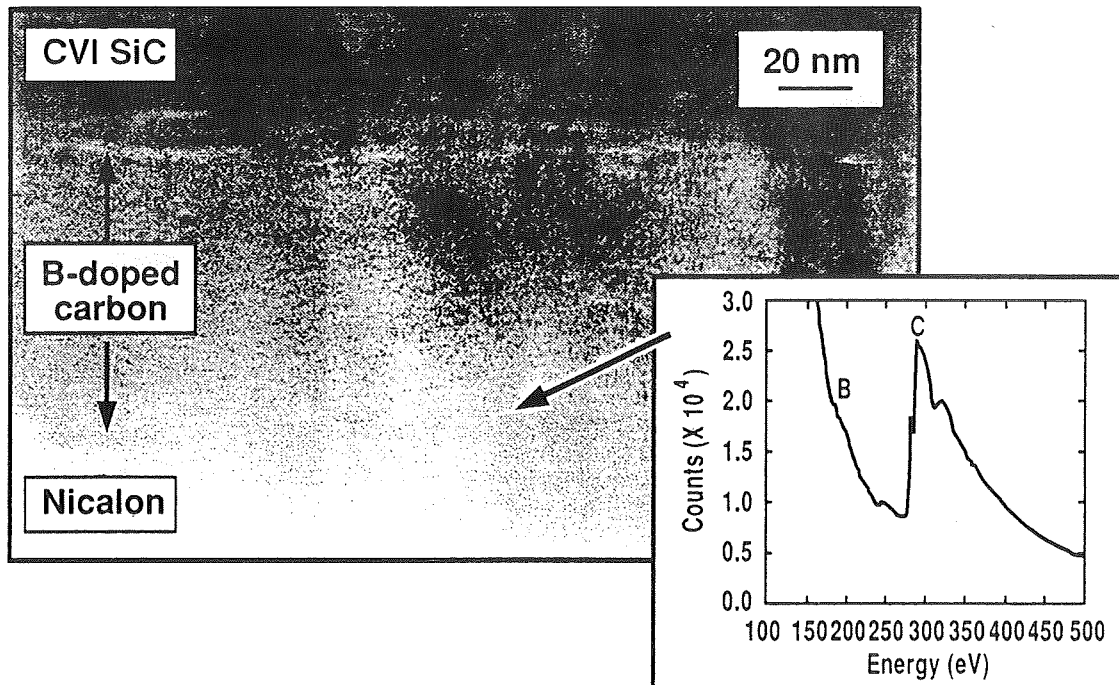


not oxidized

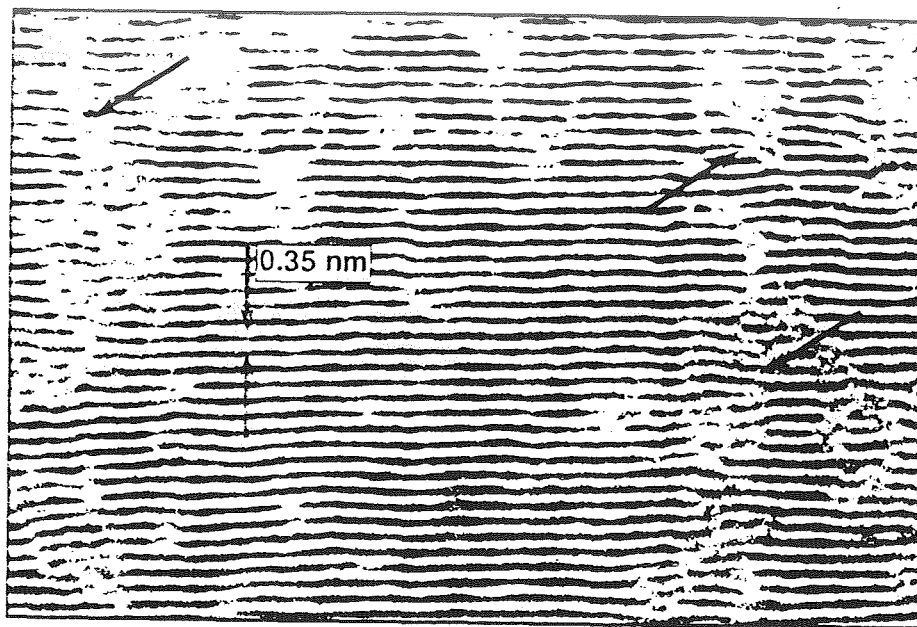


oxidized 1000 h at 1000°C

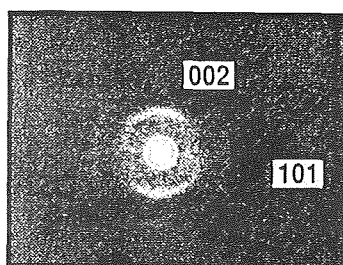
Small Additions Of BCl_3 To Methane Drastically Alters The Nature Of The Carbon Interface (C:B = 18)



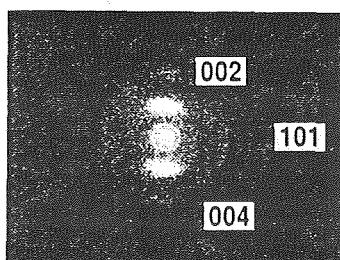
The methane-derived carbon interfacial coatings were highly aligned and contained many defects



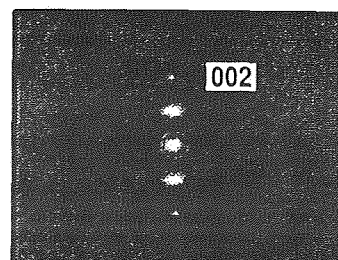
A Change In Carbon Structure Was Observed As A Result Of The Type Of Reactant Gas Used



Methane -
Partially graphitized

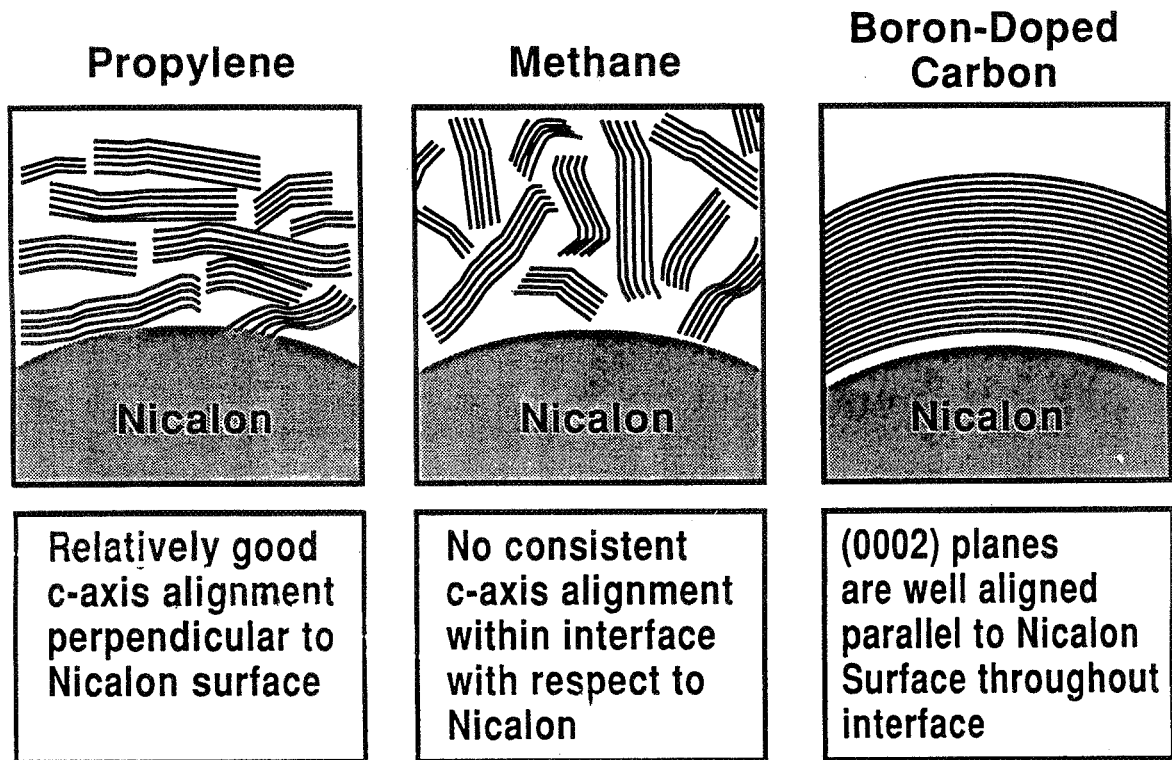


Propylene -
Partially Graphitized



B-doped Carbon
Turbostratic

Carbon Microstructures Observed



Summary

- Understanding Interfacial Microstructural Evolution During Environmental Testing/Use is Critical to the Development of Stable CFCCs for Use in “Corrosive” Environments
- The Use of Advanced Characterization Techniques is Required to Track Subtle Microstructural Changes
- Characterization Effort Must be Coordinated With Other CFCC Tasks to Completely Evaluate Interfacial Behavior

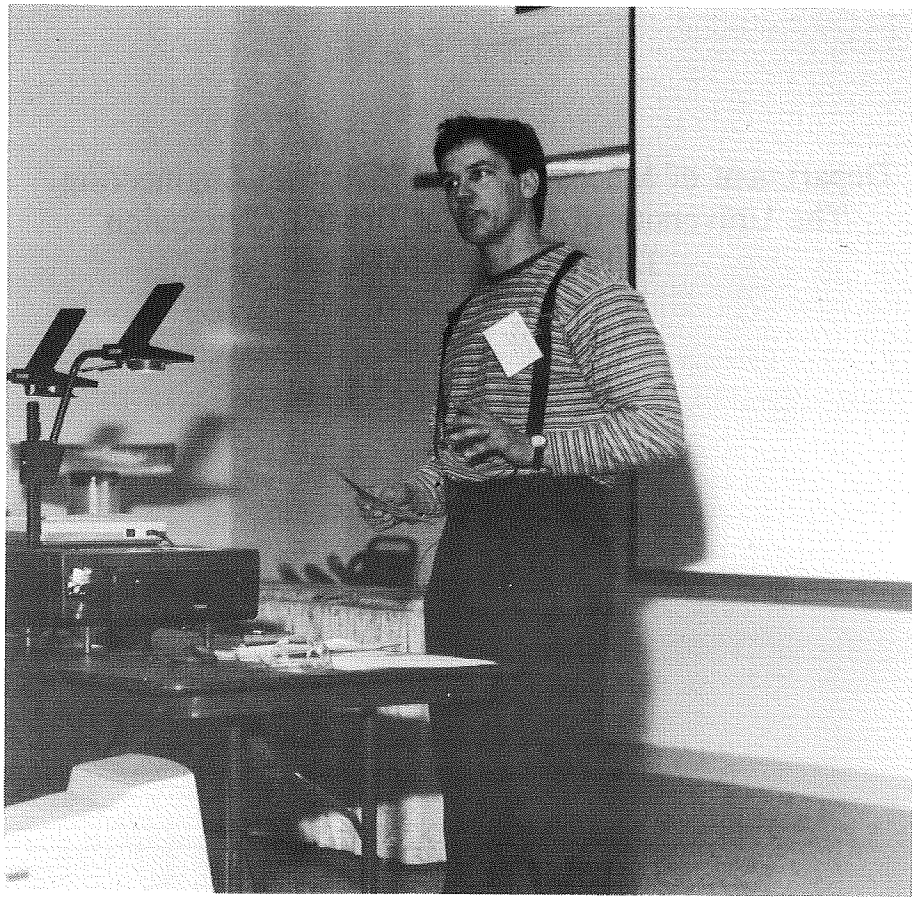
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INSTRUMENTED MATERIALS TESTING

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Instrumented Materials Testing

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Outline

- **Introduce the need for materials testing**
- **Classic Failures**
- **Fundamental Discoveries in Fracture**
- **Standard Tests**
- **Brittle vs Ductile Failure**
- **Most Practical Test**
 - **Experiments**
- **Composite Strategy - Griffith showed us that smaller was better**
- **Composite tests**
- **Stress Waves**

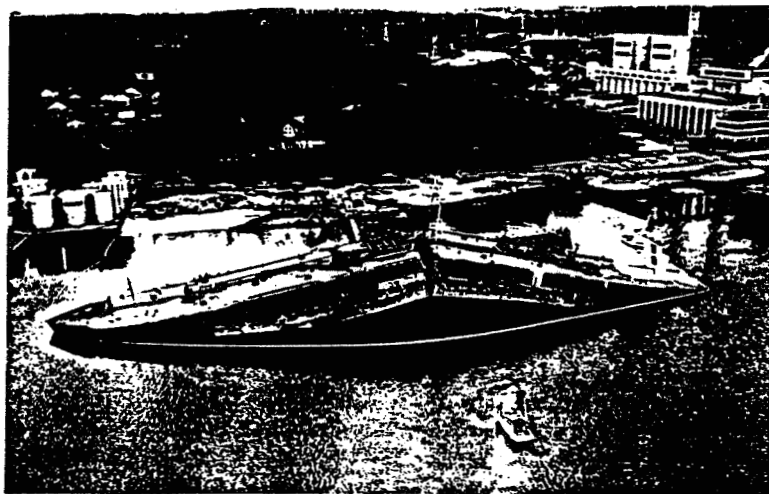
Ignorance can lead to tragedy

- **Teflon Insert for TMJ / 100% failure rate!**



Failure of Liberty Ships

- **Brittle Hull Fractures**
 - properties changed with temperature



An oil barge that fractured in a brittle manner by crack propagation around its girth. (Photography by Neal Boenzi. Reprinted with permission from *The New York Times*.)

Failure initiates at defects

- **Griffith 1920**
$$\sigma = \frac{\sqrt{2E\gamma_s}}{\sqrt{a}}$$
- **Westergaard**
$$\sigma_y = \frac{K}{\sqrt{2\pi r}} f(\theta)$$
- **Irwin**
$$K \Leftrightarrow \sqrt{2E\gamma_f}$$

Standard Tests have been identified

- **K_{Ic} test**
 - carefully machined specimen
 - fatigue pre-crack
 - satisfy test criteria, check plastic zone size

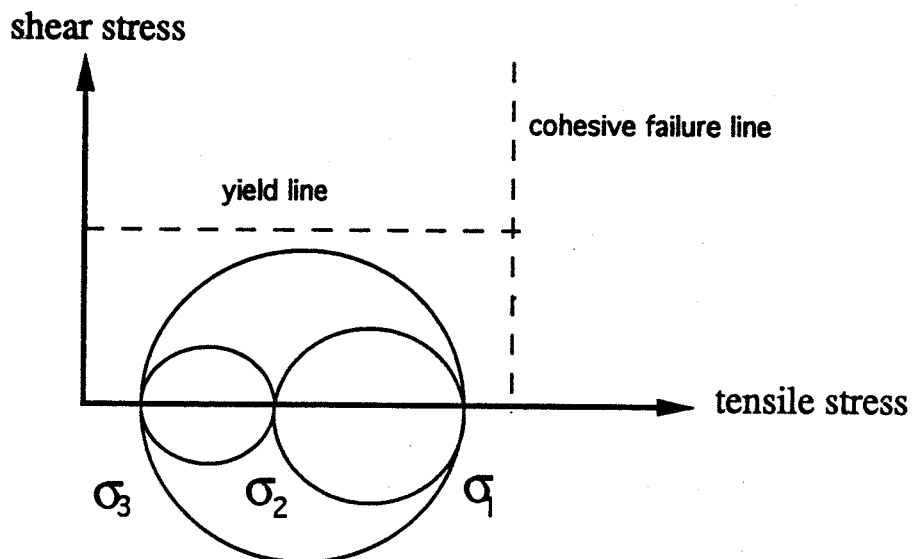
- **Charpy Test**
 - simple sample prep
 - simple experiment
- **Falling Dart**
 - simple sample prep
 - simple experiment

Instrumented tests provide more information

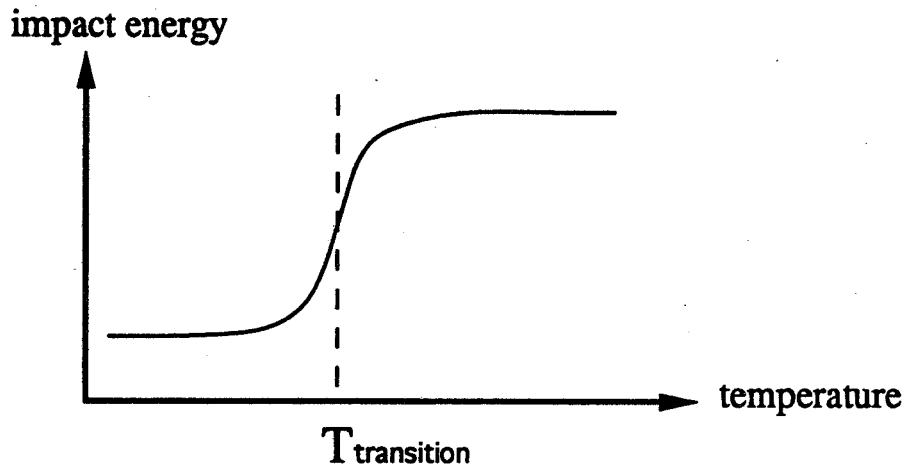
Standard Impact
Absorbed Energy

Instrumented Impact
Load-displacement
Dynamic Modulus
Yield Stress (onset of damage)
Ultimate Strength
Absorbed Energy

Is Failure Brittle or Ductile?



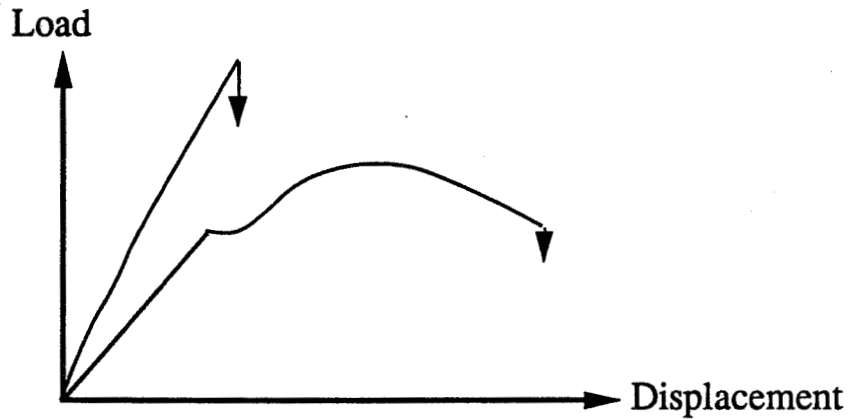
Brittle to Ductile Transition Occurs in BCC metals



Transition is due to dislocation mobility

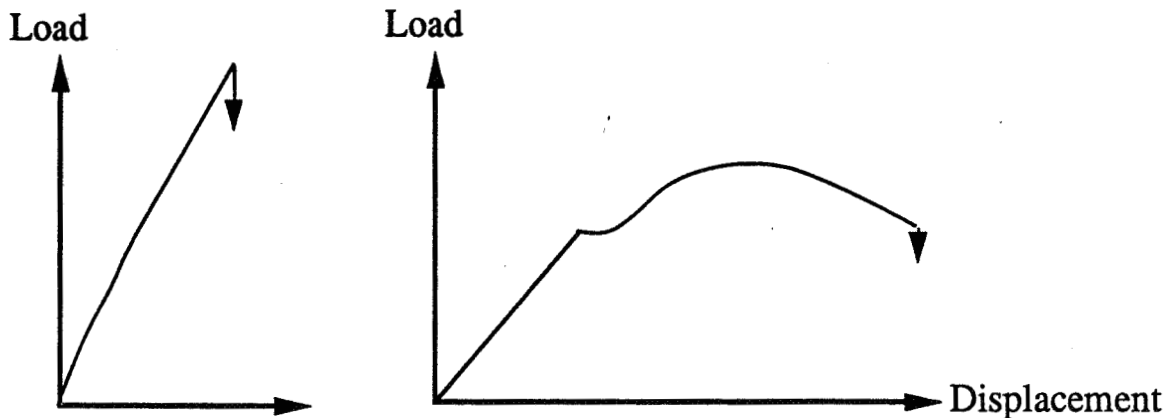
- impurities/alloy elements concentrate at dislocation core
- impurities/alloy elements relieve dislocation stress field

Impact response changes dramatically across the Brittle/Ductile Transition

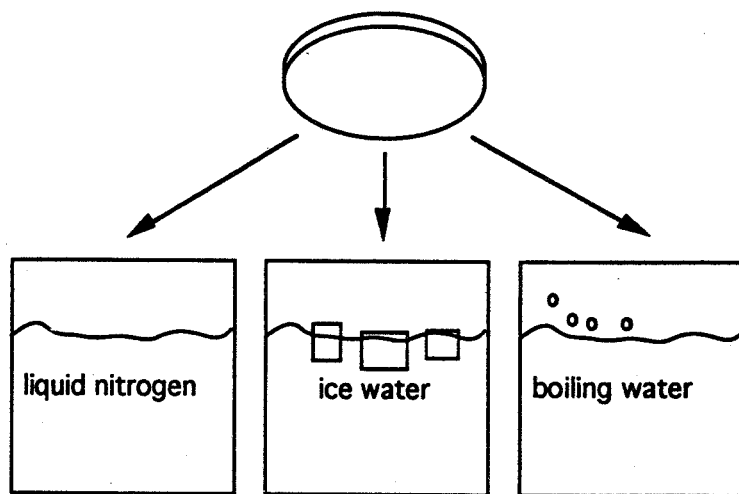


Toughness is defined as a materials resistance to being torn apart

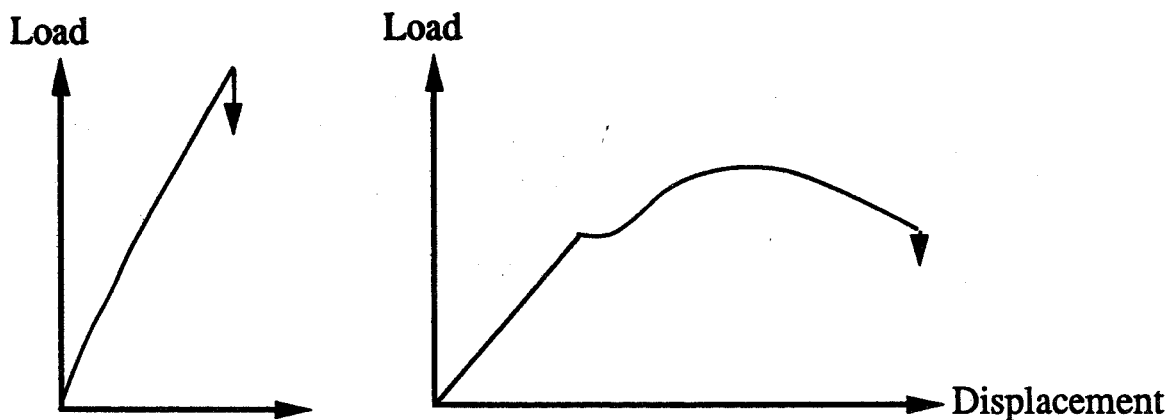
- **Work of Rupture - area under load-displacement curve**



Simple experiments illustrate brittle/ductile transition



Load-deflection curves show distinct differences with Temperature



Click on and drag the cursors so that they are close to the waveshape. Then adjust the Y scale value to that of the previous graph. Use the cursor system to obtain values to enter into the two controls below. When done, click on the PROCEED button.

THE VALUES YOU ENTER BELOW WILL BE USED AS INTEGRATION LIMITS FOR ENERGY CALCULATIONS ON THE NEXT PANEL.

time at impact
6.350 msec

time at end
9.220 msec

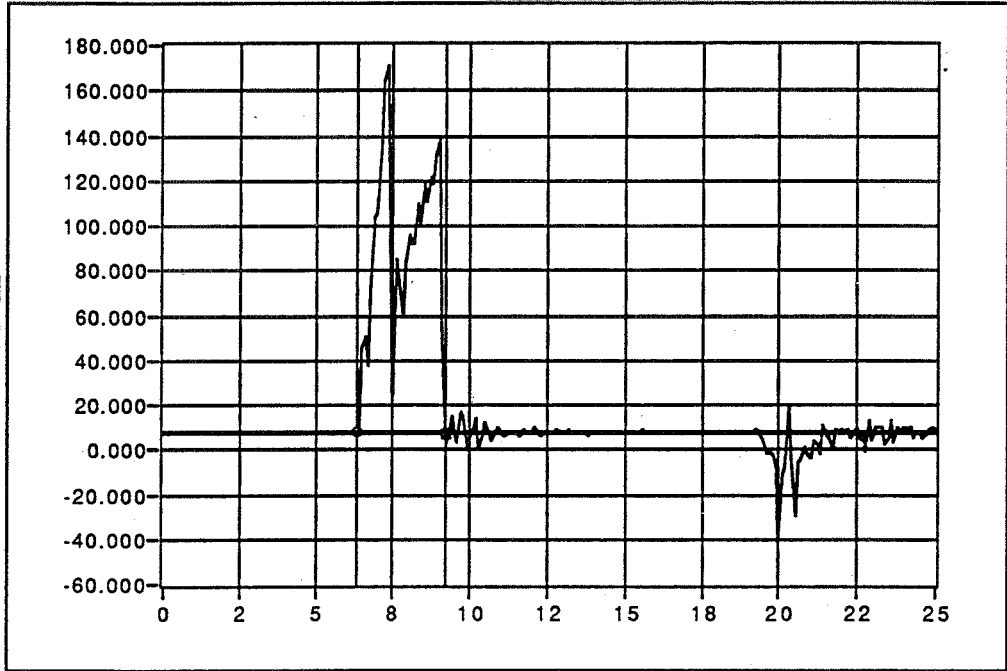
USE PRINT OPTION UNDER FILE MENU TO PRINT DATA

PROCEED TO ENERGY PLOT

	0	6.35	8.15		
	1	9.22	7.16		

filename: polyprop0C
Load units: Pounds

LOAD



0.		Lchoice	T end(us)	T impact(us)	time array	0	0.000	load array	0	7.659
1.		1	16690	6080						

Front Panel

Click on and drag the cursors so that they are close to the waveshape. Then adjust the Y scale value to that of the previous graph. Use the cursor system to obtain values to enter into the two controls below. When done, click on the PROCEED button.

THE VALUES YOU ENTER BELOW WILL BE USED AS INTEGRATION LIMITS FOR ENERGY CALCULATIONS ON THE NEXT PANEL

time at impact
6.080 msec

time at end
16.410 msec

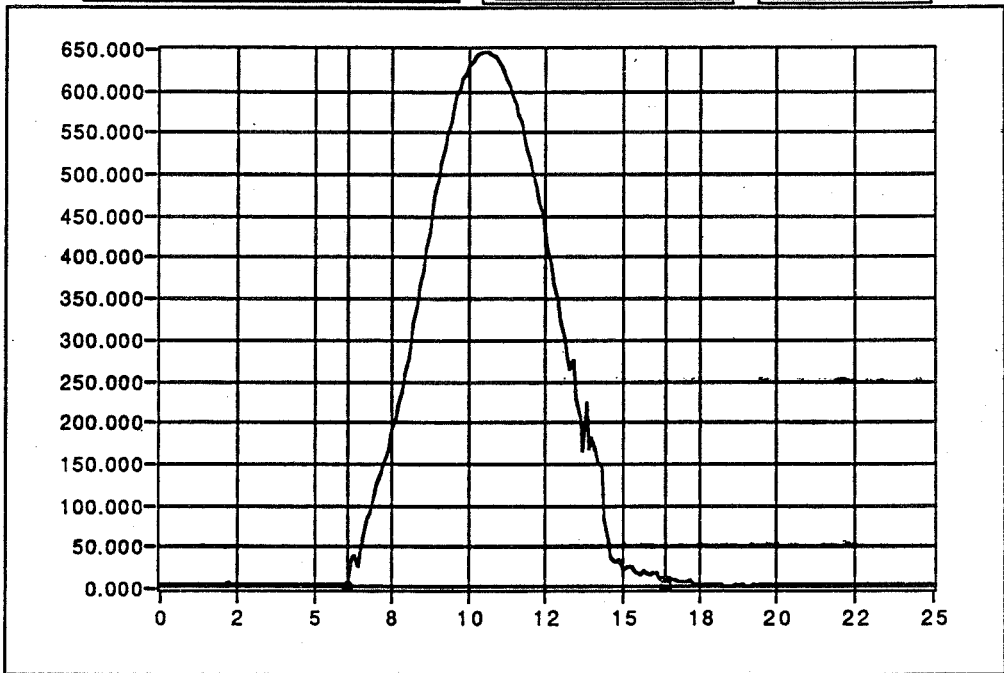
USE PRINT OPTION UNDER FILE MENU TO PRINT DATA

PROCEED TO ENERGY PLOT

0	6.08	2.67	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	16.41	2.67	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

filename: polyproprrt
Load units: Pounds

LOAD



0.	<input type="checkbox"/>	Lchoice	T end(us)	T impact(us)	time array	<input type="checkbox"/>	<input type="checkbox"/>	load array	<input type="checkbox"/>	<input type="checkbox"/>
1.	<input checked="" type="checkbox"/>	1	15640	6010	0	0.000	0	6.104		

Front Panel

Click on and drag the cursors so that they are close to the waveshape. Then adjust the Y scale value to that of the previous graph. Use the cursor system to obtain values to enter into the two controls below. When done, click on the PROCEED button.

THE VALUES YOU ENTER BELOW WILL BE USED AS INTEGRATION LIMITS FOR ENERGY CALCULATIONS ON THE NEXT PANEL.

time at impact
6.080 msec

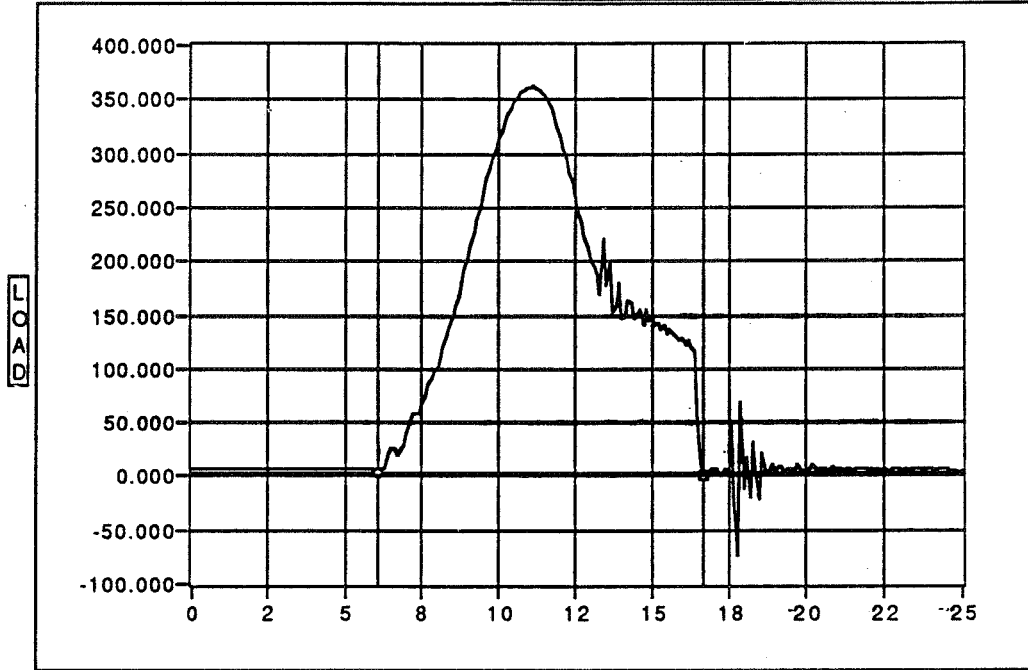
time at end
16.690 msec

USE PRINT OPTION UNDER FILE MENU TO PRINT DATA

PROCEED TO ENERGY PLOT

	0	6.08	2.67		
	1	16.69	0.82		

filename: polyprop100C
Load units: Pounds



0.		Lchoice	T end(us)	T impact(us)	time array	0	0.000	load array	0	6.822
1.		1	16410	6080						

Composite Paradigm exploits Griffith's results

- **Smaller specimens are stronger because they have smaller flaws**

$$\sigma \approx \frac{1}{\sqrt{a}}$$

- **Fibers are used as reinforcement**
 - stiffness
 - strength
 - toughness
 - creep resistance

Specific Stiffness and Strength are the main reason composites are used

Metallic Bonding

non-directional

facilitates close packing, high density

Ionic

**Requires nearest neighbors of opposite sign
restricted atomic arrangements**

Covalent

Directional

Fixed bond orientations affect packing

Materials Selection for Stiffness

$$\text{Material Selection Parameter} \Rightarrow \sqrt{\frac{\rho^2}{E}}$$

- **CFRP** **2.9** ($\times 10^3 / \text{N}^{1/2}\text{m}^{-3}\text{s}^2$)
- **Wood** **5.5**
- **Aluminum** **10**
- **GFRP** **10**
- **Concrete** **12**
- **Polyurethane** **13**
- **Steel** **17**

Materials selection to minimize weight and prevent yield

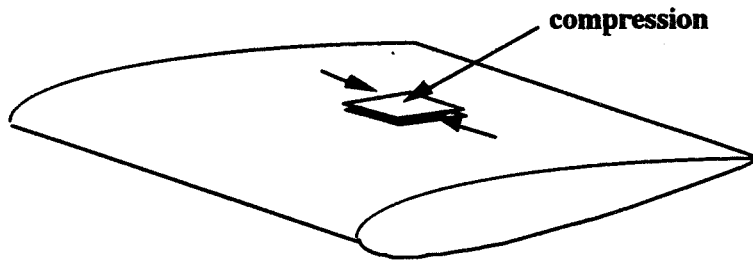
$$\text{Material Selection Parameter} \Rightarrow \frac{\rho}{\sigma_y}$$

- **CFRP** **.002**
- **Aluminum** **.007**
- **Alloy Steel** **.0078**
- **Fiberglass** **.009**
- **Concrete** **.0125**
- **Mild Steel** **.035**

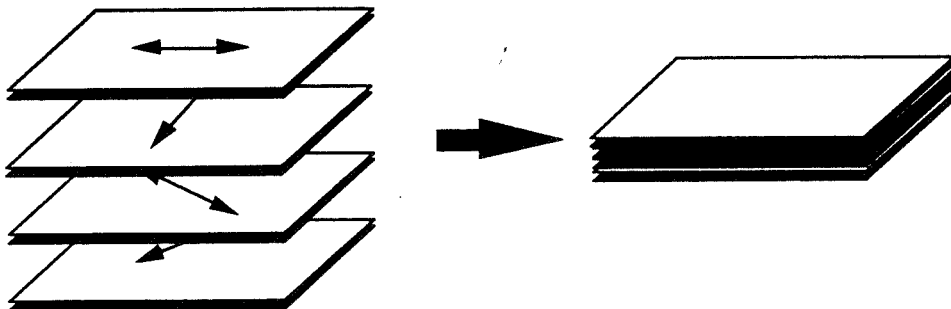
Polymer Matrix Composites are used as structural wingskins

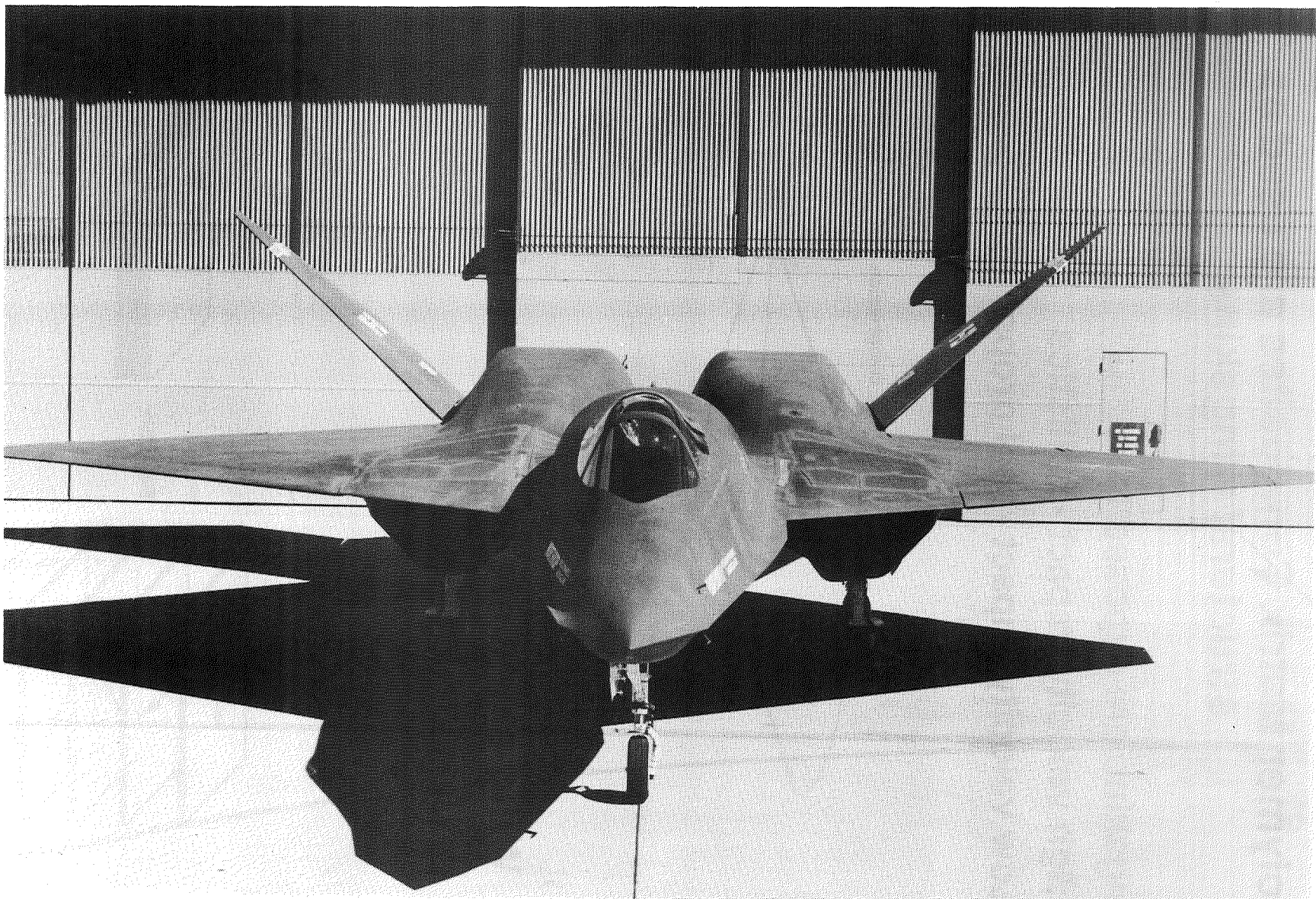
wingskins are exposed to:

- High velocity impact - ballistics
- Low velocity impact - tool drops

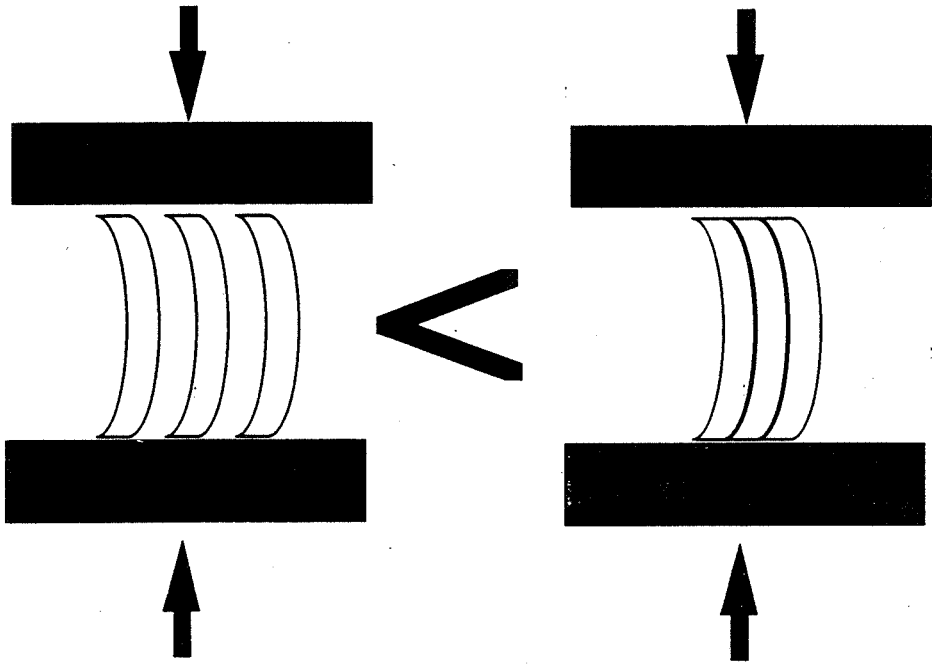


Wing skins are made by lamination

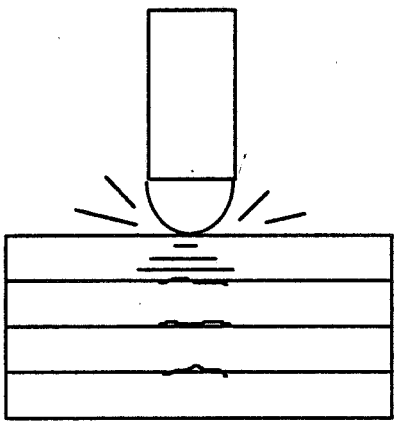




Laminate interface properties affect compressive strength

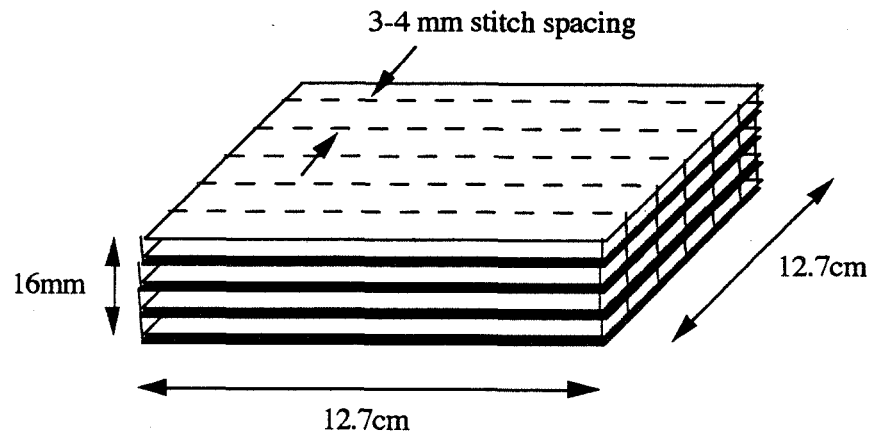


Non-penetrating impact causes sub-surface delamination

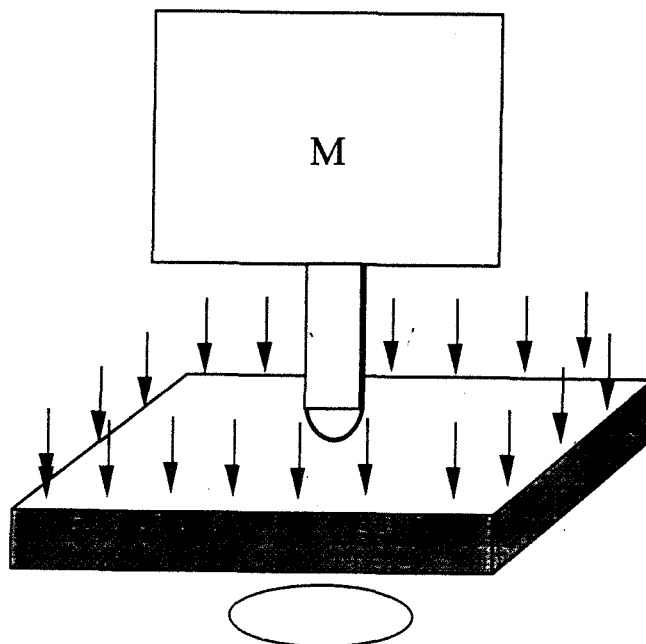


Tests were conducted on stitched-laminated composites

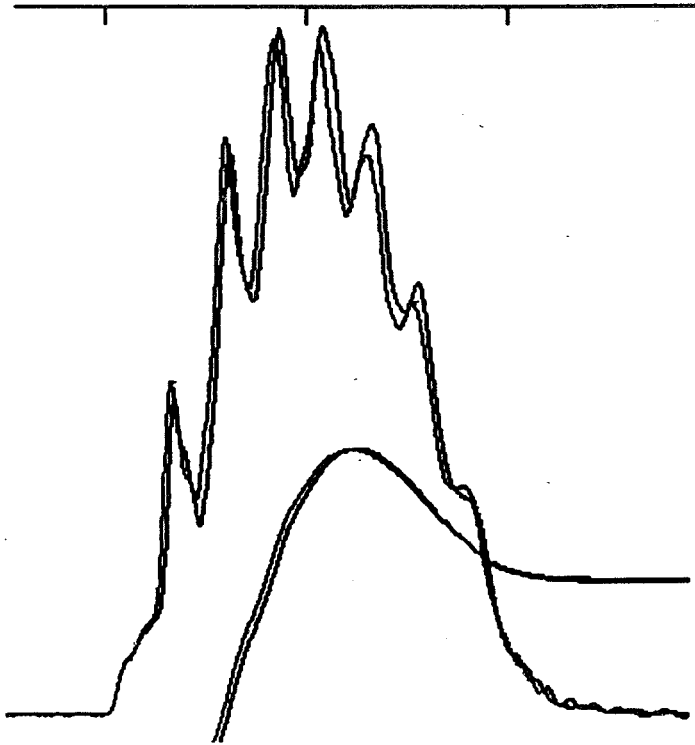
- layer thickness=1.45mm
- 10-12 layers thick



Impact tests were conducted using a DYNATUP instrumented drop weight system



Oscillations in Load-Time curve are due to stress waves



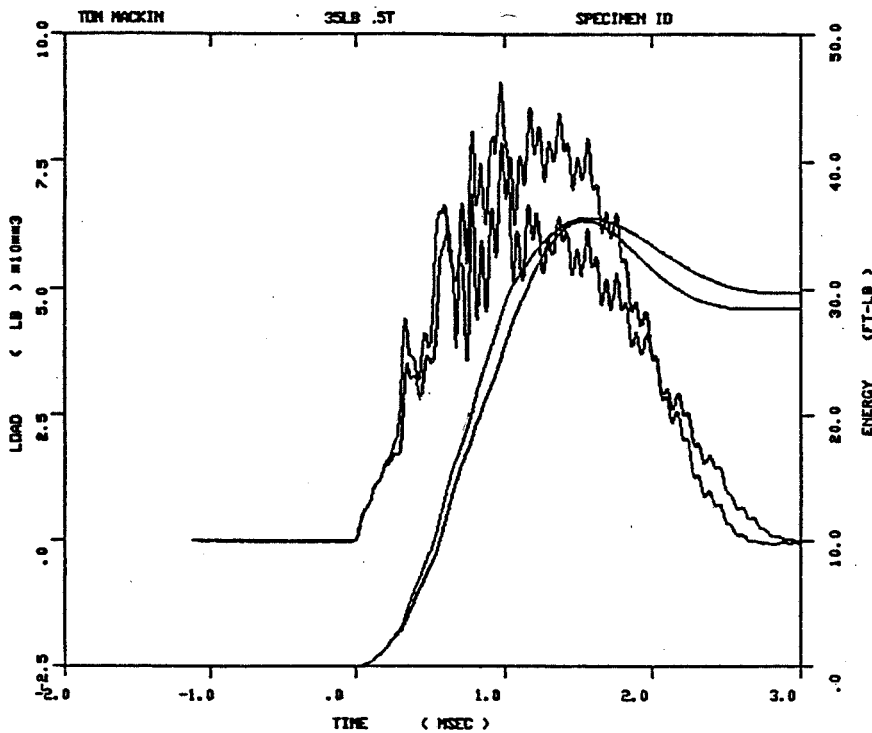
$$v = f * 2(\text{SAMPLE THICKNESS})$$

$$v = 111 \text{ m/sec}$$

TYPICAL VALUE FOR EPOXY

$$v = \sqrt{\frac{E}{\rho}} \sim 104 \text{ m/sec}$$

Damaging Impacts Exhibit Different Load Spectra



Conclusions

- **Knowledge of material properties is crucial in design**
- **instrumented testing provides important information**
 - impact is simple and efficient means of evaluating properties
- **Simple experiments can be used to illustrate key concepts**
 - brittle/ductile behavior
 - trade-off between strength and ductility
 - notch sensitivity
- **Stress waves initiate damage**

**APPLICATION ADVANCEMENTS
USING ELECTORRHEOLOGICAL FLUIDS**

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Application Advancements Using Electrorheological Fluids

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School of Industry and Technology
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KEY WORDS:

Electrorheology, electrorheological fluid, fluid power transmission, hydraulics.

PREREQUISITE KNOWLEDGE:

The student should understand the elementary concepts of magnetism. A basic understanding of fluid flow would be helpful.

OBJECTIVE:

To observe the unusual characteristics of electrorheological fluids. To understand how these fluids change from a liquid to a solid. To understand the potential power transmission advantages of these fluids.

EQUIPMENT AND SUPPLIES:

- 1) Plastic bottle containing electrorheological fluid.
- 2) Energizing probe
- 3) Personal safety equipment
- 4) Paper towels
- 5) Pen

INTRODUCTION:

Electrorheological fluids change their flow characteristics when subject to an electrical field. Response, which takes only milliseconds, is in the form of a progressive gelling that is proportional to field strength. With no field present, the fluid flows as freely as hydraulic oil (Korane, 1991).

Electrorheological fluids represent a maturing technology that has the potential to widen the performance range of automated electromechanical and electrohydraulic equipment. Research and ongoing developments are refining this technology and experts predict an important future for these fluids.

Importance of Electrorheological Fluids:

Current automation capabilities are not advanced enough to build a robot that could play tennis. Even though cameras and computers could direct the robot towards a ball, robot's move in an awkward, lumbering fashion because conventional hydraulic valves cannot keep pace with the commands of the computerized controllers.

With electrorheological fluid technology, this type of response time is possible. This technology will allow devices that can operate instantly and without mechanical valves. Increased productivity and better product quality through more dependable and responsive automated equipment is just a small part of what this maturing technology can deliver.

How Electrorheological Fluid Functions:

Electrorheological fluids are composed of two primary components. They are the carrier fluid and the suspended particles. The carrier fluid needs to be a good insulator, compatible with the materials they contact. Typical particle materials include polymers, minerals, and ceramics (Scott, 1984).

When an electrical field is applied across the fluid, positive and negative charges on the particles respond by separating, so each particle then has a positive end and a negative end. Particles of the electrorheological fluid then link together in the same manner that the north pole of one magnet is attracted to the south pole of another magnet (Duclos, 1988).

When the electrical field is removed, the particle attraction is no longer present. The fluid then begins flowing freely. Please see Figures 1 and 2.

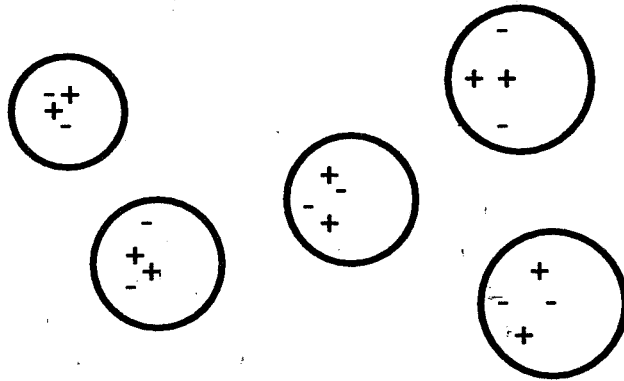


Figure 1 - No electrical field present, charges are random, no particle attraction.

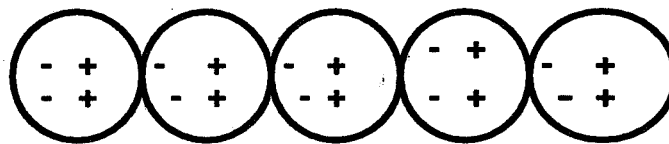


Figure 2 - Probe energizing the fluid, particles linked together.

Potential Applications:

Electrorheological fluids can change from solids to liquids so fast, they will work well with fast-acting computers. These characteristics suggest a number of unusual engineering applications such as fluid clutches and vibration isolators (Duclos, 1988).

According to Hans Conrad, professor of materials science and engineering at North Carolina State University, electrorheological fluids will lead to a whole new generation of brakes, automatic transmissions, actuator devices, hydraulic valves, pump parts, and motors (Conrad, 1992).

PROCEDURE:

Safety Considerations:

1. Be very careful to avoid being shocked by the energizing probe.
2. Protective eye wear is mandatory for all those in the lab area.
3. Do not allow the electrorheological fluid to touch anyone's skin or clothing.
4. Obtain a "Material Data Safety Sheet" on the fluid from the supplier. Read the sheet completely and ask questions relating to any information you do not understand.

Electrorheological Fluid Preparation:

1. Check the cap on the plastic bottle containing the fluid and make sure it is securely tightened.
2. Shake the bottle to distribute the stratified particles evenly within the fluid.
3. Set the bottle down on the lab bench and carefully remove the top.

Observing Electrorheological Fluid as a Liquid:

1. Slowly insert the probe into the container of fluid until the metal rods are submerged approximately two inches below the surface of the fluid.
2. Slowly withdraw the probe from the fluid and hold it slightly above the bottle. Observe what happens to the electrorheological fluid on the metal rods of the probe.
3. Set the probe on a paper towel and record your observations.

Observing Electrorheological Fluid as a Gelled Solid:

1. Slowly insert the probe into the container of fluid until the metal rods are submerged approximately two inches below the surface of the fluid.
2. Press and hold down the button on the top of the probe.
3. Slowly withdraw the probe from the fluid and hold it slightly above the bottle. Observe the status of the electrorheological fluid on the metal rods of the probe.
4. With the probe slightly above the fluid level in the bottle, release the button (de-energizing the probe) and observe what happens to the electrorheological fluid on the metal rods of the probe.
5. Set the probe down on a paper towel and record your observations.

SAMPLE DATA SHEET:

Record below the characteristics of the fluid when the probe was not energized:

Record below the characteristics of the fluid when the probe was energized:

INSTRUCTOR NOTES:

1. When the probe was removed from the fluid without being energized, students should have observed the fluid flowing off the metal rods and back into bottle. The fluid will flow as easily as oil.
2. When the probe was removed from the fluid while being energized, students should have observed a gelling of the fluid around the rods of the probe.
3. De-energizing the probe will cause the gelled electrorheological fluid to liquefy and drip into the bottle.

REFERENCES:

Korane, K.: Putting ER Fluids To Work. Machine Design, May 9, 1991, pp. 52-57.

Scott, D.: Amazing Hardening Fluids Open a New World of Hydraulic Drives. Popular Science, April 1984, pp. 42-46.

Duclos, T.G.: Electrorheological Fluids and Devices. Automotive Engineering, December 1988, pp. 45-48.

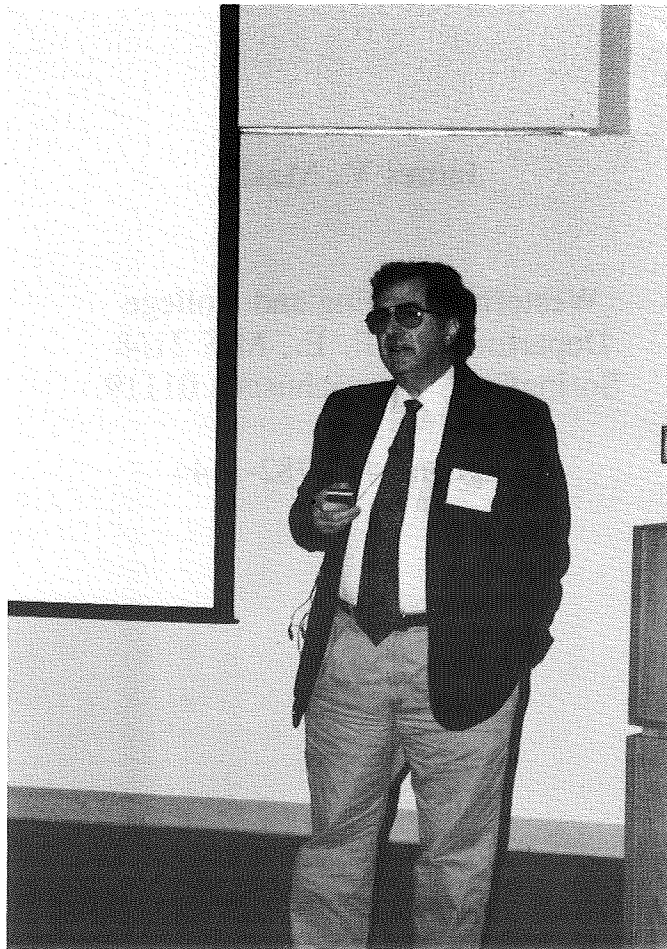
Conrad, H.: The Impact of ER Fluids. Compressed Air Magazine, March 1992, pp. 14-17.

**EXPERIMENTS IN NATURAL AND SYNTHETIC
DENTAL MATERIALS:
A MOUTHFUL OF EXPERIMENTS**

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EXPERIMENTS IN NATURAL AND SYNTHETIC DENTAL MATERIALS:
A MOUTHFUL OF EXPERIMENTS

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KEY WORDS: Biomaterials, dental, corrosion, composite, amalgam

PREREQUISITE KNOWLEDGE: The student should be familiar with the basics of materials science, metallography, and chemistry. Levels at which these experiments are performed are second semester junior year and either semester senior year. The students are first given lectures on fracture mechanics, metals, alloys, and composites. They should have already had a laboratory experiment on metallography and sample preparation. A video on the deterioration of restorative materials in the oral environment is used as a backdrop for the experiments.

OBJECTIVES: The objectives of these experiments are to show that the area of biomaterials, especially dental materials (natural and synthetic), contain all of the elements of good and bad design, with the caveat that a person's health is directly involved. The students learn the process of designing materials for the complex interactions in the oral cavity, analyze those already used, and suggest possible solutions to the problems involved with present technology. The N.I.O.S.H. Handbook is used extensively by the students and judgment calls are made, even without extensive biology education.

EQUIPMENT AND SUPPLIES:

- (1) Metallurgical preparation and polishing apparatus (eg. Buehler Co.),
- (2) Amalgam triturated samples (Johnson & Johnson, Inc., Degussa Chemical, etc.),
- (3) Titanium, gold crowns, graphite, and stainless steel (316L) posts and fixtures (J. & J.),
- (4) Teeth with amalgam, ceramic, and composite restorations (Local dentists),
- (5) Selenium oxychloride solution (Hg stain from Fisher Scientific, etc.),
- (6) Metallurgical microscope (Olympus, Zeiss, etc.), and
- (7) SEM with EDAX (optional).

INTRODUCTION:

There are few materials which capture the essence of materials science as dental materials and the amazing, adaptive natural dental materials. In the same vein, these materials are all subject to the same mechanical, electrical, chemical, and biological laws as all other materials. Certain of these synthetic materials are now deemed potentially harmful in the human bio-system. Newer materials have shown promise of solving the restoration problem. At Western New England College, two senior projects and some extensive research have led to the development of a two-part experiment involving natural and synthetic materials such as actual previously extracted teeth, amalgam filled teeth, stainless steel orthodonture material, gold alloy crowns, composite restoration material, titanium implants, and graphite endodontic posts. Tests involve corrosion couples, sectioning and microscopic investigation of alloys and composites, and bond strength of polymer adhesives.

The problem of restoration of carious regions, the materials used, and the associated appliances employed in orthodonture and implantology provide a complex electrochemical scenario to be sorted out by the practitioner and patient alike. Add to this the fact that many scientists cannot even agree on the cause/effect relationships associated with pathologies resulting from the release of ions, metallic vapors, and molecules from the man-made materials placed in the oral cavity, and the problem of imagination vs reality eludes even the more astute practitioner, much less the patient.

These experiments detail the basics of corrosion and material function and failure in the oral environment, listing many of the possible combinations of materials that could be and are employed in the practice of oral restorations, implants, and orthodonture. Known facts will be isolated from conjecture, while visual observations and measurement techniques will be explained in the light of good electrochemical practice and common sense approaches. Standard tests, ranging from expensive and highly sophisticated ones to simple, inexpensive tests will be enumerated, while less expensive ones will be employed. Bases for agreement on fundamental starting points for future "good practice" techniques will be discussed as part of the experimental writeup. Some of the materials covered will be: mercury amalgams (redundant: amalgam means "with mercury"), noble metal inlays, appliances, posts, fixtures, implants, ceramics, and polymeric composites. A section on background theory is given in the Appendix for use as a pre-lab lecture or as reference for the student and laboratory instructor.

EXPERIMENTS:

The specific aims of these experiments are to classify these mechanical effects, thermodynamic phase diagram realities, electrochemical and corrosive effects, identify the species involved, use certain measurement devices, and show the physical data associated with the actual restorations, appliances, and implants and their attendant biodental engineering effects.

Phases in amalgam and their electrochemical potentials:

The student should refer to the Appendix in Figure A3 to observe the ternary phase diagram for mercury-silver-tin. This will serve to help the student identify the polished samples produced by the following procedures. Samples of high copper amalgams are prepared by trituration according to the specifications of the manufacturer/supplier. Typical mixture morphologies and trituration apparatus are shown in Figure 1. These samples are then mounted in phenolic or suitable cold mounting polymers and observed under a suitable optical microscope or electron microscope at magnifications appropriate for phase detection. A typical polished sample is shown in Figure 2. Make sure that the students note the "droplets" of free mercury which result.

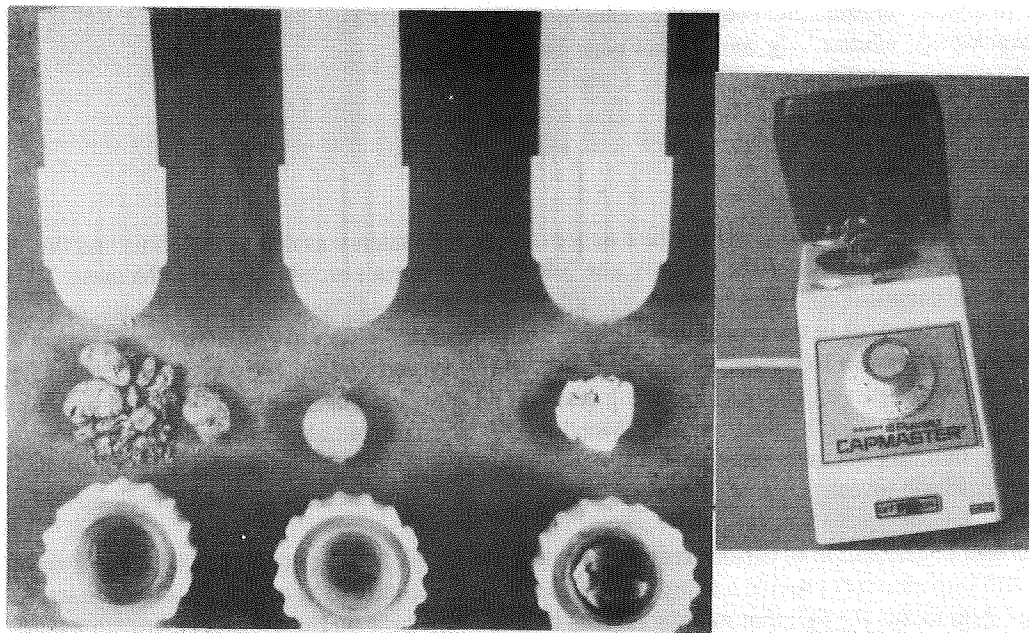


Figure 1
Mixed Amalgams and Triturator

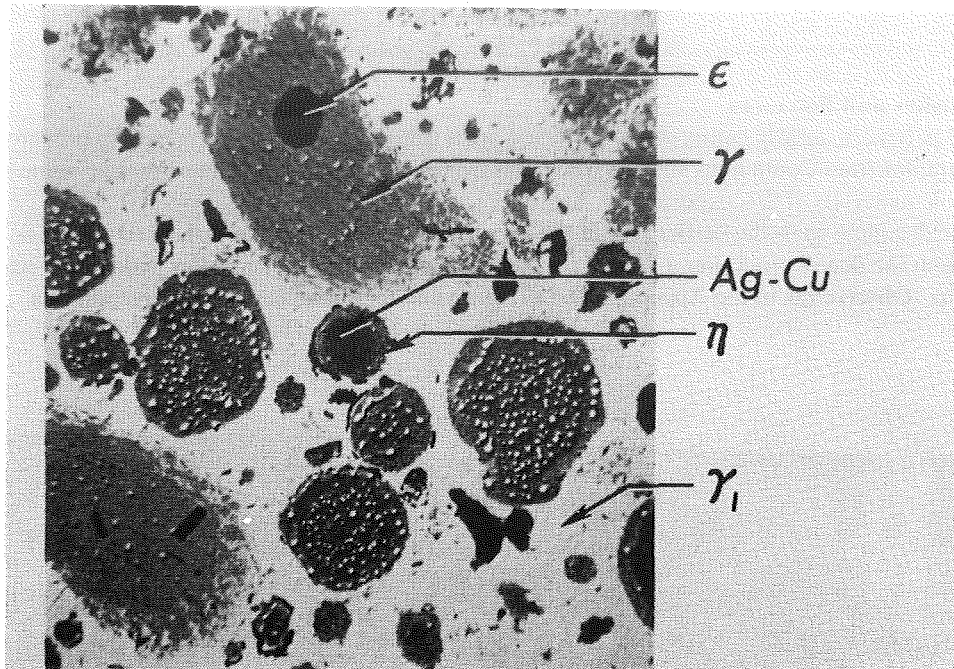


Figure 2
Photomicrograph of Polished Amalgam Sample

If a potentiostatic or potentiodynamic apparatus is available, measurements can be made on the electrochemical potentials and anodic polarization curves of restoration alloys with amalgams. Phases can be made from scratch, using standard alloying techniques. Potentiometric corrosion curves typical of some of the restoration materials, appliances, and implant materials are shown in Figure 3.

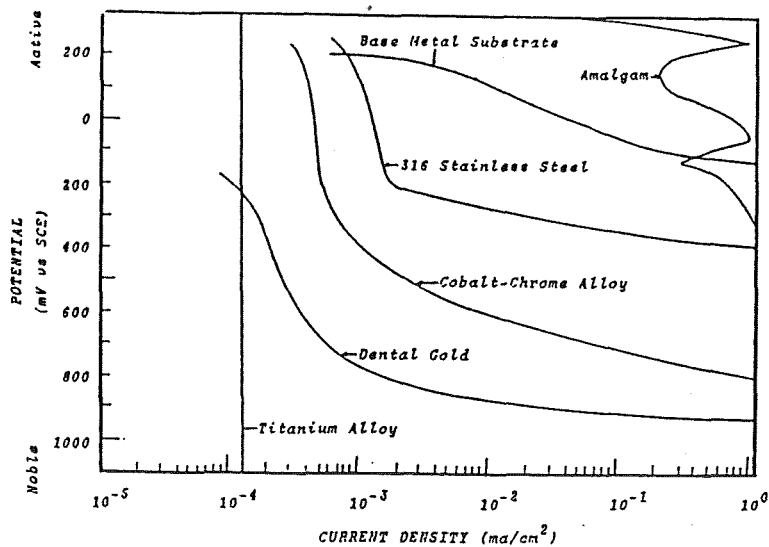


Figure 3
Potentiometric Corrosion Curves of Some Restoration Materials

These curves verify the degree of corrosion under given corrosion potentials. Note the consideration of area in the current density on the ordinate of the graph. Area of the anode and cathode influence greatly the rate of corrosion of the materials involved. For instance, if the area of the cathode is much larger than the anode, the corrosion reaction will proceed at a much faster rate than if the areas of the two are the same.

Obtaining freshly extracted teeth from a local dental practitioner, the laboratory instructor may wish to show the microstructure of natural teeth and cracking from restorations. If EDAX is available on an SEM, then diffusion of Hg and Ag can be made visible on polished teeth (see Appendix).

Composites and Polymers

Composites and polymers, mostly composed of bis-GMA with fillers and colorants, are easy to prepare for observation. Samples from Companies such as Bisco and Denmat provide a basis for observing some of the most high-tech, durable materials of this experiment. Taking a small sample from the hypodermic dispenser (Figure 4), prepare a mounted sample as in the earlier part of the experiment (setup time is less than 10 minutes). Polish and prepare teeth, from the dental practitioner, which contain composite restorations and/or endodontic posts (root canal filler posts). Observe (as in the Appendix) the structure and topographics of these restorations.

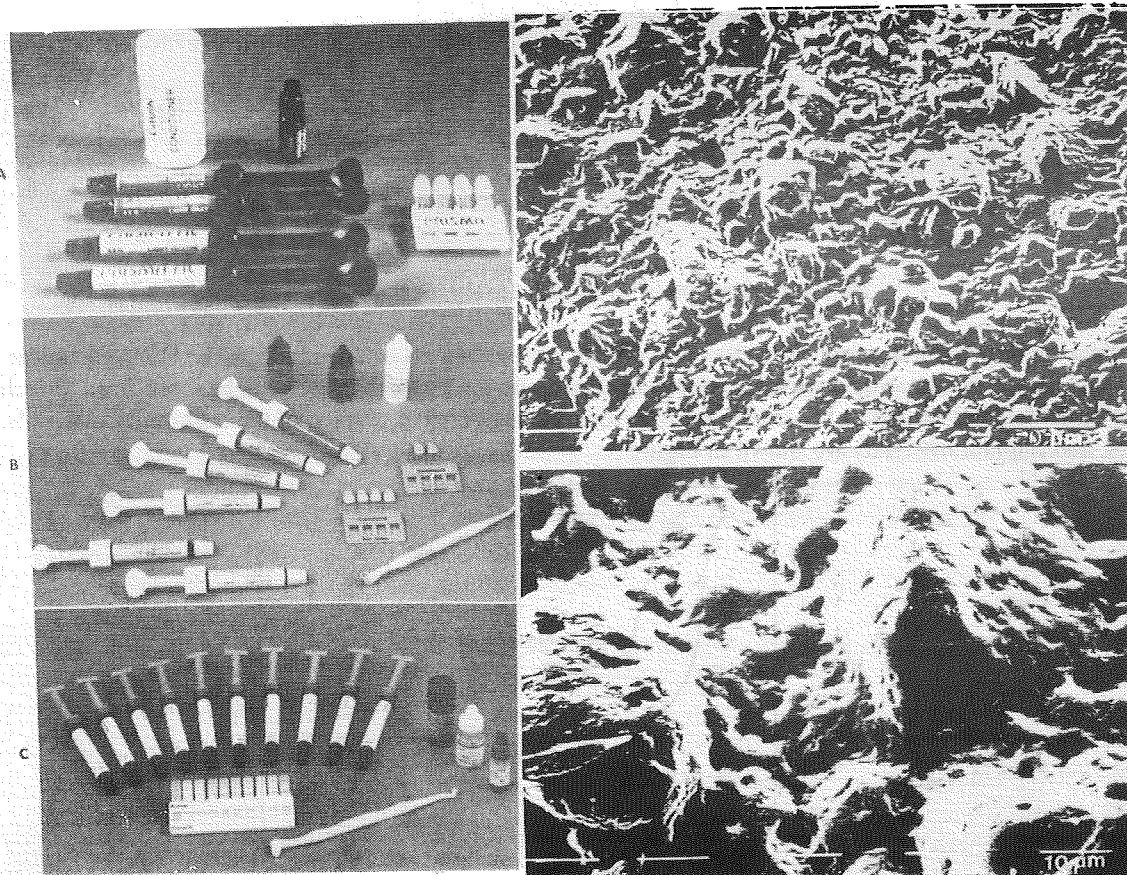


Figure 4
Composite Dispensers and Sections

Reporting

Reports should be made on preparation and observations regarding the above experiments and procedure. Judgments based on corrosion and durability, as well as structure of the materials should be detailed by the students. A "white paper" to the ADA may be composed based upon both background material and the information gleaned from the experiments. These experiments are easy beginnings for senior capstone design projects. The experiment is taken quite seriously and personally, and the comments are very positive to date. The student should be allowed to suggest other experiments to clarify concepts, both in their minds and in the scientific community. The experiments detailed here will be broken up into five distinct stand-alone modules.

APPENDIX

BACKGROUND/THEORY:

Techniques and materials for dental restorations have advanced greatly over the past decade with improved dental metals, ceramics, and polymeric composites. The mechanical properties and ease of fabrication of restorative fillings of mercury-silver amalgams have undoubtedly been the strong driving force for the retention of this practice in modern dentistry. The reality of the electrochemistry of "oral galvanism" first appeared in 1754 with a paper by Sulzer (1). It was later, in 1879, that Chase (2) called this new "oral electricity", associated with the dental amalgam, hazardous. Dental amalgams have been employed in the United States as restorative materials since 1832 and, according to the American Dental Association and others (3,4,5), no cases of well-documented "patient toxicity" have been reported in the scientific literature. This view is in sharp contrast to other researchers (6,7,8,9), to mention a few, documenting literature and physico-chemical effects of the vapor and corrosive release of mercury in the oral environment. Work has been done to elaborate on the degradation of amalgams and the implications of this degradation in the oral environment (4). The purpose of these experiments is not to discuss the medical or physiological effects of the restorations or possible etiology of other pathologies, but to explain and document the mechanical, materials science, electrochemical, and chemical phenomena attendant to the placement and use of many of these materials alone or together in the oral environment.

Corrosion

Corrosion can be defined as the destruction or deterioration of a material because of its reaction with its environment (10). This definition includes both metals and non-metals. The general classifications of corrosion are wet or dry, direct combination or electrochemical.

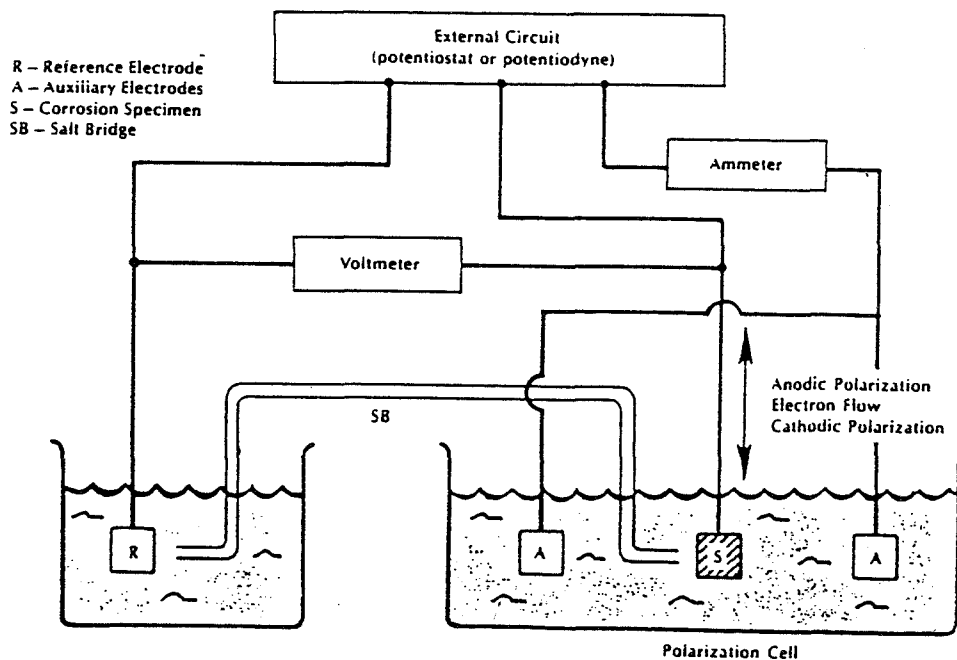
For the purpose of this study, wet electrochemical corrosion occurring in electrolytes is considered. The principles underlying corrosion state that there are two basic requirements for electrochemical corrosion: at least one anode and one cathode must be present to form a cell, and direct currents must flow. Anodes and cathodes may be near to each other (local cell) or farther apart. The current (ion and electron flow) may be self-generated (as in the case of two dissimilar metals in solution) or may be impressed from an outside source (as in plating, for example). The anode is the area where corrosion occurs, current leaves the metal in the form of dissolved ions, and enters the electrolyte solution. The cathode is the area where no corrosion occurs and current enters the metal. Two basic diagrams show the requirements for metallic corrosion, as seen in Figure A1. Note the separate and same surface scenarios for corrosion between two different materials. The governing factor for the corrosion of one material in the presence of another has to do with the Nernst equation

$$E = E_o + 2.3 \frac{RT}{nF} \log \frac{a_{oxid.}}{a_{red.}} \quad (\text{Eq. A1})$$

where E is the half-cell potential, E_o the standard half-cell potential, R is the gas constant, T is the absolute temperature, n is the number of electrons transferred, F is the Faraday constant, and $a_{oxid.}$ and $a_{red.}$ are the activities (concentration) of the oxidized and reduced species. Table A1 shows a series of half-cell potentials measured by potentiometric means, using a standard calomel electrode (SCE) as a reference in saline solution. The more active (anodic) metals corrode at the expense of the less active (more noble or cathodic) metals. For instance, mercury would be corroded (release ions into solution) in a couple with titanium or gold. Simply stated: "In any electrochemical reaction, the most negative or active half cell tends to be oxidized, while the most positive or noble half-cell tends to be reduced" (11). These determinations were made for pure metals and phases of amalgam as part of this work. Figure A2 shows a typical potentiometric schematic of a setup for the determination of the corrosion (galvanic) potential between metallic species in an electrolyte.

Table A1: Potentials of phases and alloys vs SCE

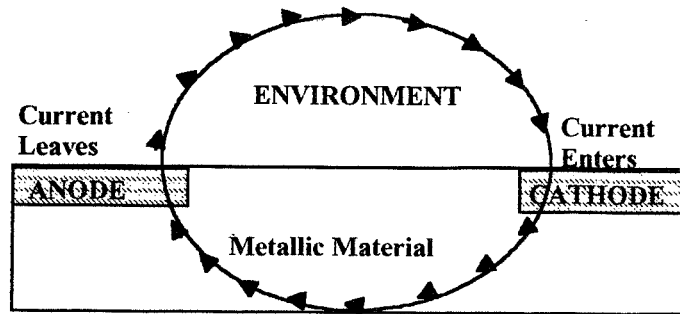
<u>PHASE/METAL</u>	<u>(av.)POTENTIAL(V) vs SCE</u>
pure gold (Au)	+0.26 (cath.)
titanium (Ti)	+0.05
Ti6Al4V	+0.01
316 stainless steel	-0.05
Silver (Ag)	-0.10
alpha Ag/Sn (100-89/0-11)	-0.10 to -0.12
gamma Ag/Sn (74/26)	-0.13
gamma 1 Ag/Hg (40/60)	-0.14
beta Ag/Sn (84/16)	-0.14
mercury (Hg)	-0.16
copper (Cu)	-0.30
epsilon Cu/Sn (75/25)	-0.31
eta Cu/Sn (54/46)	-0.32
gamma 2 Sn/Hg (88/12)	-0.33
Tin (Sn)	-0.35 (anodic)



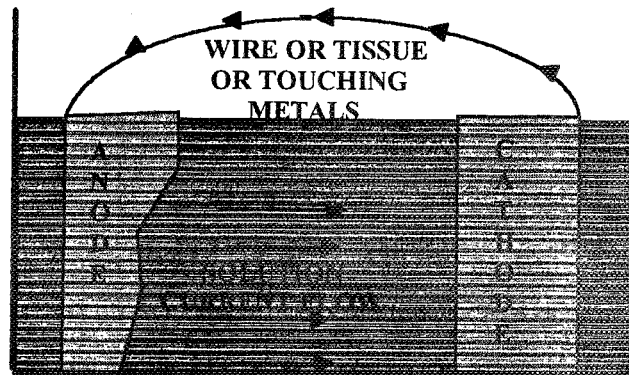
**Figure A2
Potentiometric Apparatus Schematic**

Biodental Engineering Factors

Previous work (11,12) has identified several factors acting alone or in concert to produce a variety of corrosive, fracture, physico-mechanical, and electrical effects in the oral environment. These factors are shown below in Table A2.



Anodic and cathodic regions on the same material



Separate anode and cathode in solution
Basic corrosion mechanism

Figure A1

Table A2. Biomedical Engineering Factors

Biomechanical:	Column loading Compressive and tensile forces Stress concentration
Biochemical:	Stress and fatigue corrosion Crevice corrosion Ionic transport Saliva - pH, flow rate, buffering capacity
Bioelectrical:	Piezoelectric, Hydro-electrodynamic Electrochemical potential difference between different materials Electrolysis

Combined effects of the above mentioned biodental engineering factors have been shown to exacerbate the release of metallic vapors, ions, and tooth material, both natural and man-made substitutes. Only with metallic restorations, implants, and appliances do the bioelectrical effects become dominant causal factors in the ionic release. It should also be noted that the underplay of Hg^0 mercury vapor and particulate Hg^0 by many is seldom if ever accompanied by a mention of the more vitally active ionic Hg^{++} free to combine thermodynamically in a wide variety of species. The abfraction (11) of both natural and man-made tooth substance due to bruxing, abrasion, clenching (squeezing), and malocclusive forces serves only to make the scenario an unquestionable multifactorial maze in which the scientist must "sort out" cause and effect and take proper corrective actions. Shown in Figure A3, for the purpose of basic illustration, is a ternary phase diagram (13) of the alloys of Silver (Ag), Mercury (Hg), and Tin (Sn). More complex quaternary and pentenary diagrams are not possible due to the multidimensionality of the drawing and the enormity of the data.

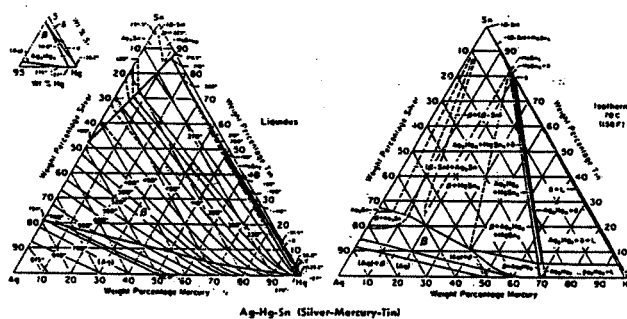
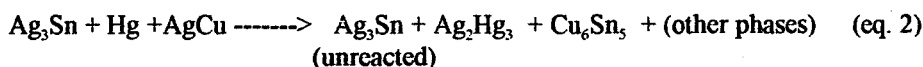


Figure A3

Ternary Phase Diagram for Hg-Sn-Ag

The multiplicity of phases and the fact that these phases are formed, not from room temperature amalgamation, but from standard elevated temperature techniques further complicates the scenario.

The overall simplified reaction (14) for the phases in amalgams can be written in general for high copper (non-gamma 2 phase materials):



Ignoring the minor phases, noting that the gamma 2 phase is no longer present in high copper amalgams, and applying the same criteria for corrosion to the phases (15) as to the bases for local and separate cathodes and anodes, the conditions for corrosion in the oral environment with mixed metals as well as the local anode-cathodic areas on the amalgam itself (due to its phases) become apparent. Amalgams, due to the multiplicity of their phases forming local anodes and cathodes, are self-corroding.

Experimental methods for determinations of mercury

There are a variety of methods of determining the presence of mercury and detecting ionic current flow. Among these are methods ranging from high cost and high sophistication to lower cost and less sophistication of technique. The most sophisticated of the methods for analyzing Hg and other metals in saline and saliva is Atomic Absorption Spectroscopy (A.A.S.). This method utilized the injection atomized species into a flame with the attendant absorption (from an Hg discharge lamp, for example) or emission from the flame of certain wavelengths characteristic of the metal to be detected. The basis of this work utilized both FAAS and GFAAS with detection limits of 0.3 to 1g/L, dependent on whether or not gold amalgamation concentration techniques (16) were used. A second method involves a slightly less expensive gold film technique called Differential Pulse Anodic Stripping Voltammetry (17), with detection capabilities down to 1 ppb (1 pg/L). A third, less expensive method for detection in vivo is a potential/current/energy meter, shown in Figure A4, which measures the potential, current, and energy between two metallic restorations.

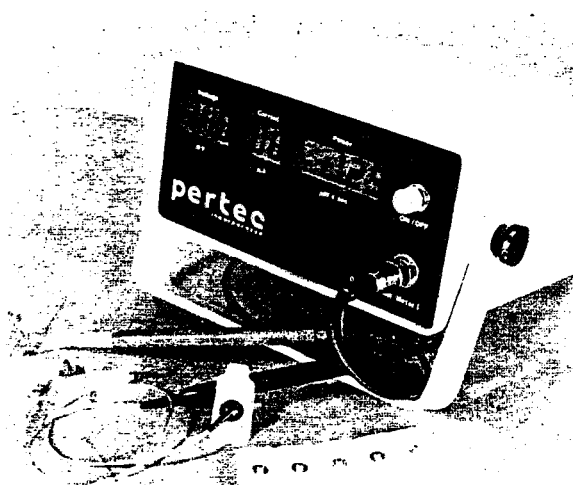


Figure A4
Oral potential meter

An inference regarding the ion exchange, anodic and cathodic regions, and possible excessive galvanic effects can be made simply, as follows:

Polarity indicates cathode vs anode; voltage gives the magnitude (driving potential) for the electrochemical reaction; and current gives the number of ions per second transferred.

eg. Hg vs Au. Au is positive, approximately 0.4 volts, with respect to Hg, at 10 microamperes (typical of measured values using this method). If N is the number of ions per second of the species, I is the current in amperes (Coulombs/second), q is the electronic charge (coulombs), n is the valence of the species (eg. Hg), then

$$N = I/nq \quad (\text{eq. 3})$$

or $N = 10 \times 10^{-6} / (2 \times 1.6 \times 10^{-19}) = 3.12 \times 10^{13}$ ions/sec., assuming Hg is available in an electrolytic environment. Further calculations lead to removal of approximately 10 ng/sec. for a constant current as measured.

Measurements made on the saliva of thirty subjects with mixed metals in the mouth (eg. combinations of one or more pairs of orthodontic stainless steel, amalgams, gold inlays, titanium posts, base metal posts, graphite composite endodontic posts, etc.) were made by A.A.S., stripping voltammetry, and potential meter. Since the A.A.S. and stripping voltammetry were ion specific (Hg), these results correlated well in total Hg concentration in the saliva. No attempt was made to mechanically disturb the restorations by chewing or similar disruption. Saliva was retained in the mouth without swallowing for a period of 30 seconds and then released into a vial four times for testing. The tests showed that the A.A.S. and the stripping voltammetry correlated within thirty percent in ranges tens to hundreds of parts per million (ppm). The measurement of ionic flow between suspected anodes and cathodes, as an estimate of Hg ion concentration, was consistently higher than predicted by the A.A.S., by a factor of two or more, probably due to the fact that the ions detected by this method were not solely mercury, but included other ions anodic with respect to the cathode chosen.

Scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDXA) of sectioned teeth with amalgams

Over sixty samples of amalgam restorations in their host tooth were mounted and polished using standard metallurgical techniques. SEM photomicrographs and EDXA scans were made to observe some of the phenomena associated with these restorations, cracking, mercury migration, and effects of mechanical pressure on the surface of the amalgam. Ten of the specimens were scanned to study the concentration of Hg vs distance from the restoration. Three notable commonalities were seen on almost all of the samples studied: (a) The samples all showed some degree of micro-cracking; (b) Migration of mercury through the dentin occurred and was accelerated down the micro-cracks; and (c) Mechanical pressure of less than 2000 Pa on the amalgam surface always produced "droplets" of mercury, exclusive of the age of the restoration. Figure A5 below shows electron micrographs of lingual and occlusal restorations along with a magnified view of a region on which a pressure of approximately 1900 Pa was applied. Note the regions of microcracking, voids, and Hg droplet formation. Mercury relative

concentration analyses were made on the teeth from the margin of the amalgam restoration to both the pulpal region and to the lateral extremity of the dentin.

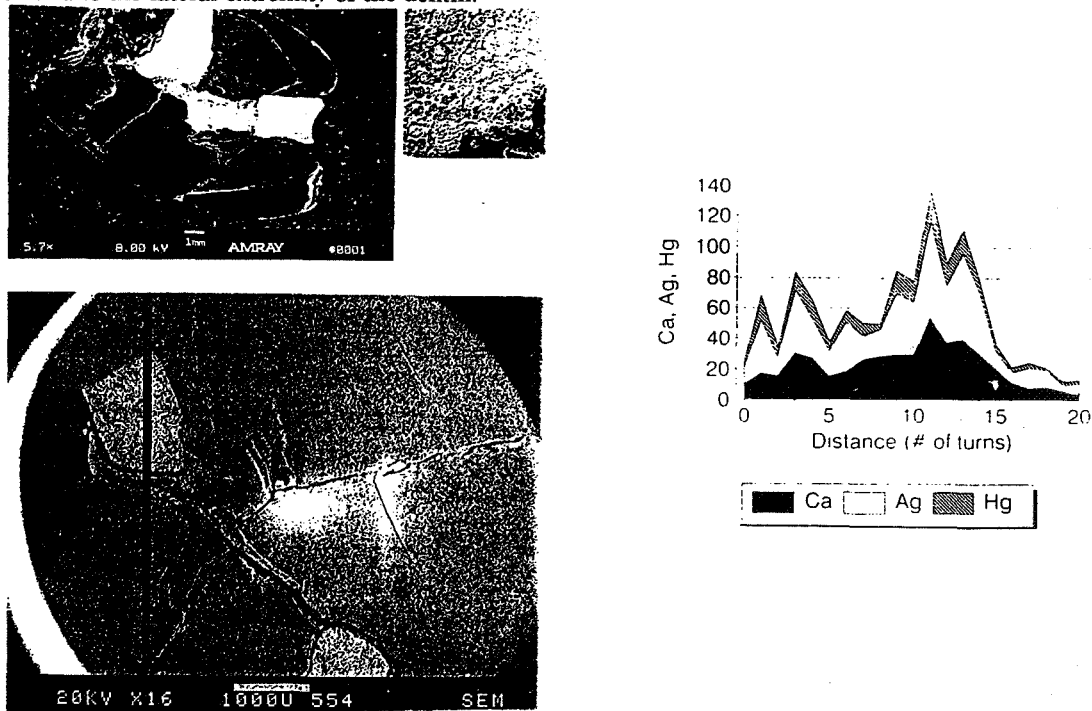


Figure A5

Restoration and EDXA measurement of Hg vs distance from the restoration

Figure A5 shows a tooth measured and the plot of relative Hg concentration vs distance both toward the outer extremity of the dentin and in the direction of the pulpal region. As can be seen from the plots and from the map of Hg in and around cracks, mercury migrates in the tooth material, most likely driven by combinations of concentration gradients and electrochemical potentials existing in the oral cavity prior to extraction. Figure A6 shows possible scenarios of corrosion (ionic current paths) in the oral environment and oxygen deprived anodic regions on the tooth (18). These paths further enhance the probability of anodic dissolution in both tissue and saliva. Some researchers (14) have found that sealing the amalgam with polymeric sealers retards evaporation of the highly volatile mercury vapor. Add to this the possibility of crevice and oxygen deprivation corrosion, and the use of mixed metals appears to be less than ideal in the oral environment, at least from a materials science perspective.

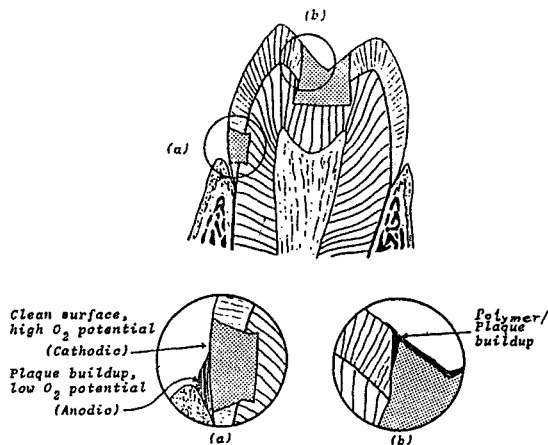


Figure A6

Possible paths of corrosion (ion flow) and oxygen cathode

Polymers and ceramics

Polymers used as restorations with and without fillers are composed of a number of materials, some of which (19) are shown in Table A3. These polymers combined with fillers such as Si_3N_4 , SiO_2 , Al_2O_3 , calcium hydroxyapatite, glass, glass ionomers, phosphates, etc. make up classes of materials called restorative dental composites. These composites, when cured with zero residue promoter or when light cured to full polymerization, possess good properties mechanically and no electrochemical ion transfer effects in the oral cavity. The strength of the materials, though falling short of amalgams for occlusal restorations, wear well. Adhesives, available from a number of manufacturers, perform very well in securing the restorations and in minimizing marginal leakage. The materials themselves are non toxic and present no reported hazard. The wear mechanism is clearly visible on filled composites, however, showing bonding failure after seven months between the filler and the matrix, leading to cracking in the restoration, as shown in Figure A7. Also shown is a margin of a restoration fabricated from both a composite and amalgam (19). There is great promise for further work in the successful development of strong, long-lasting restorations made from combinations of polymers and inorganic fillers.

Table A3. Some monomers used in dental restorations

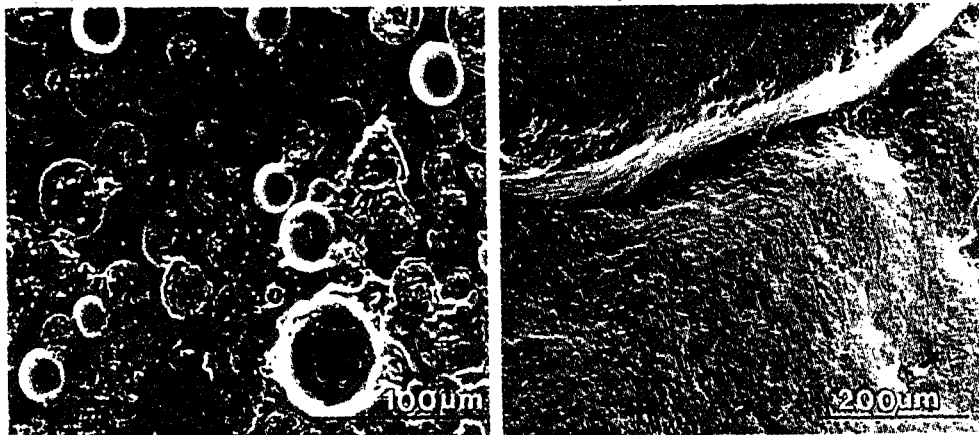
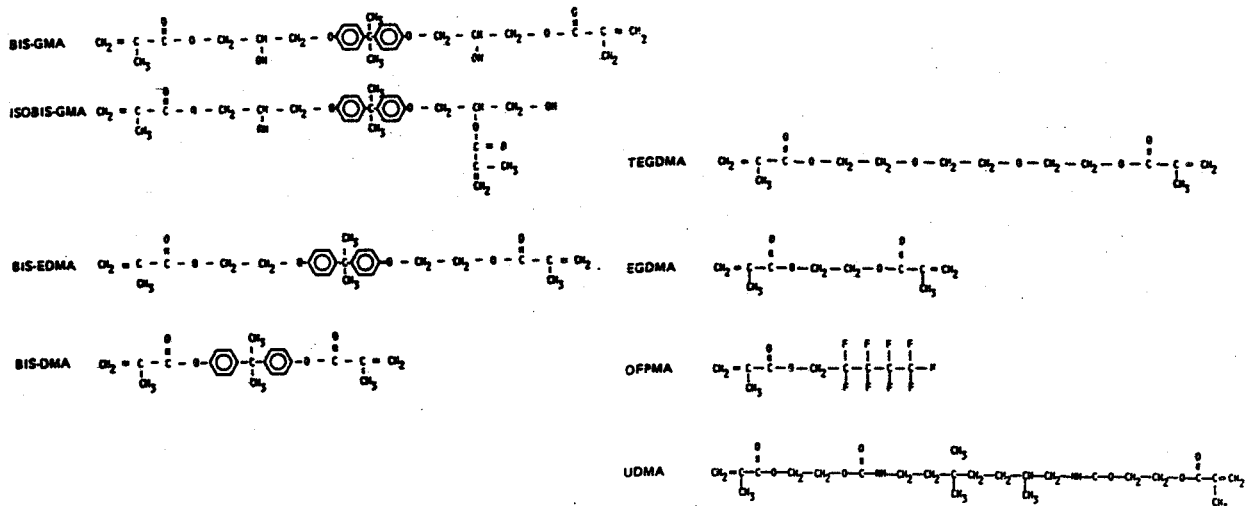


Figure A7
Seven month views of polymeric composites showing filler picking and marginal terracing

It should be noted that even occlusal regions in natural tooth enamel (a natural composite) crack and fail (20).

Ceramics composed of aluminum oxide, glass ceramic phases, hydroxyapatites, sapphire single crystals, etc. are extremely durable and inert as implant materials, but have shortcomings as restoration materials. They are mostly very hard materials and offer an abrasive surface to opposing natural teeth or other restorations. In addition, they may fracture, presenting a danger of swallowing sharp debris or cutting oral tissue near the remaining restoration. As work proceeds with these highly inert, non-ion releasing materials, it is hoped that biomimetic analogs can be developed.

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EVALUATION OF STUDENT OUTCOMES IN MATERIALS SCIENCE AND TECHNOLOGY

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**Materials Science
Technology**

**Benchmarks
and
Exit Standards**

MST BENCHMARKS & EXIT STANDARDS

1. Technological materials may be classified in categories including metals, glass/ceramics, polymers (plastics) and composites.

Student should be able to list or point to examples from each category. In general are they in metallic or oxide form, what are the basic atomic structures, and what are the general types of properties represented by each group. For example, polymers are generally formed from long spaghetti shaped molecules, they tend to be light weight and vary from soft and pliable to moderately hard and strong.

2. Each type of solid material has specific properties that can be measured.

What are some of the important properties of steel, of aluminum, of window glass, of "plastic wrap," of composites. Students should be able to read their reference text: Engineering Materials Technology to locate and describe properties such as: conductivity, ductility, malleability, strength, stiffness, corrosion, weatherability, or melting point.

3. All solid materials have either a long range crystalline structure (i.e., crystalline) or a short range amorphous structure (i.e., glassy).

Student should be able to explain the difference between metal crystal structure and an amorphous glass in terms of atomic structure, and properties. Students should recognize a crystalline and amorphous arrangement of atoms.

4. The choice of materials for a particular application depends on the properties of the material.

Student should be able to list several actual parts/components from each category and explain what material the component is made of and what properties led to the choice of that material for that application. For example, the exterior door on a car is high-strength steel, whereas the dashboard is a soft polymer, light stiff materials in a K2 snow ski, a football helmet, or non-corrosive hip implant.

5. The properties of the material depends on its crystal structure.

Students should be able to alloy and cast sterling silver or draw a copper wire to demonstrate malleability, ductility, yield, and elongation in a crystal material. Students will also batch, melt, pour, anneal, and temper an amorphous glass (generally non-crystalline material) to observe and demonstrate glass materials have different properties (brittle-catastrophic failure) than a crystal material.

6. The properties of the material depend on its microstructure (i.e., its grain structure or the microscopic arrangements of its components), which may be modified by the methods by which the material is processed (i.e., heat treatments, forming, casting operations)

Students should be able to explain, in their journal, and also demonstrate the process to anneal and temper an amorphous material (glass). Students will explain in their journal, and demonstrate, the process of sintering a ceramic body to reduce porosity, increasing densification and strength (changing the micro structure and properties).

7. Most technological materials are alloys (metals) or compounds (ceramics, polymers) containing different elements rather than pure elements.

Students should be able to demonstrate why/how chemical oxides are added to silica to form a borosilicate glass. Students should grasp why bottle glass is not made from pure silica through performing experiments with chemicals to create glass. Students should be able to explain the effect of copper as an impurity in the crystal structure and how properties of silver can change by alloying.

8. Composite materials are made up of a combination of metals, ceramics and/or polymers.

Students should be able to offer examples of composites, tell what is the matrix phase and what is the reinforcing phase, what are the special properties of both these phases and tell how they work together to yield the good properties of the composite. The students will demonstrate the application/engineering or processing of epoxy/fiberglass, epoxy/kevlar, honeycomb core/fiberglass, foam core/paper skin, and a balsa

thermoplastic skin composite airfoil to gain understanding of the properties. The students will measure the strength versus stiffness and in their journal, write observations explaining the concepts of tension and compression in relation to the foam core/paper skin beam, and the airfoil.

9. Writing, observation skills, and creativity are developed in a student technical journal.

The student will write and sketch in their laboratory journal specific to fostering creativity and the processing of materials applied in their experiments and projects. Technical writing will consist of student written summaries from professional journal articles, periodicals, notes, sketches, calculations, tools, apparatus, modifications, process, observations, frustrations, successes, and ultimately the "Why."

This portfolio will demonstrate student participation, management of time, connections to our text, and in general student success.

Students will also successfully complete a research paper or written report focusing on a material, process, or application using technology in our school library.

Students will research, write an outline, and prepare visual aids for an oral presentation using the text: Engineering Materials Technology as a reference.

10. Students will receive exposure to the world of work, post secondary educational opportunities, and in general learning that will lead to a technologically literate intelligent citizen.

Guest speakers from the materials sciences arena and the private sector will speak with students about materials concepts, careers, and the future. Field trips to Boeing Commercial Aircraft and Siemens Power Corporation will provide students the opportunity to experience first hand processing, assembly, careers, safety, and a whole host of inspiring real world connections.

11. The students will process materials by successfully performing numerous experiments and projects that pertain to the nature, properties and technological application of polymers, composites, alloys, glass, and ceramics.

The technical journal, instructor observation, and dialogue between

students and the instructor will help ensure students' success and participation.

12. Students will be immersed into their world of materials understanding that materials dictate our quality of life and that a society that dominates materials dominates technology.

The student will demonstrate through reading, writing, general discussion, and performing numerous experiments and projects students an understanding and appreciation for materials.

13. Students shall understand there are a variety of techniques for characterizing materials properties and structures.

Students will read information generally explaining electron microscopy (SEM), metallography, and prepare a metallography sample for microscope observation. Students will test materials and write data/observations using laboratory devices that will apply deflection, tension, compression, and hardness forces. Through field trips students will see industrial /research applications.

14. Students will understand that materials can change their structure with time and exposure to the environment (weatherability) affecting the materials performance.

Students will read about weatherability and through discussion and observing their world become aware of materials or structures that have degraded or failed because of the environment. Examples are corrosion on the Aloha Air 737 airframe, ruptures in highways, bridge coatings, tires cracking, and concrete cracking.

MST Benchmarks and Exit Standards Contributors

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American Association for the Advancement of Science
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Oakridge National Laboratory
1995

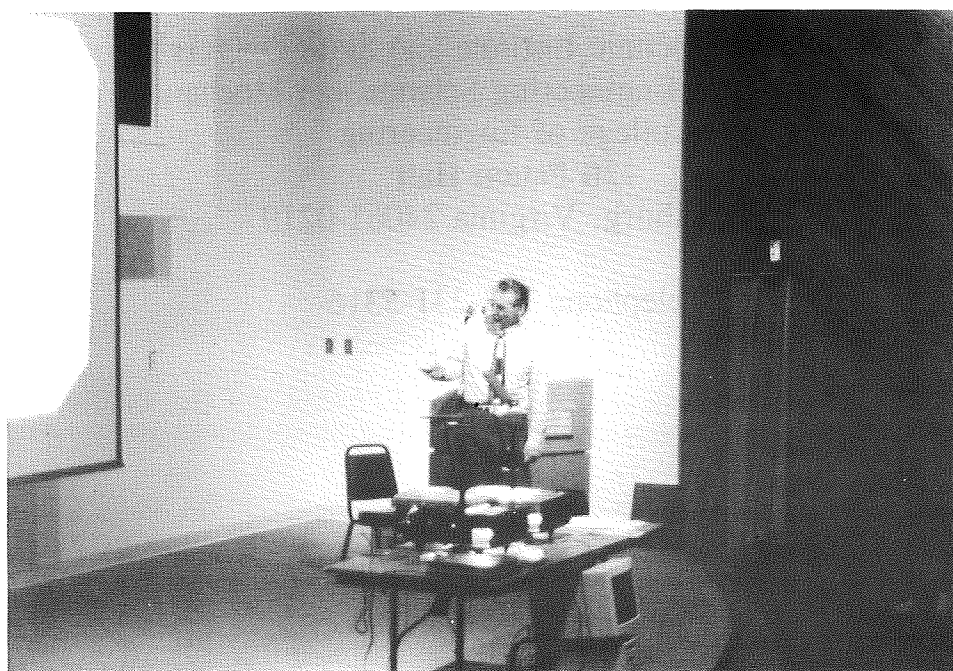
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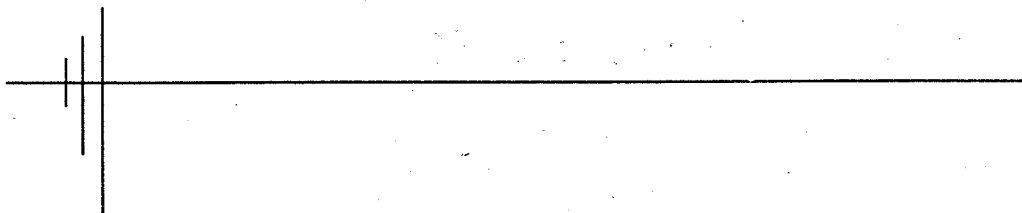
DESIGNING WITH BRITTLE MATRIX COMPOSITES

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Designing with Brittle Matrix Composites

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Comparative Utility

Material cost	Polymer	=====
	Metal	=====
	Ceramic	=====
Manufacturing cost	Polymer	=====
	Metal	=====
	Ceramic	=====
Corrosion resistance	Polymer	=====
	Metal	=====
	Ceramic	=====
Durability	Polymer	=====
	Metal	=====
	Ceramic	=====
Knowledge base	Polymer	=====
	Metal	=====
	Ceramic	=====
Design/data base	Polymer	=====
	Metal	=====
	Ceramic	=====

Comparative Utility

Specific stiffness	Polymer _____ Metal _____ Ceramic _____
Specific strength	Polymer _____ Metal _____ Ceramic _____
Thermal expansion	Polymer - Metal _____ Ceramic _____
Use temperature	Polymer _____ Metal _____ Ceramic _____
Thermal conductivity	Polymer _____ Metal _____ Ceramic _____
Product cost	Polymer _____ Metal _____ Ceramic _____

Ceramic Matrix Composites

Applications -

- > Gas turbines - liners, vanes, shrouds, blades
- > Radiant burners - tubes, combustors
- > Heat exchangers - tubes, headers, manifolds
- > Electronic components - boards, elements, sensors, fiber optic devices
- > Engines - power transfer, exhaust/air transfer systems
- > Hot gas filters - engines, power plants

Ceramic Matrix Composites

Manufacturing industry applications -

- > **Steel soaking pits**
- > **Aluminum remelt furnaces**
- > **Glass melting furnaces**
- > **Recycling facilities**

Ceramic Matrix Composites

Projected advantages -

- > **Engines - 10-35 percent fuel savings**
- > **Heat exchangers - recovery of large part of the 25 to 65 percent heat loss generated by high temperature combustion systems**

Ceramic Matrix Composites

-> Properties and end uses of advanced ceramics

Material	Flexural strength, MPa ^a	Hardness (Vickers), GPa ^b	Fracture toughness, MPa m ^{1/2}	Maximum use temperature, °C	Young's modulus ^c , GPa	End uses
Alumina	310	17	4	1200	310	Wear parts, cutting tools
Silicon carbide	690	22.4	4	2000	450	Wear parts, cutting tools, heat exchangers
Silicon nitride	925	15.9	5.5	1400	315	Wear parts, automotive engine applications
Zirconia	1440	12.8	8.5	800	220	Cutting tools, wear parts, experimental heat engines
Tool steel	5500	10	98	700	210	Cutting tools, wear parts

^a Megapascals.

^b Gigapascals.

^c Young's modulus defines the ratio between stress and strain and is an indicator of the elasticity of a material.

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Ceramic Matrix Composites

-> Advanced structural composites; applications and markets

Table 3. Various current and potential applications of ASC and application requirements

Industry	Application	Application requirements
Machine tool	Cutting tools Bearings Wire drawing dies	Wear and corrosion resistance, minimum lubrication requirements
Petrochemical	Seals Valves Pump impellers Heat exchangers	Energy-efficient heat regeneration
Automotive	Turbocharger rotors Push rod tips Rocker arms Cylinder liners	Light-weight, high-temperature, corrosion and wear resistance
Defense	Gun liners Ceramic armor	Light-weight, strength, corrosion, and high-temperature resistance

Table 2. Estimated size of current and projected U.S. markets for ASC (in millions of dollars) (6)

Item	1992	2000
Wear parts	120	540
Cutting tool inserts	85	300
Bearings	75	300
Bioceramics	20	60
Heat exchangers	20	100
Automotive/heat engine	0	920
Aerospace, defense	80	450

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Ceramic Matrix Composites

-> Projected development of ceramic components

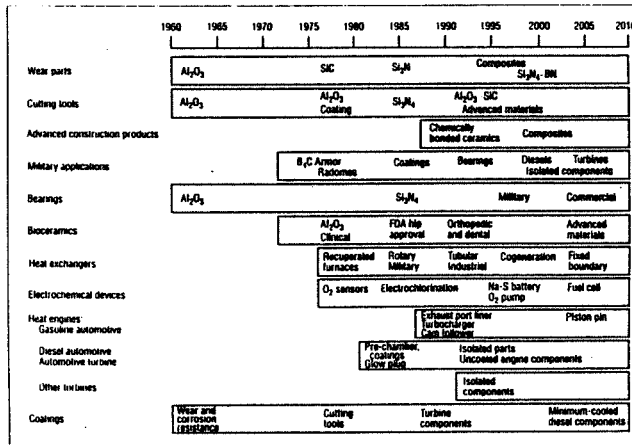


Figure 1. Estimates for implementation of ceramic components in structural application categories (4).

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Ceramic Matrix Composites

-> Application examples - benefits

DOW CORNING

Task 1 Applications Assessment Solar Turbines - Benefits

Energy Savings - Fleet of Metallic and Ceramic Engines to Meet Predicted Needs

Year	Cumulative GW Installed	Engines Required to Satisfy Need	
		Metallic	Ceramic
2005	8	814	571
2010	24	2443	1714
2015	40	4071	2856

Environmental Savings - Comparative NOx Emissions in Tons/Year for Metallic vs. Ceramic Engine

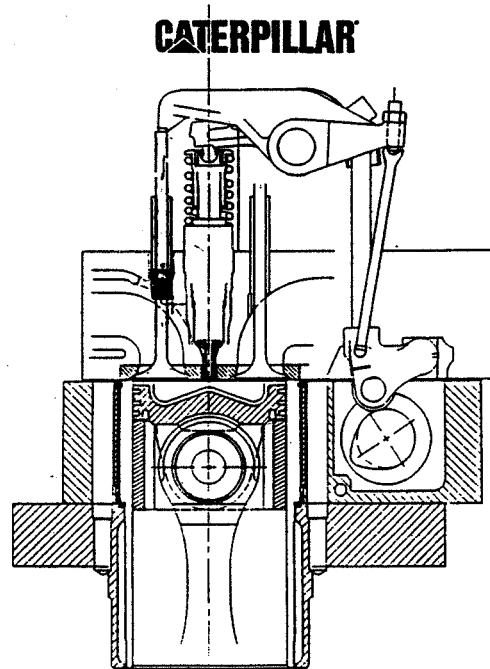
Year	GW Demand (Cumulative)	Metallic Mars T14000		Ceramic Mars	
		Need	Emissions	Need	Emissions
2005	8	814	153	571	8.6
2010	24	2443	459	1714	25.9
2015	40	4071	765	2856	43.1

Strategic Elements Savings/Engine: Cr, Co, W, Mo, Cb, Ni

Component	Total Unfinished Weight (lbs.)
Compressor	447
Turbine	1408
Turbine Diffuser Housing	839
Total	2694

Ceramic Matrix Composites

-> Application example - valve guides

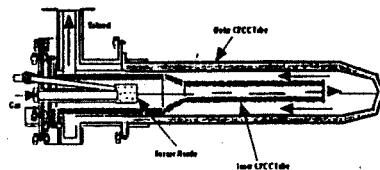


Ceramic Matrix Composites

-> Application example - immersion heater tubes

PROSPECTIVE CFCC COMPONENT APPLICATIONS

- APPLICATION AREA: PRIMARY AND SECONDARY METALS PROCESSING
- PROSPECTIVE CFCC COMPONENTS: RADIANT OR IMMERSION HEATER TUBES



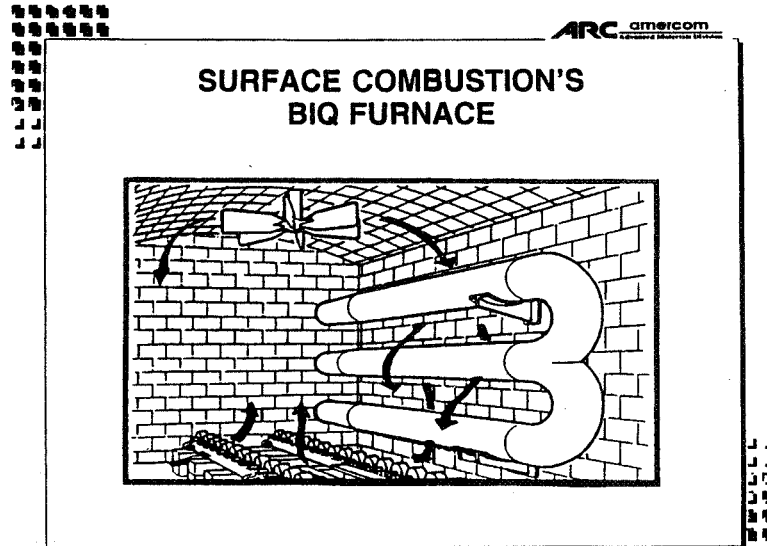
• TYPICAL ENVIRONMENTS:

- OXIDIZING, MOLTEN METAL OR INERT
- 2300-2600°F (1200-1400°C) OPERATING TEMPS
- PRINCIPALLY THERMOMECHANICAL (AND IMPACT) LOADING; (PERHAPS 15-20 ksi (100-130 MPa) STRESS LEVELS)
- ONE TO FOUR YEAR LIFETIME

TEXTRON
Specialty Materials

Ceramic Matrix Composites

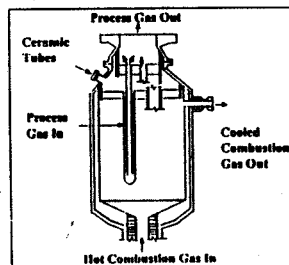
-> Application example - soaking furnaces



Ceramic Matrix Composites

-> Application example - chemical processing
PROSPECTIVE CFCC COMPONENT APPLICATIONS

- APPLICATION AREA: PETROCHEMICAL PROCESSING INDUSTRY
- PROSPECTIVE CFCC COMPONENT: CATALYTIC REFORMER OR PYROLYSIS TUBES



TYPICAL ENVIRONMENTS:

- OXIDIZING; MODERATE-HIGH PARTIAL PRESSURES OF STEAM
- 2300-2600°C OPERATING TEMPS
- PRINCIPALLY THERMOMECHANICAL (AND IMPACT) LOADING; (PERHAPS 15-20 ksi (100-130 MPa) STRESS LEVELS)
- LIFETIME UP TO TEN OR MORE YEARS

TEXTRON
Specialty Materials

Ceramic Matrix Composites

-> *Application example - radiant burner tubes*

ARC american

RADIANT BURNER TUBES
(SURFACE COMBUSTION)
CONTINUED

BENEFITS - ASSUME FULL MARKET POTENTIAL

ANNUAL ENERGY SAVINGS

BATCH INTEGRAL QUENCH FURNACES
3000 FURNACES
8000 HOURS/YEAR
CURRENT TEMPERATURE
INCREASED RECUPERATION => 280 MW-Hrs
(500 BBLs OF OIL)

ELECTRIC PIT FURNACES
900 FURNACES
8000 HOURS/YEAR
CURRENT TEMPERATURES
CONVERSION FROM ELECTRIC TO GAS FIRED => 790 MW - Hrs
(1,400 BBLs OF OIL)

Ceramic Matrix Composites

Technical Constraints -

- > Production methods and costs
- > Reliability, reproducibility, inspection methods
- > Availability of design data (static, long term)
- > Thermal stability
- > Supporting technologies -
 - * Characterization methodologies
 - * Durability, damage tolerance, life prediction
 - * Design methodologies

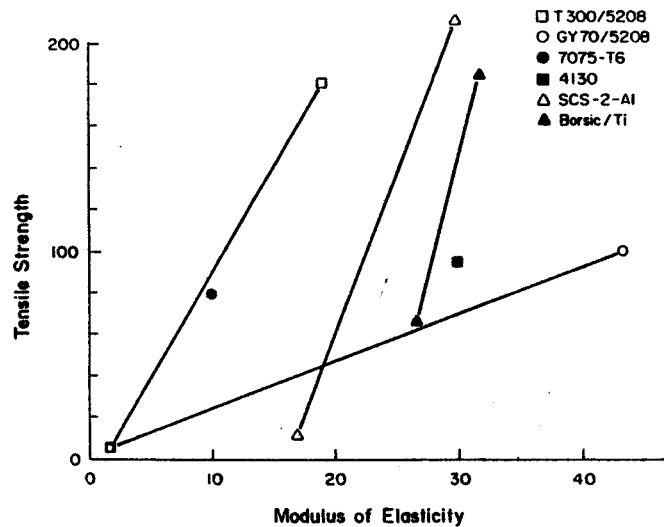
Ceramic Matrix Composites

Preliminary Design Properties -

- > Stiffness and strength (all anisotropic values)
- > Coefficients of thermal expansion
- > Thermal conductivity
- > Thermal diffusivity
- > Creep, creep-rupture, fatigue behavior
- > Environmental degradation

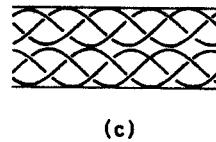
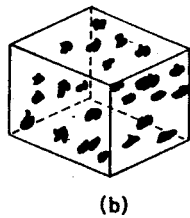
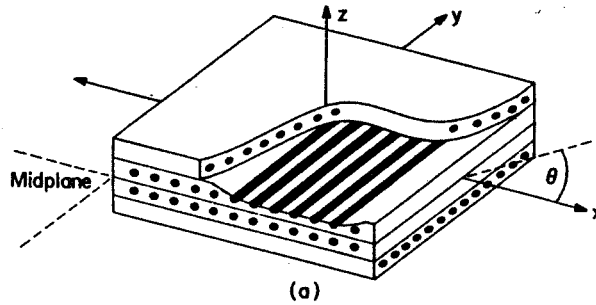
Ceramic Matrix Composites

- > **Each composite system offers a range of properties and performance**



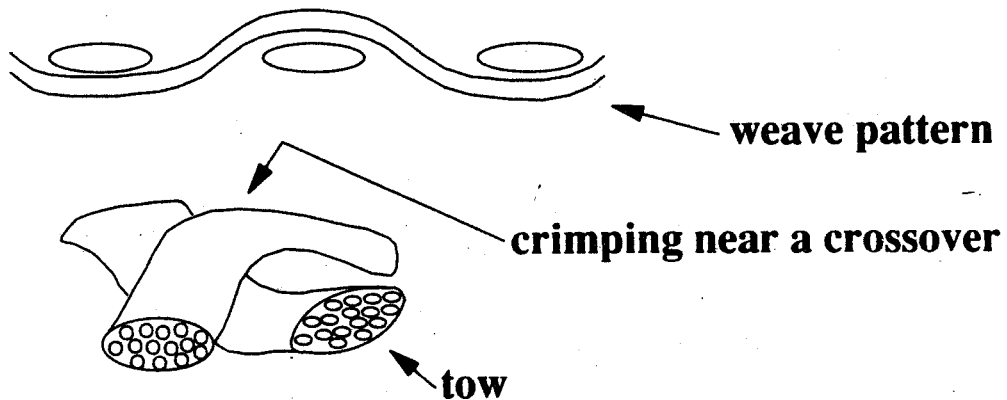
Ceramic Matrix Composites

-> Reinforcement is the key to properties and performance



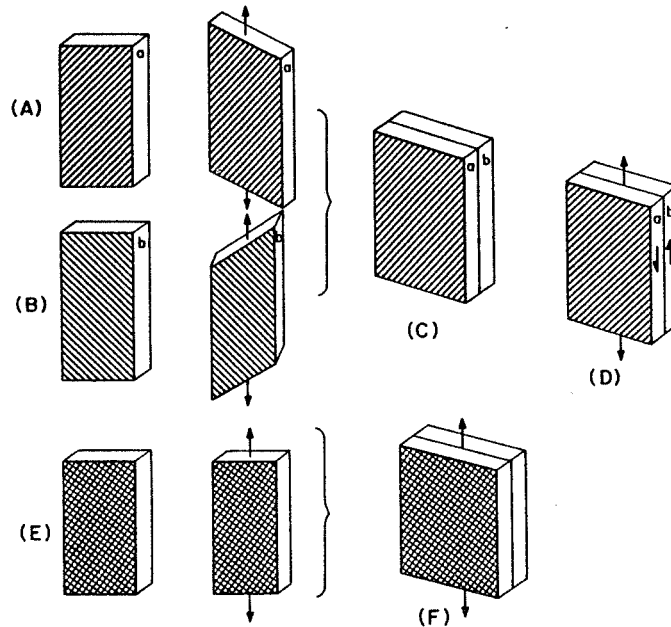
Ceramic Matrix Composites

-> Local fiber architecture influences performance



Ceramic Matrix Composites

-> Internal constraints cause thermal stresses



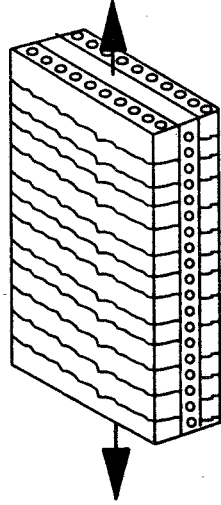
Ceramic Matrix Composites

Durability -

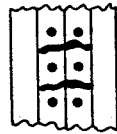
- > Damage tolerance (fatigue)
- > Resistance to creep, creep rupture
- > Resistance to aging
 - chemical
 - physical

Ceramic Matrix Composites

-> *Matrix cracking is a dominant damage mode*



Fibers control the effect of matrix cracking



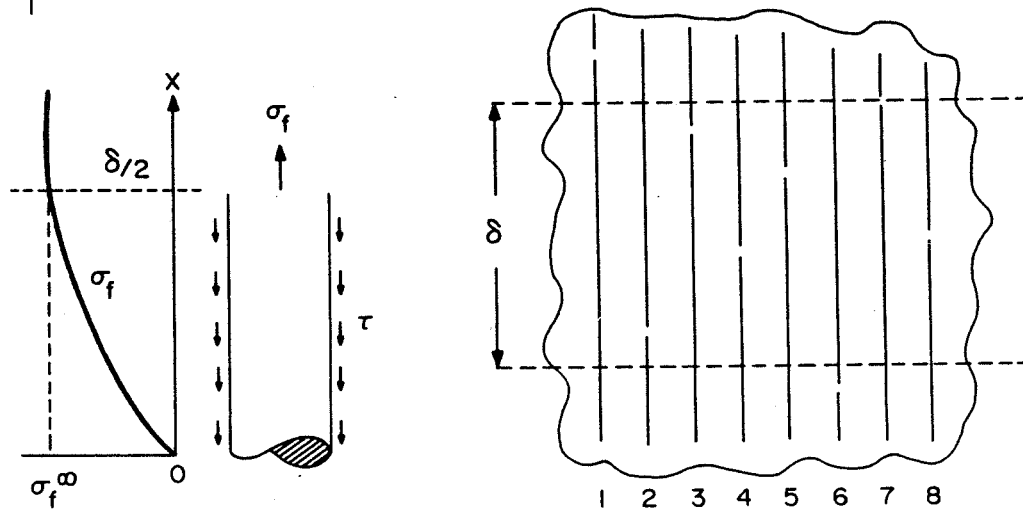
Ceramic Matrix Composites

-> *Local damage modes control damage tolerance*



Ceramic Matrix Composites

-> *Fibers can break many times before "rupture"*



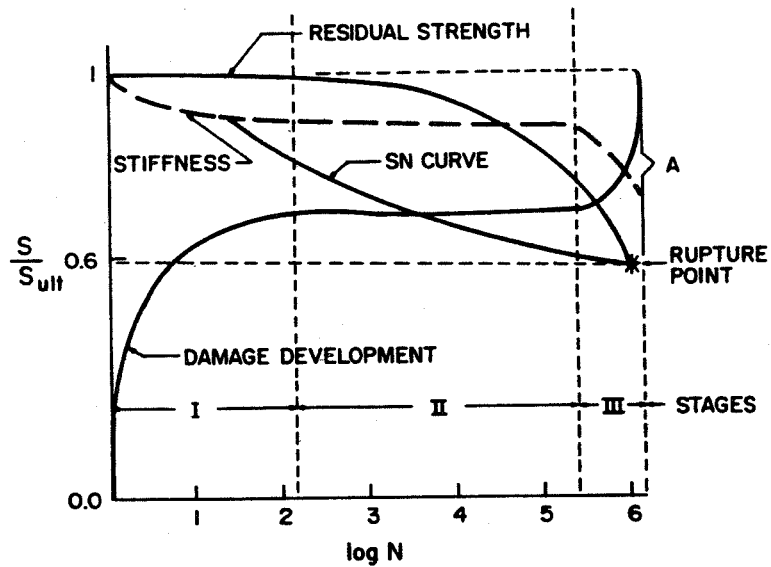
Ceramic Matrix Composites

-> *Damage tolerance (fatigue)*

- * Failure modes are similar to those for short-term behavior
- * Internal stress redistribution results from damage modes
- * Composite systems fail from the (statistical) accumulation of defects

Ceramic Matrix Composites

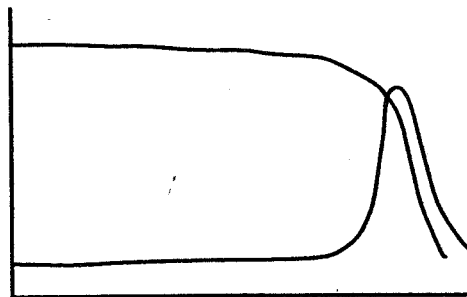
-> Damage develops by accumulation



Ceramic Matrix Composites

-> Resistance to (physical, chemical) aging

Modulus

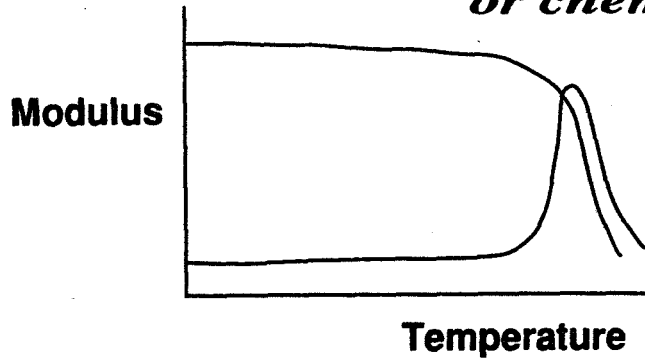


Temperature

Ceramic Matrix Composites

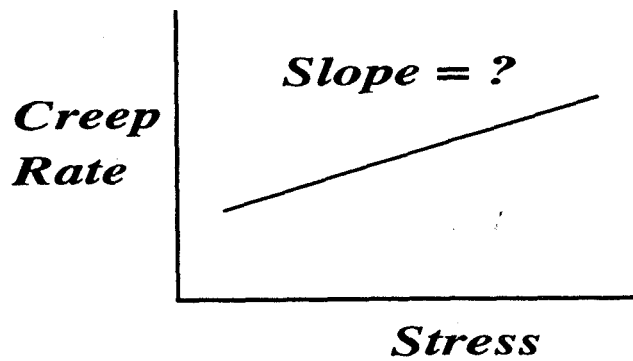
-> ***Resistance to (physical, chemical) aging***

**** Chemical reaction rates or diffusion may control rate or chemical aging***



Ceramic Matrix Composites

-> ***Resistance to creep, creep rupture***



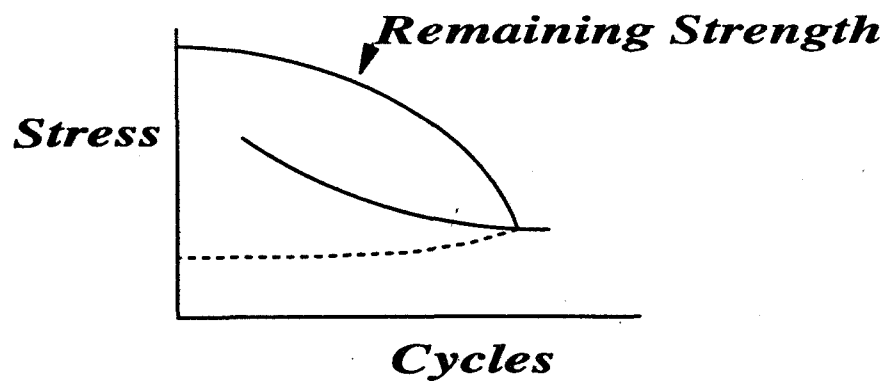
Ceramic Matrix Composites

-> *Resistance to creep, creep rupture*

- * Combined effects may be "anomalous"
- * Mechanisms control the slope of the rate curve
- * Temperature greatly affects the controlling mechanism

Ceramic Matrix Composites

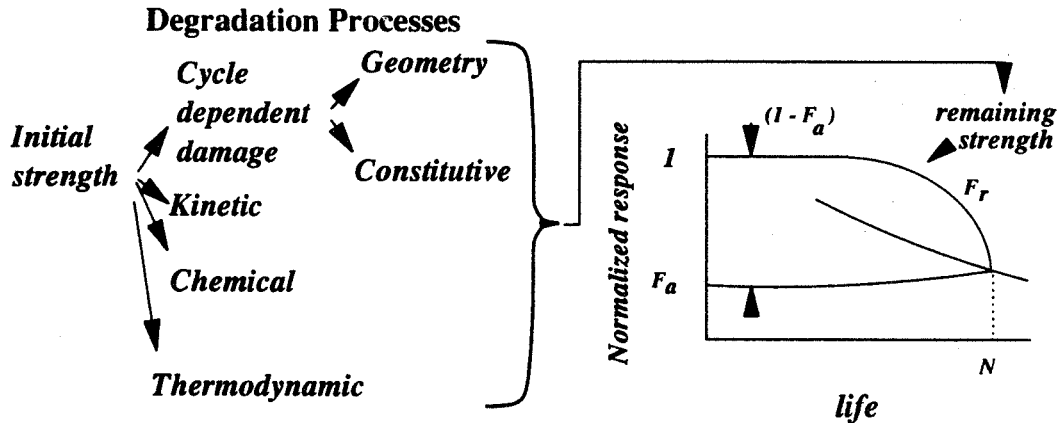
-> *Damage tolerance (fatigue)*



Ceramic Matrix Composites

Durability - The Problem:

How can we combine our data and understandings of material system behavior under long-term conditions to estimate remaining strength and life, or to make a better material system?

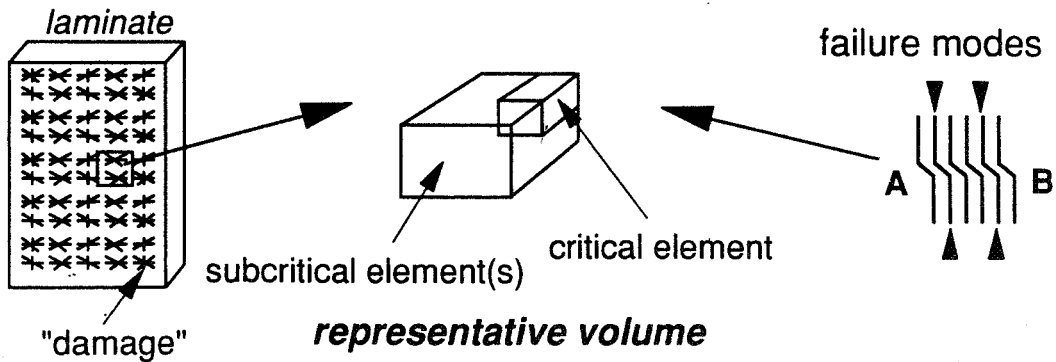


Ceramic Matrix Composites

Our Approach:

"Critical Element Concept"

- identify a local material element whose failure defines global failure for a given failure mode.



MRLife™

Ceramic Matrix Composites

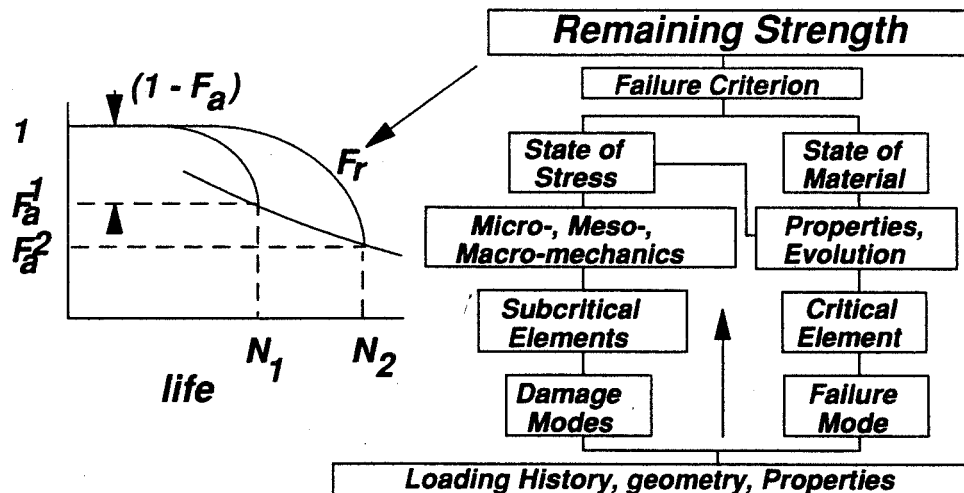
Degradation Processes Modeled:

Phenomena	Stiffness Change	Strength Change
Stress relaxation	X	
Oxidation		X
Viscoelastic creep	X	
Creep rupture		X
Moisture effect	X	X
Aging	X	X
Environmental degradation		X
Temperature effect	X	X

MRLife™

Ceramic Matrix Composites

MRLife Approach:



MRLife™

Ceramic Matrix Composites

Residual Strength Calculation:

$$F_r(n/N) = \left[1 - \int_0^{(n/N)_1} (1 - F_a(n/N))^{i-1} d(n/N) \right]$$

Residual strength → $F_r(n/N)$
 For a given failure mode → $F_a(n/N)$

Failure criterion 1. K / K_C 2. Tsai-Hill 3. $\Delta E / \Delta E(\text{critical})$ 4. (Others...)	Current life 1. Constituent SN 2. Kinetic process life
---	---

MRLife™

Ceramic Matrix Composites

Rate Equations Needed:

- >> Chemical - activation rates
- >> Cracking - density vs. applied conditions
- >> Creep - compliance vs. time (tensor components?)
- >> Delamination - rate as a function of energy release
- >> Geometry or property degradation rates

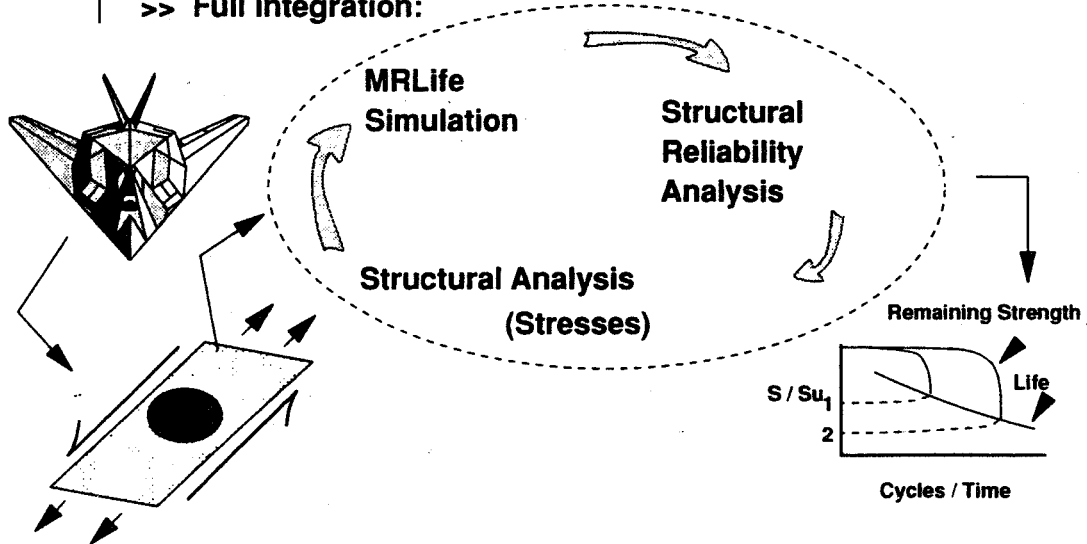
MRLife™

Ceramic Matrix Composites

Implementation:
Integration into Design Codes -

MRLife™

>> Full Integration:



Ceramic Matrix Composites

MRLife™

**A Performance Simulation Code
for Material Systems**

An Opportunity:

The MRLife code, and the critical element philosophy behind it, present a unique opportunity to design for durability, damage tolerance, reliability, and safety in a rigorous, economical, convenient, and competitive manner.

Designing with

Brittle Matrix Composites

Summary:

- Many brittle matrix composites have unique durability and damage tolerance capabilities
- We can design safe, reliable structures with brittle matrix composites
- More experimental data are needed
- Simulation of properties and performance can save time and money in material and product development

Ceramic Matrix Composites

Other issues -

- > Joining, load application methods
- > Process control methods, methodologies
- > Processing / property relationships
- > Basic understanding of behavior

Designing with

Brittle Matrix Composites

Other Issues:

- **Joining, load application methods**
- **Process control methods, methodologies**
- **Processing / property / performance relationships**
- **Basic understanding of long-term behavior**

AN INTEGRATED APPROACH TO LASER CRYSTAL DEVELOPMENT

Heidi R. Ries

**Materials Research Laboratory
Norfolk State University
2401 Corprew Avenue
Norfolk, Virginia 23504**

Telephone 804-683-8020



An Integrated Approach to Laser Crystal Development

**Heidi R. Ries
Associate Director
Materials Research Laboratory
Norfolk State University
Norfolk, VA**

Abstract

Norfolk State University has developed an integrated research program in the area of laser crystal development, including crystal modeling, crystal growth, spectroscopy, and laser modeling. This research program supports a new graduate program in Chemical Physics, designed in part to address the shortage of minority scientists.

Background

Norfolk State University, founded in 1935, is a historically black college or university (HBCU) with an enrollment of nearly 9,000 students. As one of the largest HBCU's in the nation, Norfolk State has a special responsibility to address the educational needs of the minority population. One area of particular need is the sciences, where African Americans are significantly underrepresented. The university has already had a positive impact on undergraduate minority science education via the Dozoretz National Institute for Minorities in the Applied Sciences (DNIMAS). Over ninety percent of DNIMAS students enter graduate or professional school upon graduation.

However, the national percentage of degrees conferred to African Americans in the physical sciences declined from 4.2% at the B.S. level to 0.7% at the Ph.D. level [1]. Since HBCU's are more successful than majority institutions in graduating minority students at the baccalaureate level [2], this decline may be attributable to the fact that fewer than 15% of all HBCU's nationwide offer graduate degree programs in the sciences. Norfolk State University's commitment to implementing new, quality graduate science programs is in part a response to this imbalance.

The Graduate Program

The first graduate science program at Norfolk State, the Master of Science in Chemical Physics with research emphasis in materials science, was initiated in the Fall of 1994. The purpose of this program is to provide students with the knowledge, analytical skills, and research experience necessary to contribute significantly to federal and commercial research efforts on the forefront of chemical physics and materials science. Therefore, the curriculum includes an overview of materials science and current research areas, in-depth study of relevant physical theories, and basic research. All coursework has been designed to emphasize applications to solid state physics, chemistry, and materials science where appropriate. In addition to required coursework, students must complete a master's thesis on a topic approved by the Chemical Physics Graduate Committee. Students are also expected to present their findings at national conferences and to participate in related workshops and short courses.

Research Program

All graduate programs in science must also address a national research interest. For Norfolk State to have a significant impact, it was decided in 1991 to develop an integrated research program in laser crystal development. In contrast to inefficiently pursuing several unrelated efforts, the laser crystal research was designed to take maximum advantage of existing faculty expertise and obtainable resources. Study of polymeric materials, particularly those of interest to NASA, was identified as a secondary area of research to further utilize existing equipment.

With funding from NASA, the Materials Research Laboratory (MRL) was established in 1992 at Norfolk State University to pursue laser crystal growth and characterization. Recent funding from the Department of Energy for additional faculty and facilities has permitted expansion of the research program to include a full range of activities from laser crystal modeling to design of resonators for demonstration laser systems.

The crystal field splitting model software developed by Clyde Morrison et al. at Harry Diamond Laboratories has been installed at Norfolk State, and plans are being made to update the program. This model will provide ab initio calculations of energy levels in the crystals to be studied. Version 6.04 (1995) of the EPR-NMR computer program from the Department of Chemistry at the University of Saskatchewan has also been installed and will be used to simulate EPR and NMR crystal spectra.

A Czochralski crystal growth laboratory has recently been commissioned at Norfolk State by Dr. George Loutts. Lei Lin, one of the first graduate students admitted to the M.S. Chemical Physics program, is expected to complete his thesis in May, 1996. Entitled "Crystal Growth and Characterization of Neodymium Doped Yttrium Orthoaluminate", the overall objective of Mr. Lin's thesis work is to study and try to eliminate defects in Nd-doped $YAlO_3$ single crystal grown from melt.

The laser spectroscopy laboratory, operated under the supervision of Drs. George Miller, Carl Bonner, and Waldo Rodriguez, is equipped with several lasers including a state of the art femtosecond laser. This facility is capable of measuring many physical parameters of interest including radiative and nonradiative transition rates, Einstein emission and absorption coefficients, index of refraction as a function of wavelength, nonlinear optical susceptibilities, birefringence, and spectral half-widths over a broad wavelength range, near UV to $\sim 1100\text{nm}$. The laser laboratory has the facilities necessary to conduct harmonic generation, optical pumping, and laser modeling experiments on nonlinear optical (NLO) crystals such as those grown in the Czochralski crystal growth laboratory. Two graduate and three undergraduate students are presently pursuing laser spectroscopy research.

A Bruker EMX X-band electron spin resonance (ESR) spectrometer with 1.3 T magnet is presently being installed. Dr. Heidi Ries is planning studies of the rare earth ion dopants and point defects in NLO crystals. Measurements of hyperfine coupling constants and g-factors will be made from 10 to 300 K. ESR may also be used to study radiation effects in polymers.

Dr. Larry Mattix operates a 300 megahertz high resolution (narrow spectral line) nuclear magnetic resonance spectrometer for both liquids and solids. This instrument is capable of observing a large number of nuclei, including ^1H , ^2H , ^7Li , ^{13}C , ^{15}N , ^{19}F , ^{29}Si , ^{27}Al , and ^{31}P , with ^1H (proton) decoupling, and measures chemical shifts, scalar couplings, relaxation times, and quadrupole coupling constants. NMR studies of the lineshapes and spin-lattice relaxation times, complementary to the ESR studies, may yield valuable information about electric field gradient in the lattice and the local structure of the NLO crystals. James Toy is studying " ^{129}Xe NMR as a Probe for the Characterization of Microvoids in Polymers" and is also scheduled to complete the M.S. Chemical Physics in May, 1996.

References

1. **Race/Ethnicity Trends in Degrees Conferred by Institutions of Higher Education: 1980-81 through 1989-90** National Center for Education Statistics, U.S. Department of Education Office of Educational Research and Improvement NCES 92-039, May 1992
2. 40% of all degrees earned by African Americans are from HBCU's, although only 18% of African American college enrollment is at HBCU's. **Black Colleges Still Carrying Their Load - And Then Some** Charles S. Farrell, Black Issues in Higher Education May 7, 1992 p. 10.

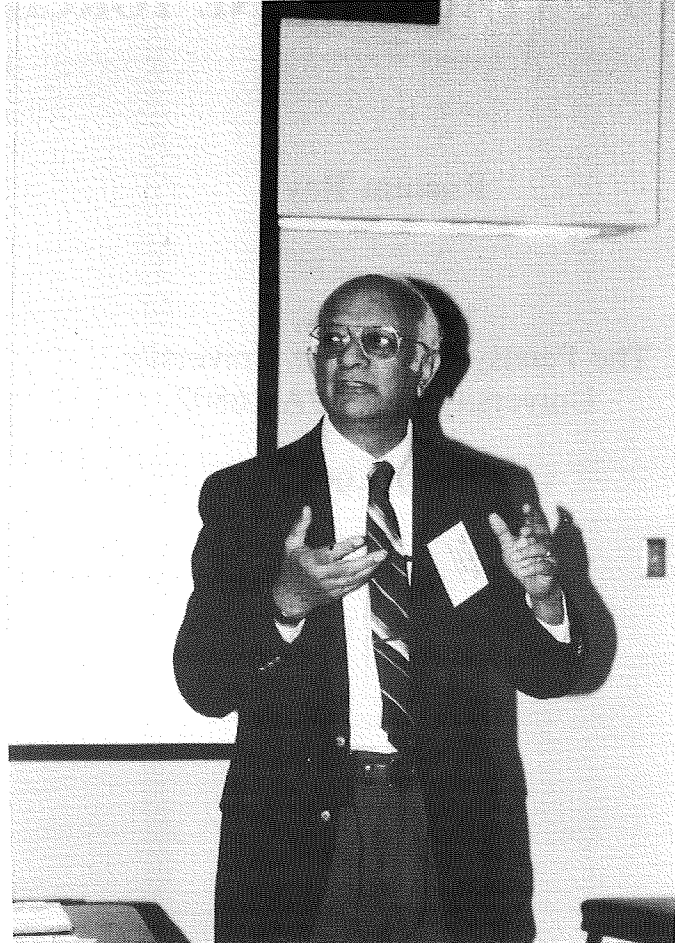
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**DIAMOND RESEARCH OVERVIEW AND A
MODEL FOR LAB EXPERIMENTS
USING OXYACETYLENE TORCH**

Rustum Roy

102 M.R.L.
The Pennsylvania State University
University Park, PA 16802

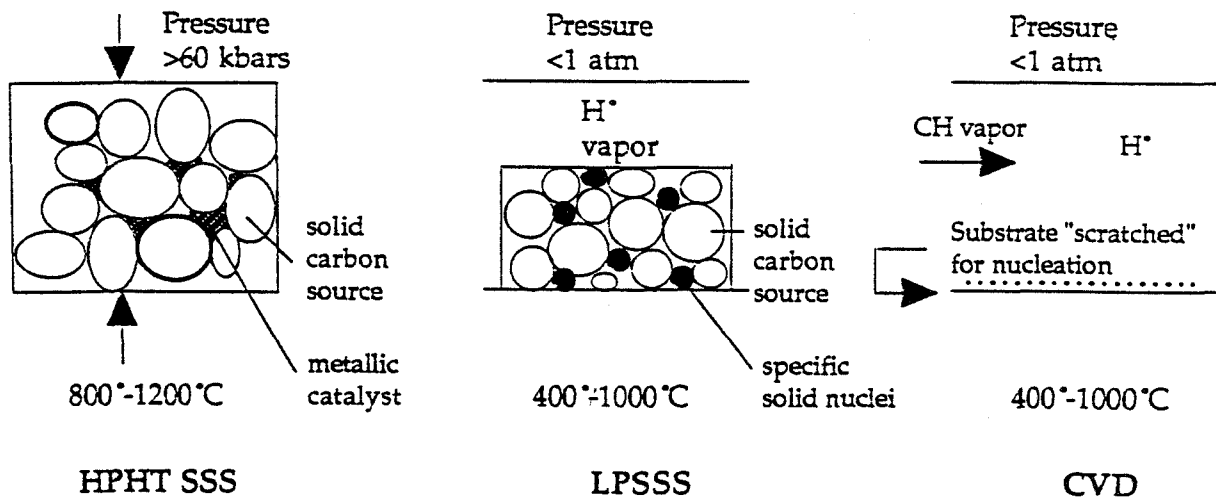
814-865-9951



DIAMOND SYNTHESIS 1995

1. High pressure synthetic diamonds now a commercial product for 40 years. (Price of diamond grit dropped by a factor of 10 in last 2 years.) Total value less than \$1 billion.
2. CVD process invented by Soviets 30 years ago. Developed by Japanese 20 years ago. Brought to U.S. by speaker 10 years ago.
3. New syntheses (Penn State leading) focus on liquid and solid phase approaches.
4. Three CVD processes: (a) microwave plasma; (b) hot filament; (c) oxy-acetylene torch.
5. Oxy-acetylene torch is an excellent materials synthesis lab experiment. Emphasizes SIMPLICITY of all effective science, *not* complexity and bigness.

The Three Diamond Synthesis Processes.



The traditional high temperature high pressure process used worldwide for diamond synthesis starts with solid carbon which is transformed to diamond by use of a liquid metal phase as a catalyst.

The new process, which also uses a *pre-shaped* solid source consisting of carbon mixed with a very fine second solid phase of isostructural semiconductor or heterotypic metals. The fluid catalyst likely will involve the H⁺ vapor.

The CVD process utilizes carbon atoms brought into the chamber as a *vapor*, and deposits them on a substrate, often scratched or nucleated with a second phase.

SOLID OR LIQUID PHASE APPROACH

- Why?** Condensed phases are 1000× more dense. Structure is different.
- What solids?** Carbon. Shock waves—old; laser—new.
- What liquids?**
1. Metallic-carbon solutions used in high pressure. Substitute H° for low pressure (LPSSS)
 2. Aqueous solutions, learn from nature.
 3. CO₂ (+H₂O)? (No advantage.)
- Status** Penn State has succeeded with both 1 and 2 at *low* pressure
NIRIM (Japan) with 3 at high pressure.

STATUS OF DIAMOND FILM (CVD) DEPOSITION RESEARCH

- DIAMOND FILM DEPOSITION IS A TEXTBOOK CASE OF A GENERIC DUAL-USE, ENABLING TECHNOLOGY.
- ONE CAN DEPOSIT DIAMOND COATINGS ON VIRTUALLY ANY MATERIAL (FERROUS ALLOYS NOT EASILY).
- TYPICAL HIGH RATES ARE 10μ/HR (MAXIMUM REPORTED 900μ/HR).
- LARGEST AREAS IN THE ORDER OF 20-30 IN².

- **THICKEST FILMS MADE: 1-2 MM.**
- **LOWEST TEMPERATURES FOR CRYSTALLINE FILM $\approx 350^{\circ}\text{C}$. FASTEST AT $\approx 900^{\circ}\text{C}$.**
- **MANY VERY DIFFERENT METHODS FOR GROWING FILM.**
- **SINGLE HOMOEPITAXIAL CRYSTALS EASY.**
- **ISOTOPICALLY ENRICHED CRYSTALS GROWN.**

STATUS OF PRODUCT DEVELOPMENT ALREADY ACHIEVED

1. **ACOUSTIC IN SONY SPEAKERS.**
2. **DIAMOND COATED CUTTING TOOLS.**
3. **FUJITSU HEAT SINKS.**
4. **X-RAY LITHOGRAPHY MASKS.**
5. **X-RAY WINDOWS.**

DIAMOND IS AN ENABLING TECHNOLOGY

X-RAY MASKS FOR LSI .

LUBRICATION-FREE DIAMOND BEARING/JOURNAL SURFACES .

MICROWAVE AND MILLIMETER WAVE DIAMOND AMPLIFIERS .

* DIAMOND THERMAL SPREADERS FOR COMPUTER CHIPS PACKAGED 6 TIMES CLOSER.

** DIAMOND'S HIGH ACOUSTIC "Q" FOR MORE CHANNELS PER UNIT SPECTRUM.

* DIAMOND CUTTING TOOLS FOR ALUMINUM IN THE AUTOMOBILE AND RELATED INDUSTRIES.

ALL FAR TOO OPTIMISTIC

DIAMOND THIN FILMS MARKET

(made by Business Groups NOT PSU)

APPLICATION ITEM 1988 1990 1995

LOUDSPEAKERS	\$ 5 M	\$ 30 M	\$ 50 M
COATED KNIVES & TOOLS	10 M	40 M	150 M
MEMORY DISK COATINGS	-	5 M	70 M
OPTICAL COATINGS (PASSIVE)	2 M	40 M	70 M
LASER COATINGS (UV INCLUDED)	-	-	25 M

1988 PREDICTIONS MUCH TOO OPTIMISTIC DIAMOND THIN FILMS MARKET (cont)

	APPLICATION ITEM	1988	1990	1995
Chances look poorer check in 2000.	COMMERCIAL SEMICONDUCTORS -		1-5 M	400 M
	MILITARY SEMICONDUCTORS -		?	10-300 M
Here, but small.	MILITARY OPTICS -		2 M	400 M
Here, but slow & small.	CUTTING TOOLS			\$1000-2000

DIAMOND SYNTHESIS FROM VAPOR

A. VAPOR COMPOSITIONS

1% CH₄ + 99% H₂ - Best Typical

+

C₂H₂, C₂H₄, (CH₃)₂CO, C₂H₅OH, O₂, etc.

Halogenated carbon compounds (new)

B. SUBSTRATES

Silicon

Diamond

SiO₂; Al₂O₃

Nickel; WC; titanium

Silicon carbide, etc.

MAJOR PROCESS TARGETS

RATE OF GROWTH

1+ μ /HR BY ALL METHODS

300+ μ /HR BY DC PLASMA

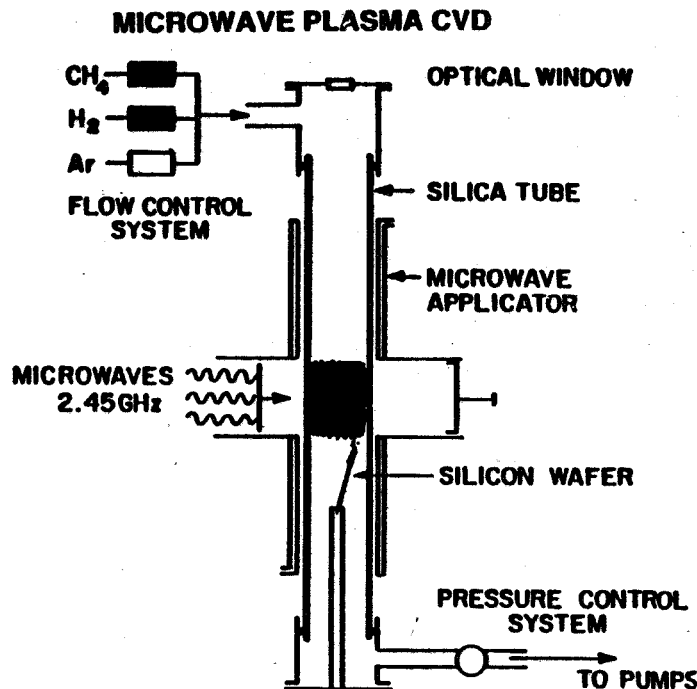
LARGE AREAS

W-FILAMENT, MICROWAVE PLASMA FOR TENS OF CM^2

FLAME OR ?? FOR SQUARE METERS

ADHESION

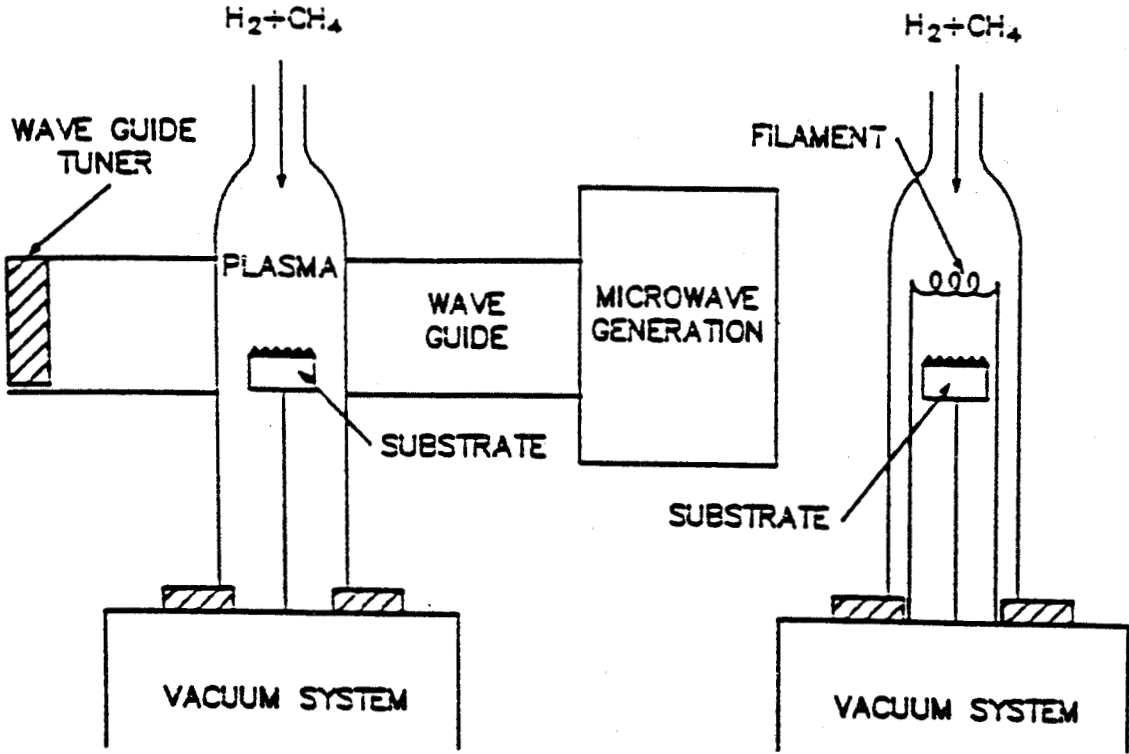
SOLVED EMPIRICALLY IN EACH CASE.



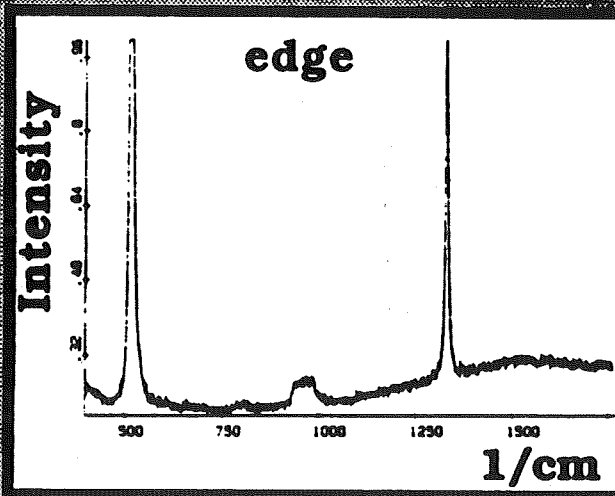
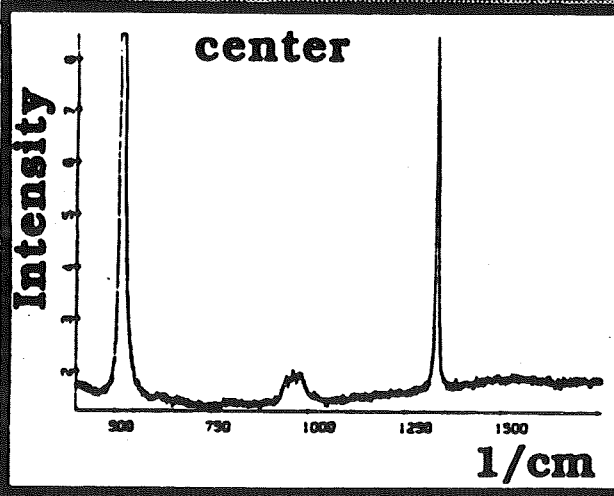
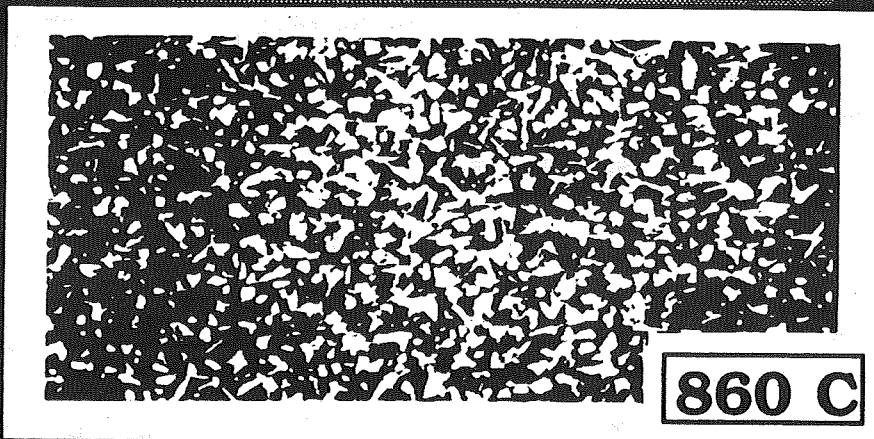
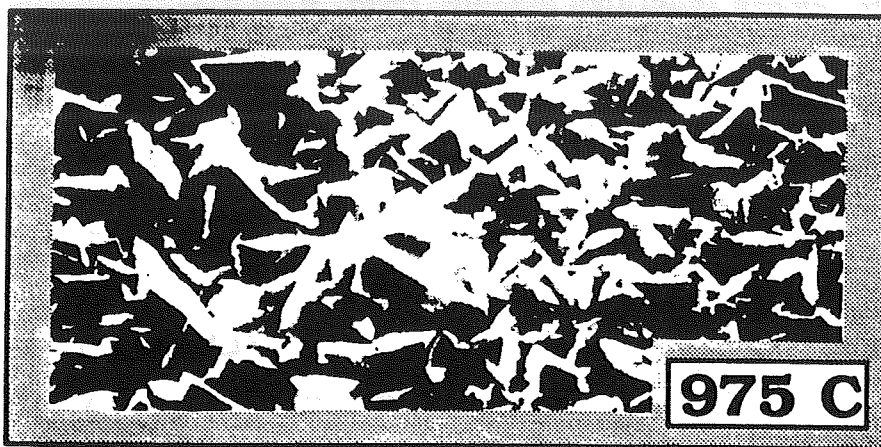
PRESSURE	4-10 Torr	SUBSTRATE TEMPERATURE	BELOW 700
FLOW	20-100 sccm	GROWTH RATE	0.03-0.1 $\frac{\mu\text{m}}{\text{h}}$
CH_4/H_2	0.5-2%	THICKNESS	UP TO 1 μm
POWER	400-600W		

A. BADZIAN et al. APPL. PHYS.

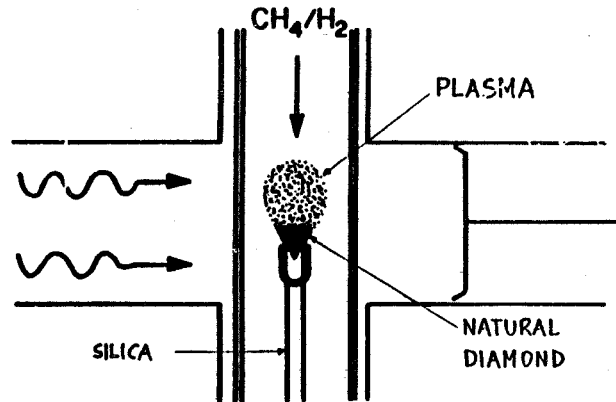
Schematic representation of apparatus for deposition of diamond by CVD. Left: with microwave generated plasma; right: with filament.



Temperature Dependence of the Morphology of a Diamond Film



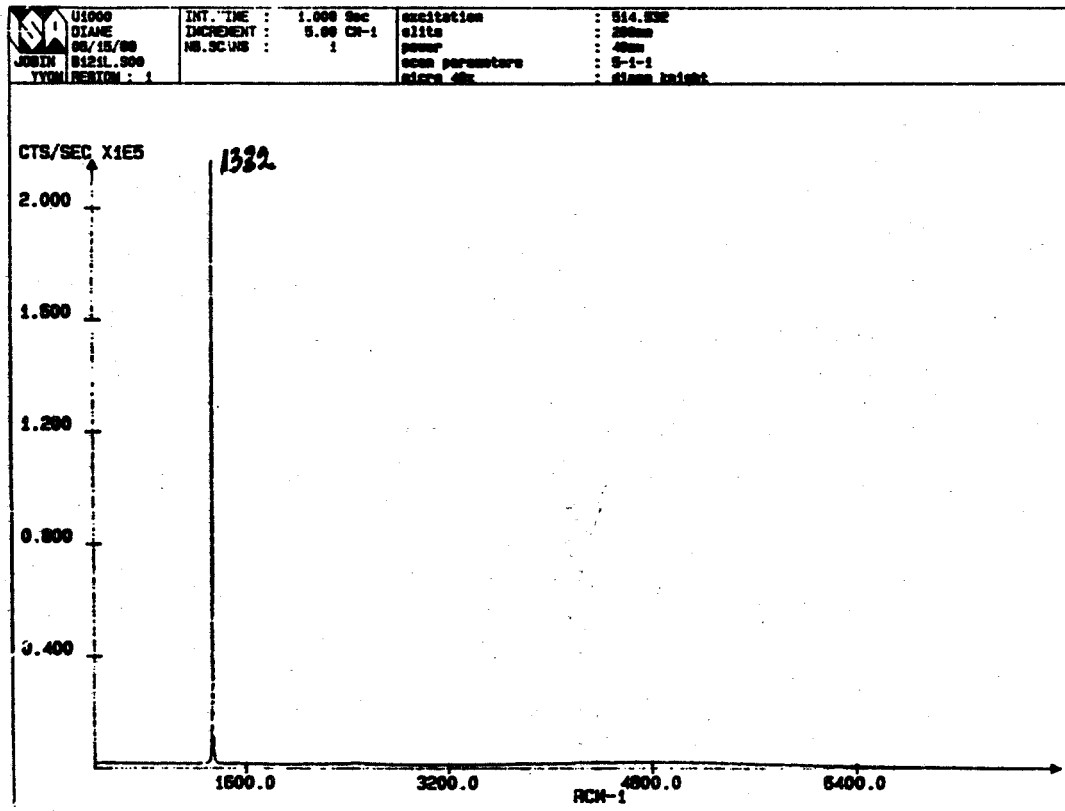
MICROWAVE PLASMA ASSISTED CHEMICAL VAPOR DEPOSITION



THE MICROWAVE APPLICATOR USED FOR HOMOEPITAXIAL DIAMOND GROWTH

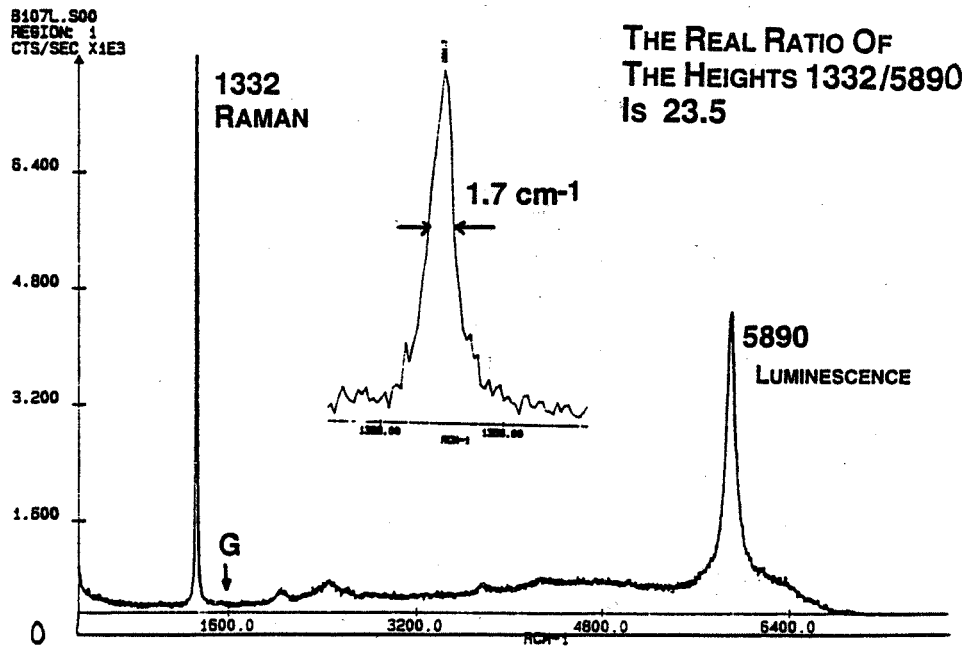
TEMPERATURE	850-900°C
PRESSURE	80 TORR
CONCENTRATION OF CH ₄ IN H ₂	1%
FLOW	100 SCCM
GROWTH RATE	~1μM/H

RAMAN SPECTRUM OF EPITAXIAL FILM ON Ia CRYSTAL

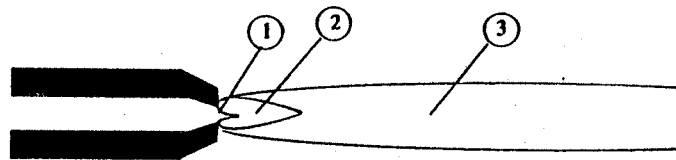


HOMO-EPITAXY.

RAMAN SPECTRUM OF DIAMOND FILM ON DIAMOND (30 μ)

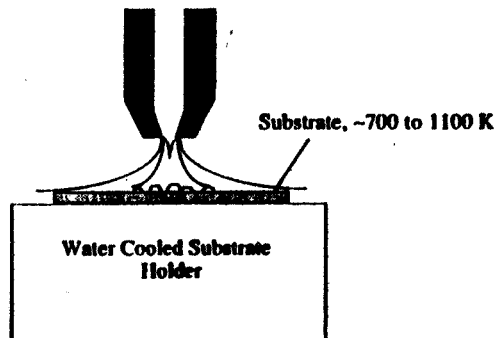


Combustion Synthesis of Diamond



Various "zones" in an oxyacetylene brazing torch (~1:1 O/C or less)

1. Transparent, colorless. Preheat zone. Premixed gas at high velocity is heated to combustion.
2. Bright incandescent white. Primary combustion. Premixed acetylene and oxygen burns to produce primarily CO and H₂. Adiabatic combustion temperature (1:1 C₂H₂ - O₂) 3300 K. Much H₂ expected to be atomic. Diamond growth observed here.
3. Blue, transparent. Secondary combustion. Combustion of the CO and H₂ produced in primary combustion in the surrounding air.

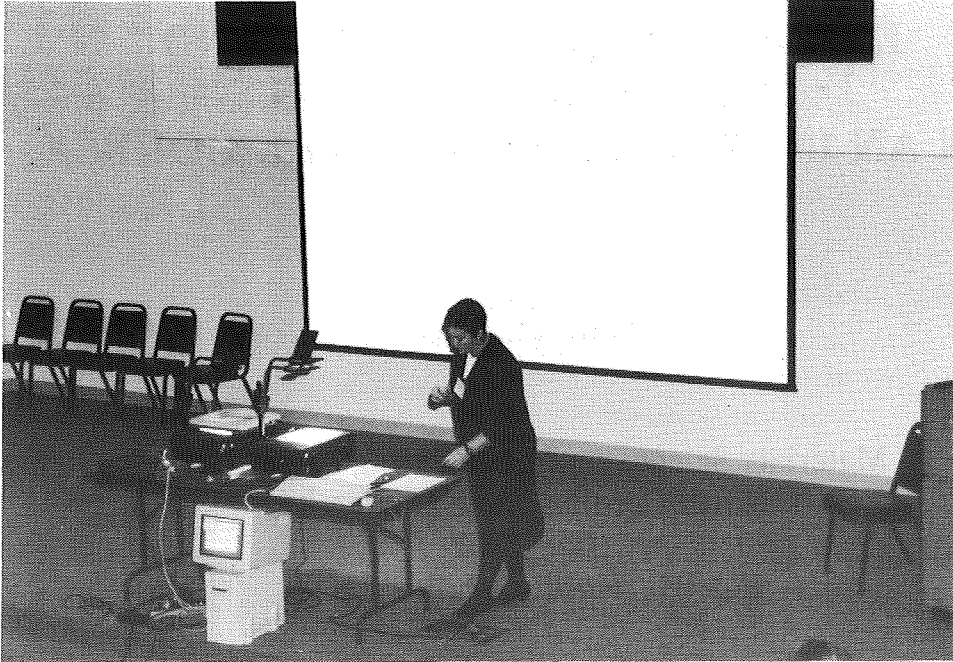


**IMPACT OF MULTIMEDIA AND
NETWORK SERVICES
ON AN INTRODUCTORY LEVEL COURSE**

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Presented by

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Impact of Multimedia and Network Services on an Introductory Level Course

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North Carolina State University, Raleigh, NC 27695

Keywords: Multimedia, CD-ROM, computer animation, computer graphics, simulations, network connectivity, interactive hypermedia, self-paced learning.

We will demonstrate and describe the impact of our use of multimedia and network connectivity on a sophomore-level introductory course in materials science. This class services all engineering students, resulting in large (>150) class sections with no hands-on laboratory. Concerned that traditional lecture and textbook approaches did not reach many students whose learning style is primarily visual and interactive rather than auditory and passive, we began in 1990 to develop computer graphics that might substitute for some laboratory or real-world experiences, and demonstrate relationships hard to show with static textbook images or chalkboard drawings.

With some NSF funding through Project Succeed and strong local support from the College of Engineering and our Department, we have used student labor to create a comprehensive series of modules that cover the entire course contents. Called VIMS (Visualizations in Materials Science), these are available in the form of a CD-ROM (Macintosh version available now, PC version early next year), and also via the Internet (<http://vims.ncsu.edu>). The CD-ROM version, which is in use at more than 20 universities worldwide, uses a Hypercard front end with succinct but complete highlights that correspond (and are keyed to) all of the introductory materials science textbooks, with hyperlinks and a searchable index. This provides the student with a valuable resource to select the important information from the enormous amount of material covered in an introductory course.

Extensive graphics in the form of nearly 700 Quicktime movie files are available at the click of the mouse to explain the concepts presented in the text. These include digitized movie clips from laboratory or demonstration experiments, cartoon graphics that clarify difficult concepts, computer simulations to illustrate physical principles, etc. Many of the movies show side-by-side presentations of complementary views or related material. Of course, this rich amount of information is most valuable to students who can access it at their own self-paced rate, and test their knowledge with the built-in self-quizzes. The CD also includes about 300 worked problems including all of the assigned homework and many example problems from the text. These are not just answers, but heavily annotated step-by-step solutions using Theorist, an interactive math package that allows students to solve complex equations, substitute numeric values, and plot results.

The VIMS webserver was introduced this fall (1995), and makes the text and graphical information available on our campus workstation network (as well as worldwide). Combined with a listserver that allows students to ask questions, express frustrations, and share insights with each other and with the faculty, this electronic connectivity provides a new level of support for students. The response has been overwhelmingly positive, and we have extensive statistics from control-group experiments and student questionnaires that indicate higher interest levels and better performance from students who use these new capabilities.

This result justifies the enormous cost, primarily in human effort and many hours of faculty and student time needed to develop these multimedia materials, and also points the way to extension of the technology to other venues. We are particularly interested in the applicability of some of the same materials, with the addition or substitution of appropriate descriptive language, for use in primary and secondary schools. VIMS has already been used as part of a third-grade science curriculum based on materials science that has been recently introduced in the Wake County (North Carolina) public schools.

***Impact of Multimedia
and Network Services
on an Introductory
Level Course***

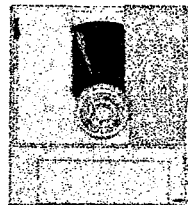
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*Material Science and Engineering
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NC State University

Presented by
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VIMS 2
***Visualizations in
Material Science 2***

- CD-ROM
- Context
 - Background
 - History
- Results
- Demo
- Latest Developments
- Ordering Info



Insight Gained



- Computer rendered unit cells
digital movies - rotation
- Color choice
Hue & brightness
Saturation
Inconsistent use
- The amazing shrinking atoms!
- Cut away view

- Phase diagrams
isopleth, cooling curves,
microstructure

100% 100% 100% 100% 100% 100% 100% 100% 100% 100%

100% 100% 100% 100% 100% 100% 100% 100% 100% 100%

Development Time



3600:1

"It takes on average 1 hour to
produce each second of final
digital movie."

P (Believe it | No Experience) = 0

P (Doubt it | Experience) = 0

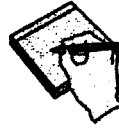
100% 100% 100% 100% 100% 100% 100% 100% 100% 100%

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Evolution

- Classroom-based multimedia
 - LCD projection panel
 - Bright overhead projector

- CD-ROM
 - VIMS
 - VIMS2 interactive



- Internet

★ Student input



Support

- Financial
 - NSF - Project SUCCEED
 - NC State College of Engr
 - Department

- Moral/Administrative
 - Department & Head
 - COE
 - University

- Students



Demonstration of VIMS2

Title Page	Overview of Structure & Icons	
Table of Contents	Index card format	
<u>Subject Area</u>	<u>Subsection Title</u>	<u>Key word, icon</u>
Chapter 3	Highlighted terms Problems icon Cubic unit cells BCC, FCC Directions & Linear Density Planes & Plane Density Ionic Crystals I	FCC, BCC Picture: FCC Graph: QQ2 Picture: planes NaCl shrinking
Chapter 4	Deformation Simulations I	film clip corn cob corn borer
Chapter 6	Tensile Test Tensile Testing Equipment Failure Examples	stretches neck & fail Picture looked at several
Chapter 7	Cold Rolling Cold Rolling & Microstructure Examples	strained sequence Graph rolling mill elongated
Chapter 9	Solidification of SS Alloy	Graph Picture
Chapter 10	Eutectic Alloys Hypo & Hypereutectic	Graph Graph-graph Hypo

Results

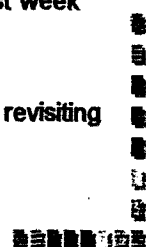
- Overwhelmingly positive
- Better with each generation
- High level of student participation
 - Usage
 - Development
- Software requirements
 - Mac - Quicktime
 - PC - Quicktime for Windows



Latest Developments

WWW

- <http://vims.ncsu.edu>
- Fall semester, 1995
 - 8000 accesses in first week
 - Homework solutions
 - Listserver
 - Juniors and Seniors revisiting the course material



Beyond the Horizon



- More topics
- Better graphics
- More real world examples
 - Mechanism is in place

- Extend downward
 - Primary and secondary schools
 - Fundamentally alter the education of engineers and scientists



Ordering Information

- Int'l Thompson Distribution Ctr
Parent of PWS Kent
 - * One copy free if teaching
 - 1-800-423-0563

- Individual Orders \$20.25
1-800-354-9706
ISBN 0534-942490



- Site Licenses available
- Technical Services 1-800-214-2861

-
- Feedback
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VIRTUAL REALITY LAB ASSISTANT

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Key Words:

Virtual Reality, Toolkit, Hardware, Software, Lab Experiment, Simulation

Prerequisite Knowledge:

Knowledge of computer hardware, software, graphics, 3-dimensional lab environment

Objective:

Virtual Reality Lab Assistant (VRLA) demonstration model is aligned for engineering and material science experiments to be performed by undergraduate and graduate students in the course as a pre-lab simulation experience. This will help students to get a preview of how to use lab equipment to run experiments without using the lab hardware/software equipment.

Equipment:

1. Silicon Graphics Indigo2/Extreme computer
2. VRLA Software toolkit specific to the desired pre-lab
3. Compatible VR Head Mounted Display (HMD)*
4. Ascension "flock-of-birds" 6-DOF Tracker System*

*note: These items are only required for an "immersive" experience.

Introduction:

The science of virtual reality (VR) is beginning to find many uses in Government and industry. As a tool, VR is being used to study complex processes, explore hazardous environments remotely, visualize abstract ideas, and to entertain. While there has been a wealth of applications emerging in these areas, however, relatively few applications of VR to secondary education have been introduced. Never before has such a captivating teaching tool as VR been available for personal training and instruction. By tapping into this learning resource, students will be able to receive detailed visually oriented learning at a pace that best benefits the student. This paper explores the area of virtual reality as it can be applied to education and, specifically, to the college level electrical engineering laboratory. Access to a "virtual mentor" in the laboratory would result in a higher success rate, quicker results, less equipment damage, and a more thorough understanding of the underlying theory.

Procedure:

Given the rapidly expanding body of knowledge associated with nearly every experimental science and engineering discipline it is becoming increasingly difficult to present the student with meaningful laboratory exercises that represent a wide cross-section of the discipline. This is largely due to the fact that laboratory procedures are difficult to design and perfect, requiring a substantial investment in time on the

part of the instructor. As a result, laboratory experiments, once perfected, tend to remain in the course longer than they should and eventually become less meaningful to the student. Furthermore, performing the laboratory experiment can be costly, time consuming, and sometimes hazardous to the student and the facilities. From the student's perspective, experiments are often tedious and offer only a modest learning experience. This is usually because the student is unfamiliar with the laboratory environment, experiment procedures, or the equipment and apparatus needed to perform experiment. Clearly, if the student was able to *experience* the experiment *prior* to actually entering the laboratory facility the chances for successfully achieving the objectives of the experiment are greatly enhanced.

The concept of training the experimenter prior to performing the experiment is not a new one. It has been applied with very successfully, for example, in the military and commercial aviation arenas. It is unheard of in today's high-tech world for a pilot to be qualified for flying a jet without first spending many hours in a computer controlled virtual flight simulator. The reasons are many but include the cost of operating an actual aircraft for training, the potential collateral damage or loss of life resulting from a crash, and the limited resources, both human and other, that are available for training the pilot. Until today, the use of this type of "virtual environment" (VE) for training has been unavailable or uneconomical for all but the military and other niche markets. With the general power and availability of personal and workstation computers today, along with the tremendously vast and ever increasing knowledge base of virtual reality research, VEs are becoming a viable option for training at nearly every level.

"Virtual reality" is a very broad and often misunderstood concept. For the purposes of this paper, we use virtual reality to mean a computer generated audio-visual environment with which the student can interact using standard or specialized computer input devices to predictably affect the environment. Likewise, a "virtual environment" is the synthetic, or computer generated, "world" with which the participant interacts. Recent advances in computer hardware and software are making it possible to create VEs and allow VR interaction with them using off-the-shelf computer platforms and the addition of relatively inexpensive and cost effective peripherals designed for VR use. The resulting potential of VR for teaching is staggering. For the first time, meaningful interactive learning is possible using virtual reality in the laboratory.

Benefits of Virtual Reality in the Laboratory

Invariably, a certain percentage of the students in a given laboratory will not achieve success in the experiment. In many cases this failure could be mitigated through the use of a VR pre-laboratory because the student would be better trained prior to actually performing the experimental procedures. Before the actual experiment is performed, the student has already performed the virtual experiment and understands the required procedures and expected outcomes. Familiarity with the experiment will allow the student to recognize failure early in the experiment and correct the mistake before the experiment is unsalvageable.

Laboratory time is a valuable commodity both to the student and to the instructor. The time spent performing meaningful experiments in the laboratory is directly related to the student's practicable knowledge of the underlying theory of the experiment. For the laboratory instructor, much of the time is spent resolving issues relating to equipment operation and experimental procedures. The use of VR in the laboratory can maximize the student's time in the laboratory by better preparing the student for the experiment. Training in the basic operation of equipment and procedures as well as a reinforcing of the goals of the experiment are just a few of the ways that VR will help prepare the student and maximize time spent in the laboratory. The instructor will also benefit from the student's preparation since the student will require less assistance in performing the experiment.

A successful laboratory experiment requires access to reliable equipment and apparatus. Unfortunately it is often the case that needed equipment is not working in the laboratory. While a percentage of this equipment failure can be attributed to equipment life cycle, a larger percentage is usually due to misuse by students. Traditionally, students are much more knowledgeable about the experiment and its procedures than about the laboratory equipment needed to perform the procedures. This is understandable but results in a higher than necessary frequency of broken or miscalibrated apparatus. Clearly, better training in the use of the equipment would result in a lower incidence of equipment failure. This is another area where virtual reality offers assistance. Training the student in the basic operation, hazards, and maintenance of laboratory equipment using virtual reality techniques would result in a higher quality laboratory environment, foster quicker assimilation of experiment results because the student is free to concentrate on the experiment itself -- not the apparatus and equipment, reduce the time needed to complete the experiment, and increase the chances of a successful experiment outcome.

The laboratory experiment is designed to reinforce theory learned in the classroom and to give practical meaning to seemingly abstract theory. While there is no real substitute for true "hands on" training, virtual reality can help the student bridge the gap between the theory and practice. The unique nature of virtual reality allows the student to at once visualize theory and see its application. Interaction within the properly designed virtual environment leads the student to extend understanding by reinforcing theory with (simulated) application and, visa-versa, pointing out theoretical bases for observed (simulated) results. The synergy between the virtual reality simulation and the student creates a rich learning environment that is unavailable in the classroom or laboratory alone.

To summarize its benefits, a virtual reality laboratory "mentor" would result in a higher success rate, quicker results, less equipment damage, and a more thorough understanding of the theory underlying the experiment.

Prototype Experiment Description

The experiment is similar to one found in many electrical engineering curriculums in which a student builds a passive electrical circuit, stimulates it using a signal generator, and observes it using an oscilloscope. Prior to performing this experiment, however, the student will participate in a virtual reality pre-lab. In the pre-lab, the student will interact with the virtual environment to construct a breadboard circuit. Components and wires are taken from a "palette" of parts and placed onto an experimenter's breadboard one by one. As the circuit is constructed, environment is visualizing the breadboard, components, parts palette, and the circuit schematic. When components are correctly placed on the breadboard, the schematic visually changes to cue the student that the component selection and placement were correct. Similarly, the student is informed when a component is incorrectly chosen or placed. The student is given a chance to try again after the environment removes the incorrect component.

Once the circuit is complete, the student may connect the signal generator to the circuit input terminals. Again, successes and failures are acknowledged interactively. Finally, the student can utilize the oscilloscope to attach one or two probes to the circuit.

The signal generator can be adjusted by the student to present various amplitude and frequency signals to the circuit. Similarly, the oscilloscope can be attached at any terminal and adjusted by the student to any amplitude and time scaling. Two oscilloscope traces are available and can be used independently or together in x-y mode.

An illustration of the layout of the experiment components is given in figure 1. Notice that a rendering of the correctly constructed circuit breadboard is given in the upper right, followed by the schematic, the component pallet, and the blank breadboard showing signal generator terminals already connected. The oscilloscope with probes is in the upper left followed by the signal generator below.

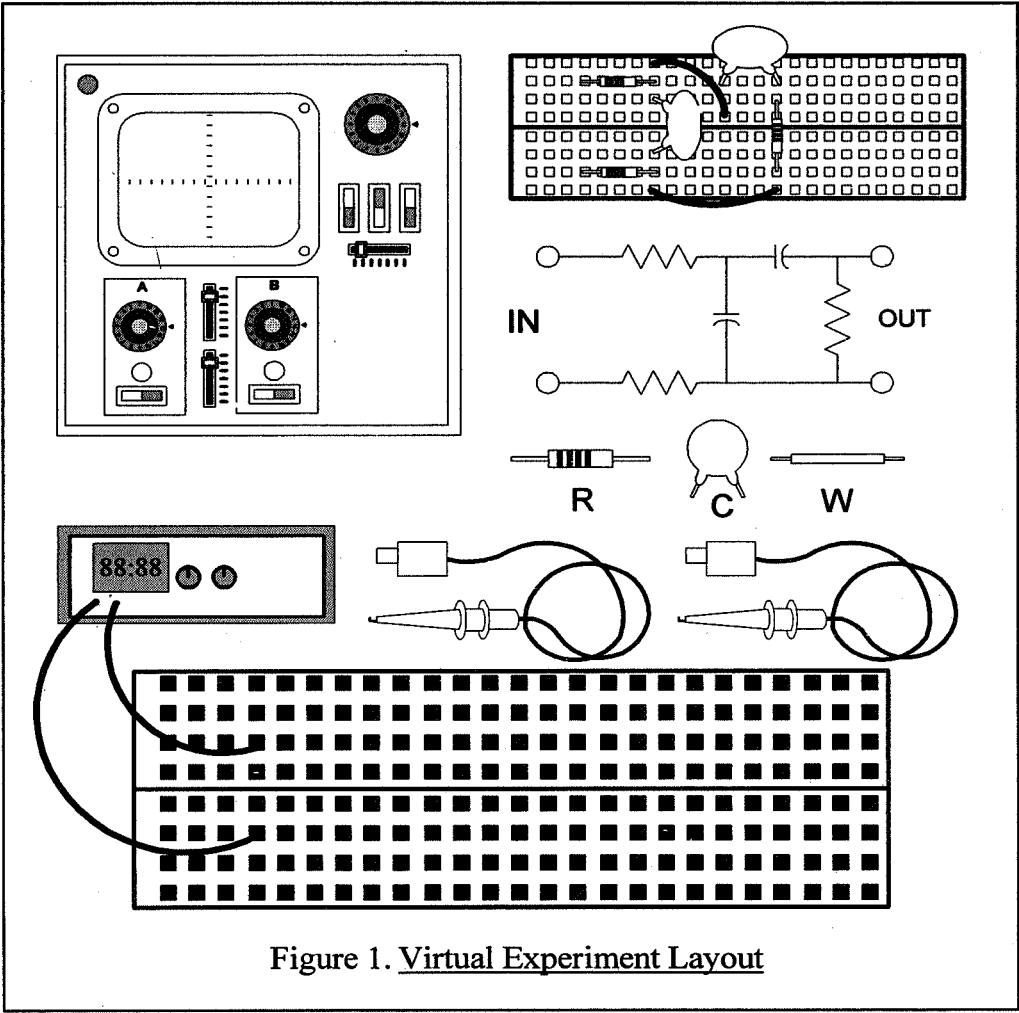
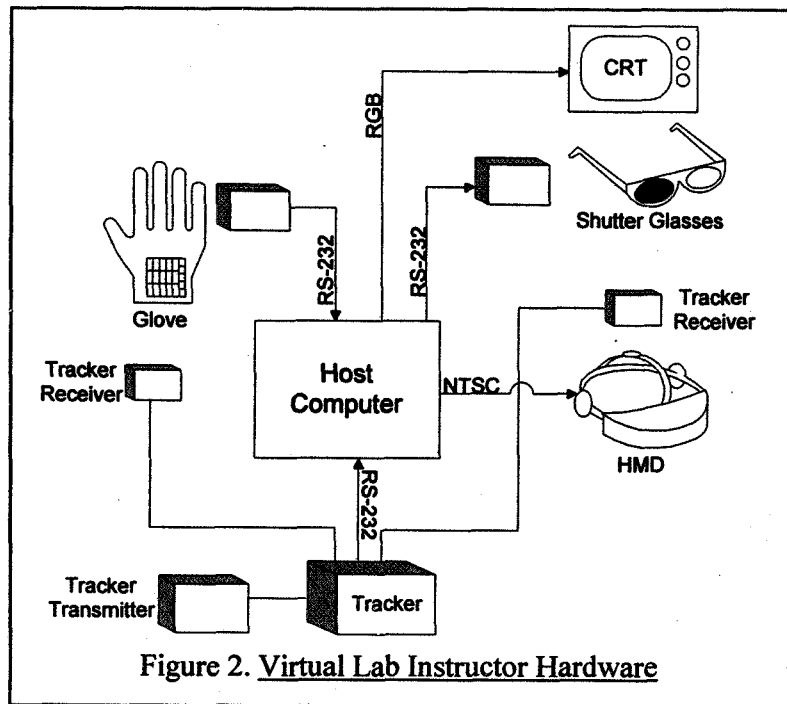


Figure 1. Virtual Experiment Layout

Notes to the Instructor:

The components of the example virtual laboratory are shown in figure 2. A Silicon Graphics Indigo2 computer is used to accept user input via a mouse and keyboard and display the results graphically. The student can view the results on the monitor or use a virtual reality helmet mounted display (HMD) for a fully immersive experience. The Indigo2 computer has excellent graphics for this type of experience and provides auxiliary inputs for virtual reality devices such as gloves and hand/head position trackers.

The software used for this example experiment was a combination of off-the-shelf and custom designed. An off-the-shelf computer graphics modeller, *Wavefront*, was used to generate the models used in the graphics part of the experiment. Custom software for interfacing with the virtual reality peripherals, scripting the experiment, and performing the circuit and equipment simulations was used.



Step by Step Instructions

1. Insure that the Indigo2 computer is properly connected to power and any peripherals in use, such as the HMD, glove, and tracker. The HMD connects to the NTSC video output of the Indigo2 computer. The glove and tracker connect to the “tty1” and “tty2” ports of the Indigo2, respectively. The experiment can be configured to run without any peripherals. In this case all student interaction will be visualized on the main Indigo2 monitor and input using the system mouse.
2. Apply power to the Indigo2 and wait for the system to show the “login” screen.
3. Login to the system using as “vrla” (there is no password required). The VRLA prototype pre-lab will appear as shown in figure 1.
4. The pre-lab experiment can now be performed following the procedures outlined in the procedures section and given below with greater detail. These procedures assume that the main input device is the system mouse and the output device is the Indigo2 video monitor.

Wires are added to the blank breadboard by clicking on one end of the wire shown in the parts palette and “dragging” the end (while holding the mouse button down) to the desired breadboard hole. The wire will “snap” into the hole when the mouse button is released. The other end of the wire is attached in the same manner. A wire end can be moved by clicking in the hole where the wire is connected and dragging the end to a new location. A wire can be removed completely by dragging both ends outside of the breadboard area. Components are added to the breadboard in a manner similar to wires. Component terminals are “dragged” into holes on the breadboard. Moving and removing components

is also the same as outlined for wires, above. As the circuit is constructed, the schematic visual will change to indicate proper part placement.

Once the circuit is complete, the VRLA will automatically apply power to the oscilloscope and signal generator. The oscilloscope probes can be attached to the oscilloscope and to points on the breadboard using the same techniques as for wires and components. The oscilloscope can be adjusted for desired time base and amplitude scaling using the knobs on the face of the virtual oscilloscope. This is done by clicking on the desired knob and “dragging” the knob in the desired direction. Similarly, the oscilloscope modes can be changed by clicking on the buttons on the face of the oscilloscope. Controlling the signal generator is performed in the same manner.

5. VRLA can be stopped at any time by pressing the “Quit” button on the VRLA screen.
6. The Indigo2 computer can be powered down by clicking on the “Shutdown” icon from the main login screen.

Concluding Remarks:

This paper describes the usefulness of virtual reality and shows an example application of virtual reality as a teaching tool in the laboratory. Although the example was for an engineering discipline, similar methodology can be applied to other disciplines such as medicine, agriculture, the sciences, and any other that requires hands-on interactive training.

As the power of computers and virtual reality peripherals improves, and as the working concept of virtual reality evolves, so must its application to teaching. Nothing can replace the teacher in the classroom nor actual “hands-on” experience. However, the quality of the time available for experimenting in the laboratory can be significantly improved through the use of virtual reality technology.

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**SOME EXPERIMENTAL RESULTS IN THE
ROLLING OF Ni₃Al ALLOY**

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SOME EXPERIMENTAL RESULTS IN THE ROLLING OF Ni₃Al ALLOY

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PREREQUISITE KNOWLEDGE: Rolling, Tensile Test, Microhardness, Grain Structure

OBJECTIVE: To investigate the rolling properties of a Ni₃Al alloy and to determine the factors affecting its rollability.

EQUIPMENT:

Rolling Machine
Tensile Test Machine
Vickers Microhardness Tester

INTRODUCTION:

Alloys based on the nickel aluminide, intermetallic compound Ni₃Al [1,2], possess many desirable properties including: (1) lower density; (2) superior fatigue, wear, oxidation, and cavitation erosion resistance; as well as (3) excellent creep and high-temperature strength. Early studies indicated that Ni₃Al alloy for structural applications has been limited because of their low ductility and brittle fracture. While Ni₃Al has been ductilized recently by small additions of boron, the nickel aluminides remain difficult to fabricate by conventional methods. Considerable development work is required for the processing of these alloys by conventional methods. These include development of an understanding of the effect of alloying and microstructure on room temperature properties, as well as their processing and fabrication.

The rolling process is to reduce the cross section of the incoming material, improve its properties, and obtain the desired section at the exit from the rolls. The process can be carried out hot, warm, or cold. In this study, the cold rolling properties of a Ni₃Al alloy (IC50) is investigated. Various experimental methods have been employed. The cold rollability of Ni₃Al has been found to be very sensitive to the starting thickness.

PREPARATION OF MATERIALS

The Ni₃Al alloys used in this study were produced at Oak Ridge National Laboratory, Armco Research and Technology, and Allegheny Ludlum Corporation. At Oak Ridge National Laboratory, the materials were prepared by nonconsumable-arc melting process. This operation yielded 0.5"- and 3/16"-thick ingots. The 0.04"-thick sheet was produced by direct casting process at Allegheny Ludlum Corporation. The 2.7"-diameter ingot was produced by vacuum-induction melting (VIM) process at Armco. The nominal composition of Ni₃Al alloy (IC50) under investigation is listed in Table 1.

EXPERIMENTAL PROCEDURES AND RESULTS

1. Cold Rolling Test (Specimen Without Heat Treatment)

The first rolling test was conducted on three as-cast specimens with different thickness (0.5", 3/16", and 0.04"). In all the rolling processes, the roll diameter was 4 inches, roll speed was set at 15 ft/min, and the reduction per pass was 3%. Each specimen was cold rolled until the first crack appears.

Figure 1 shows the percentage of reduction in thickness for initiation of cracking. It has been observed that the thicker specimen develops cracking at lower % deformation as opposed to thinner specimen. This result indicates that cold rollability of Ni₃Al-based alloys is very sensitive to the cast thickness. On the other hand, the direct cast 0.04"-thick sheet possesses excellent rollability. It can be cold rolled extensively without developing cracking.

2. Cold Rolling Test (Specimen With Heat Treatment)

Possible factors contributing for the observed cracking tendency of Ni₃Al alloy are the chemical inhomogeneous of the as-cast microstructure and the relatively large grain size. In order to improve the homogeneity of the cast microstructure, one 0.5"-thick section was annealed in air and the other in vacuum at 1100°C for one hour. A comparison of the rolling behavior for the different processing conditions is made in Table 2. It should be noted that the crack initiation was significantly improved for specimen annealed both in air and vacuum. It is also observed from Table 2 that air annealing is slightly degraded compared with vacuum annealing. This may indicate that some of the boron at boundaries near surface grains may be oxidized and ductility for the specimen annealed in air is reduced.

3. Tensile Test

In order to understand the mechanical properties, tensile tests were conducted on samples machined from 0.5"- and 3/16"-thick ingots and punched out of 0.04"-thick sheet. The result of tensile tests, a comparison of stress-strain curves, is made in Figure 2. These curves reveal that the thicker Ni₃Al alloys have higher work-hardening rate. Generally speaking, nickel aluminides have very high work-hardening rates, which means the materials can possess very high hardness

with small amount of cold work.

4. Microhardness Test

The microhardness test was conducted to determine the effect of initial thickness and cold rolling on transverse (the thickness direction) hardness distribution. Results of the test for Ni_3Al alloy with different initial thicknesses in as-cast, and in as-cast plus 20% cold rolled condition are compared in Figures 3(a) and (b), respectively. Transverse hardness data were plotted as a function of distance from the surface.

It is observed from Figure 3 that the Vickers hardness reading is extremely high along the rolling surface of specimen with 0.5" initial thickness. It appears that the observed hardness values correlate well with the tensile test results. The 0.5"-thick specimen has higher work-hardening rate and tends to work harden rapidly. During the rolling, this will make the material more and more difficult to be deformed.

5. Grain Structure

The macrograph of 2.7"-diameter VIM ingot is shown in Figure 4. The equiaxed grains are observed near the center, and the columnar structure is elsewhere. In order to understand the effect of grain structure on the rollability, the ingot was sequentially cut into plates with various thicknesses. Plates containing only columnar grains and plates consisting of only equiaxed grains were used to compare the rolling behavior of those two grain structures. The results are listed in Table 3. It should be noted that the columnar structure responds to cold rollability better than equiaxed structure.

DISCUSSION AND CONCLUSION

This study has examined several issues to understand the cold rollability of Ni_3Al alloy. It has been found that the cold rolling response of Ni_3Al alloy (IC50) is very sensitive to the starting thickness. The segregation of elements is worse for the thicker casting as opposed to the thinner section. This is exemplified by the point that cast plus annealed pieces showed cracking at much larger reduction as opposed to the as-cast piece. Increase in the thickness of the casting produces more complex microstructure. For example, in Figure 4, the center of the cross section is clearly equiaxed microstructure, which is surrounded by columnar microstructure on the outside. It has been found that a material with columnar grain structure has greater rollability than a material with equiaxed grains. The 0.5"-thick casting shows very high work-hardening rate, which may result in reduction in ductility values and lead to poor rollability.

ACKNOWLEDGMENTS

This research was supported by an appointment to the Nuclear Regulatory Commission's HBCU Faculty Research Participation Program administered by Oak Ridge Institute for Science and Education through a cooperative agreement between the U. S. Department of Energy and the U. S. Nuclear Regulatory Commission.

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2. Wright, R. N., Rabin, B. H., and Knibloe, J. R., "Consolidation of Ni₃Al Powders By Hot Isostatic Pressing", *Materials and Manufacturing Processes*, Vol. 4, No. 1, 1989, pp. 25-37.

Table 1. Compositions of Ni₃Al Alloy (IC50)

Element	Ni	Al	Zr	B
Weight, %	88.08	11.30	0.60	0.02

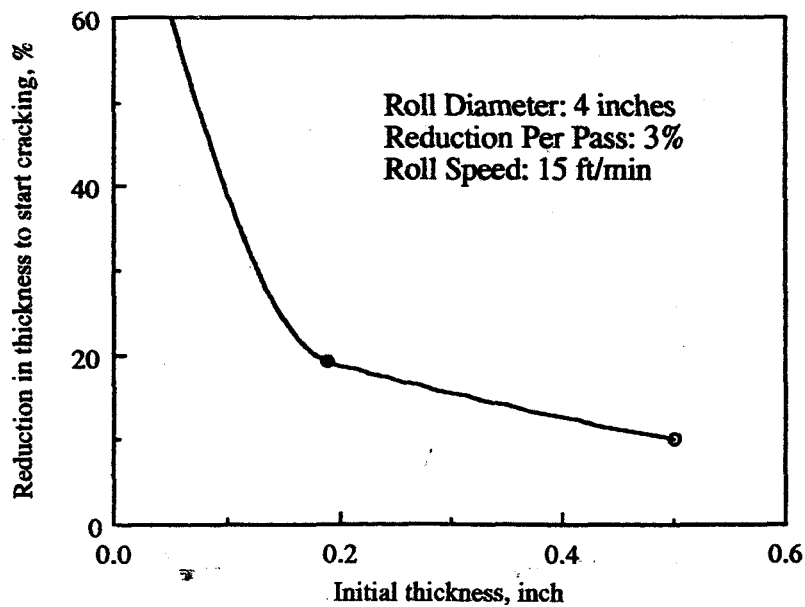


Figure 1. Effect of initial thickness on initiation of cracking during rolling of as-cast Ni₃Al alloy.

Table 2. Effect of Anneal on the Rolling Behavior of a 0.5"-thick Ni₃Al Alloy

Processing Condition	% of Reduction in Thickness to Start Cracking
Cast	10.0
Cast + Anneal in Air	24.0
Cast + Anneal in Vacuum	30.0

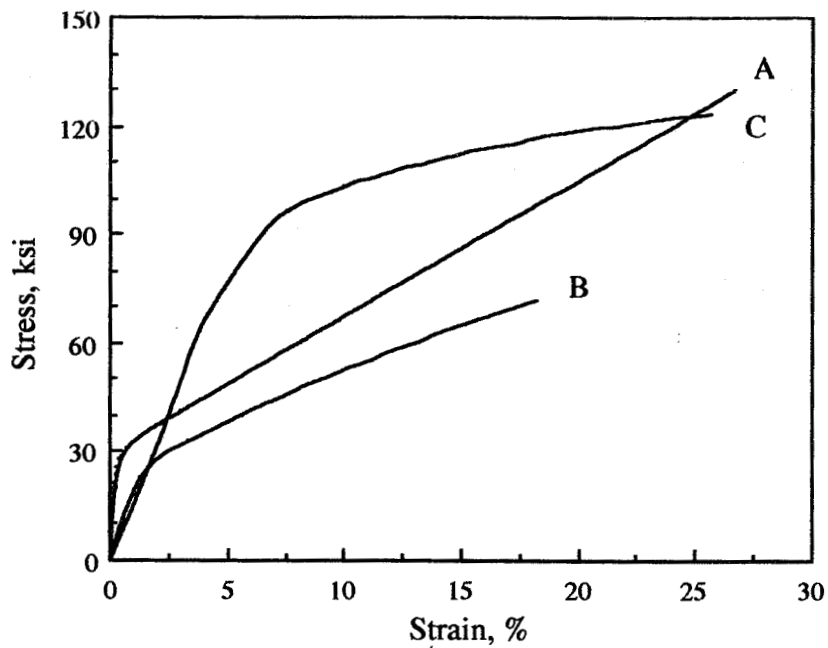
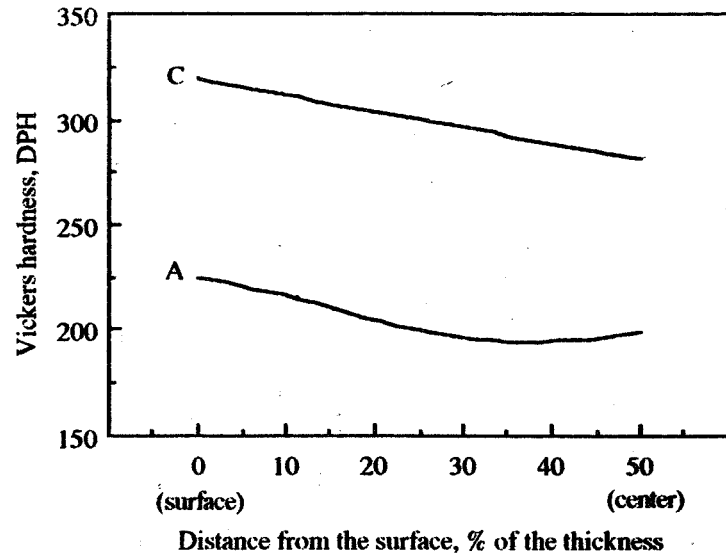
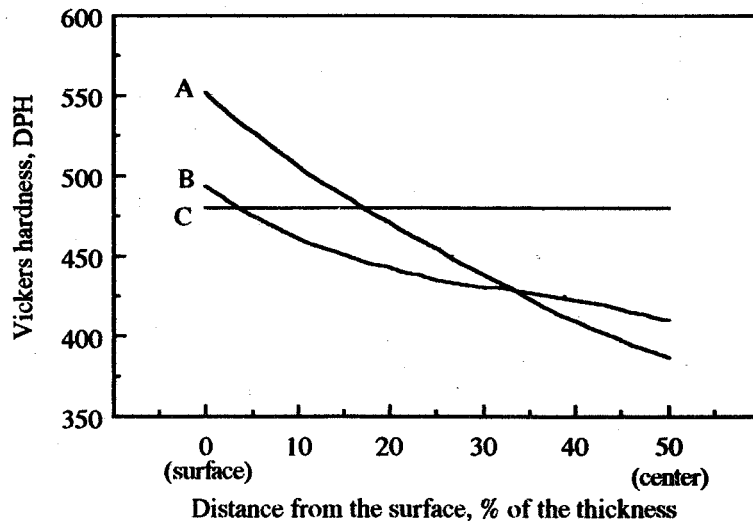


Figure 2. Comparison of stress-strain behavior of Ni₃Al alloy in as-cast condition.

- A: specimen machined from 0.5"-thick ingot
- B: specimen machined from 0.1875"-thick ingot
- C: specimen punched out of 0.04"-thick sheet



(a)



(b)

Figure 3. Distribution of transverse hardness for Ni_3Al alloy: (a) in as-cast condition, (b) in as-cast plus 20% cold rolled condition.
 A: specimen with 0.5" initial thickness
 B: specimen with 0.1875" initial thickness
 C: specimen with 0.04" initial thickness

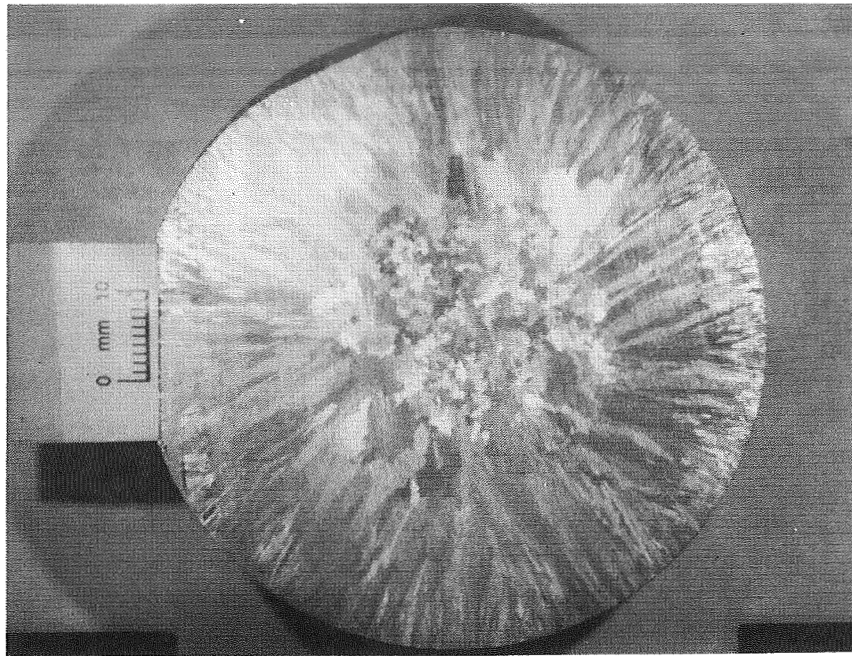


Figure 4. Macrograph of VIM ingot of Ni₃Al alloy.

Table 3. Comparison of Cold Rollability of Columnar and Equiaxed Grain Structures

Grain Structure	Initial Thickness (inch)	% of Reduction in Thickness to Start Cracking
Columnar Grain	0.350	30.8
	0.625	23.0
Equiaxed Grain	0.350	25.7
	0.625	16.6

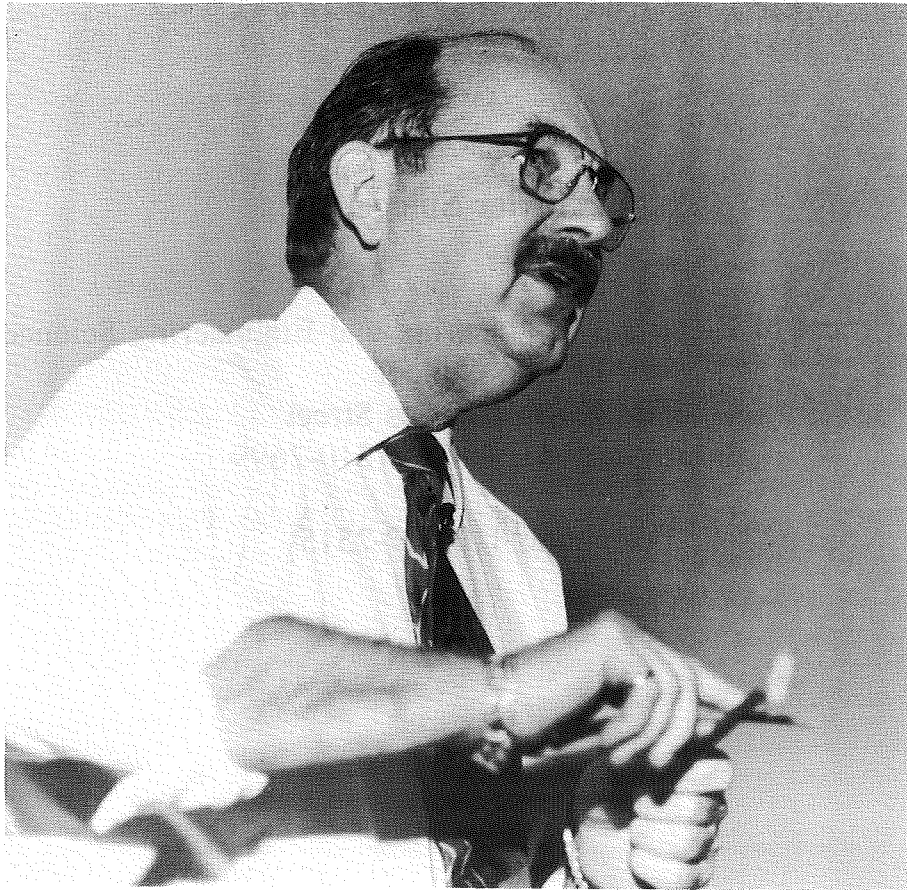
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**THERE ARE GOOD VIBRATIONS
AND
NOT SO GOOD VIBRATIONS**

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THERE ARE GOOD VIBRATIONS AND NOT SO GOOD VIBRATIONS

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ABSTRACT: This paper investigates several instances where mechanical vibrations are explored to enlighten the reader about some of the results of these vibrations.

REQUISITE KNOWLEDGE: Curiosity.

KEY WORDS: Mechanical Vibration, Damping, Coupling, Modulation
Chladni Plate, Water, Telephone, Modulation.

OBJECTIVES: The purpose of these demonstrations is to illustrate some interesting responses of materials to vibrations.

EQUIPMENT AND SUPPLIES:

- 1) Wooden Dowels
- 2) Violin Bow
- 3) Aluminum Plate
- 4) Movement from a Mechanical Music Box
- 5) Eye Dropper

THE VIBRATING STICK: If a wooden dowel (.75 cm dia. x 12 cm) is notched along its surface (8 or more notches in the form of vees .5 cm wide and .2 cm deep) are equally spaced and a flat piece of wood (.2 cm x .5cm x 3 cm) is attached to the end of the dowel with a wood screw so that the flat piece of wood is free to rotate, a very interesting behavior of the device can be demonstrated by rubbing another piece of wood back and forth across the notches. The flat piece of wood will wobble but not rotate uniformly. (See Figure 1.) However, if the dowel is touched by stroking hard on one side, the flat piece will rotate in one direction, and if touched on the other side it will rotate in the opposite direction. The original stroking causes random vibrations throughout the device; however, when one side of the dowel is touched while being stroked, some of the vibrations are damped and there are no longer random vibrations but instead a driving vibrational mode is set up which causes the flat piece of wood to rotate in a preferred direction. Please note that the end piece is not a propeller, that is, it does not have a pitch. The author has used twigs to demonstrate this phenomenon on many occasions. The dimensions given above do not appear to be critical.¹

THE CHLADNI PLATE: If an aluminum plate (25 cm x 25 cm x .25 cm) is supported in the middle by attaching a handle (a dowel about 2 cm in diameter and 12 cm

long), a very interesting phenomenon can be demonstrated by sprinkling sand or salt on the plate and then stroking the plate with a violin bow. (See Figure 2.) Standing patterns will appear on the surface. These will change according to the stroking motion. The plate has been put into vibration by the stroking motion and only certain parts of the plate are not in vibration. The material which was originally at rest will hop around on the plate and settle on parts of the plate which are not vibrating. Different patterns can be obtained because there are several vibrational modes which the plate can accommodate.^{2,3,4,5}

WATER TELEPHONE: If a mechanical music box mechanism is removed from its sounding board and wound there will hardly be a perceptible sound heard. If the mechanism is placed on a piece of wood or in fact onto most materials, a much more perceptible sound will be heard. The interesting concept of modulation can be demonstrated using this mechanism, along with an eye dropper and a constant water supply. If the eye dropper is placed through one of the holes (attachment points for the sounding board) of the mechanism and a constant stream of water is flowing through the eye dropper, a steady stream will be noticed when the mechanism is not playing. However, if the mechanism is wound and the stream is observed you will notice that the flow of water is now altered. This is a form of modulation of a signal, very similar to the way that radio signals are modulated. A signal, which was once pristine, is now carrying some sort of information. This information could be music, voice or data to mention a few.⁶

DISCUSSION: There are many examples of the results of vibrations in materials. Among these are musical instruments including our voices, whistling, ultrasonic cleaners, friction welding and induction melting, and some undesirable results such as friction, wear, heat, fatigue, loosening of bolts and screws and nails, the hum of a motor or transformer and such natural phenomena such as earthquakes, tidal waves and in general noise. These demonstrations can lead an audience to explore the effects of vibrations and the control of desirable and undesirable types of vibration.⁷

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ACKNOWLEDGEMENT: The author wishes to thank Mary L. Spiegel for processing this manuscript.

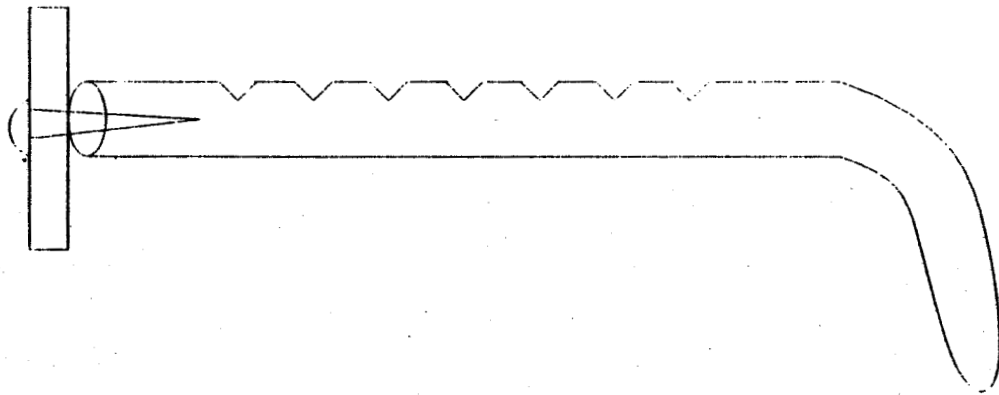


FIGURE 1
VIBRATING STICK

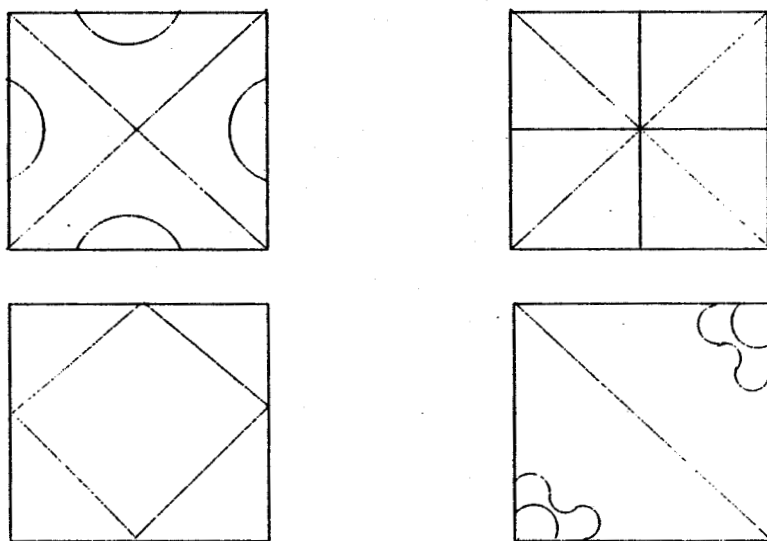


FIGURE 2
TYPICAL CHLADNI PATTERNS

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A NOVEL APPROACH TO HARDNESS TESTING

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A Novel Approach to Hardness Testing

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Key Words: Hardness, rebound, scleroscope, coefficient of restitution

Prerequisite Knowledge: Knowledge of physical testing of metallic materials

Objective: To demonstrate a simple rebound hardness measuring device and explore its applications and limitations.

Equipment:

1. Rebound hardness tester as outlined in Reference 1.
2. Several metallic samples of various compositions and hardnesses.

Introduction:

This paper gives a description of the application of a simple rebound time measuring device and relates the determination of relative hardness of a variety of common engineering metals. A relation between rebound time and hardness will be sought. The effect of geometry and surface condition will also be discussed in order to acquaint the student with the problems associated with this type of method.

Procedure:

A complete description of the construction of the apparatus is contained in Reference 1. This device, constructed for under \$100, is designed to repeatedly drop a 5.59 mm (0.220 in.) diameter ball from a fixed height of 9.0 cm (3.54 in.) onto a metal specimen clamped to a rigid base. A microphone coupled through an operational amplifier precisely relays the initial contact and subsequent rebound contact. A timing circuit is used to measure the interval between these events and calculates the rebound time, relatable to the coefficient of restitution of materials, an indication of the energy loss of the ball during the initial contact event.

Results and Discussion:

As shown in Table 1, there is a general trend for the materials with lower hardness to exhibit lower rebound times. Figure 1 shows that a linear relationship exists for Shore Scleroscope hardness numbers with Brinell hardness numbers over the entire range of steel samples tested. Figure 2 indicates that a linear relationship between rebound time and Brinell hardness can be established for steels having hardnesses measurable on the Rockwell C scale (Brinell hardness 300-500). The hardness relationship, unfortunately, does not extrapolate well into the Rockwell B range for steels. As also observed in Table 1 and Figure 3, there exists a relatively linear relationship for aluminum with hardness measurable on the Rockwell F scale.

Like the apparatus described in Reference 1, the Shore Scleroscope is designed to drop a steel ball or diamond indenter from a fixed height onto a test specimen placed on a clamping stand; the rebound height is either visually noted or recorded on a dial and used to indicate relative hardness. With the test apparatus described in this paper, the time interval is measured by digital circuitry, giving this method an enhanced degree of precision over the scleroscope. With both of these devices, the portability, ease of use, and relative non-destructive interaction with the material are significant with respect to Brinell testing in the field as well as in the undergraduate laboratory.

While cost, convenience, simplicity, and apparent correlation with conventional hardness tests are advantages of this devised testing method, sample geometry and surface condition can appreciably affect the precision of the device. As reported in Table 1, four copper specimens, all with the same hardness as measured by the Rockwell F test, did not give the same rebound time. The difference in each of these was either geometric or in the condition of the test surface. However, it should be possible to explain the results in terms of energy absorption mechanisms and/or sample-base coupling. For instance, on the oxidized surface, the interaction with the surface layer (fracture, dissipation of rebound energy at the layer interface) could reduce the rebounding. A bent specimen (even with concave side up) could lower the rebound by inefficiently reflecting the stress wave moving through the test piece. The reduced rebound time with the thinner specimen suggests that, as in static indentation tests, there could be a minimum specimen size necessary to characterize the hardness of the bulk material.

Notes to the Instructor:

The above results give rise to many thought-provoking, yet simple experiments for the students. They could investigate rebound time vs. sample thickness (for the same material hardness). Would a stack of thin specimens give the same result as one thick specimen? What is the effect of surface finish on rebound time?

Acknowledgment:

The authors would like to express their appreciation to Stamos Courpas, graduate assistant in the Department of Physics and Computer Science at Loyola College, for his efforts in the design and construction of this testing device.

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Sample Material	Thickness (in.)	Rockwell Hardness	Scleroscope Hardness	Brinell Hardness*	Rebound Time (0.001 seconds)					Ave.	Std. Dev.
					1	2	3	4	5		
1018 Steel											
	3/32	C48	64	451	156	157	161	156	155	157.0	2.3
	3/32	C48	64	451	155	162	168	159	165	161.8	5.1
	3/32	C43	57	400	150	148	150	144	151	148.6	2.8
	3/32	C38	51	353	137	145	135	144	142	140.6	4.4
	3/32	C33	46	311	131	131	136	135	132	133.0	2.3
	3/32	B80	23	150	130	126	130	123	129	127.6	3.0
3/32	B80	23	150	129	130	129	126	128	128.4	1.5	
3/32	B57	17	103	108	111	106	112	118	111.0	4.6	
Aluminum											
	1/8	F9			46	46	55	53	44	48.8	4.9
	1/8	F70			83	78	75	88	91	83.0	6.7
	1/8	F90			97	101	105	103	108	102.8	4.1
Copper											
	Oxidized	3/16	F85		128	132	129	131	126	129.2	2.4
	Clean	3/16	F85		144	144	144	146	147	145.0	1.4
	Bent	3/16	F85		126	133	129	137	128	130.6	4.4
		1/8	F85		95	90	95	89	95	92.8	3.0

*3,000 kg load, 10 mm standard ball

Table 1: Hardness Values vs. Rebound Times

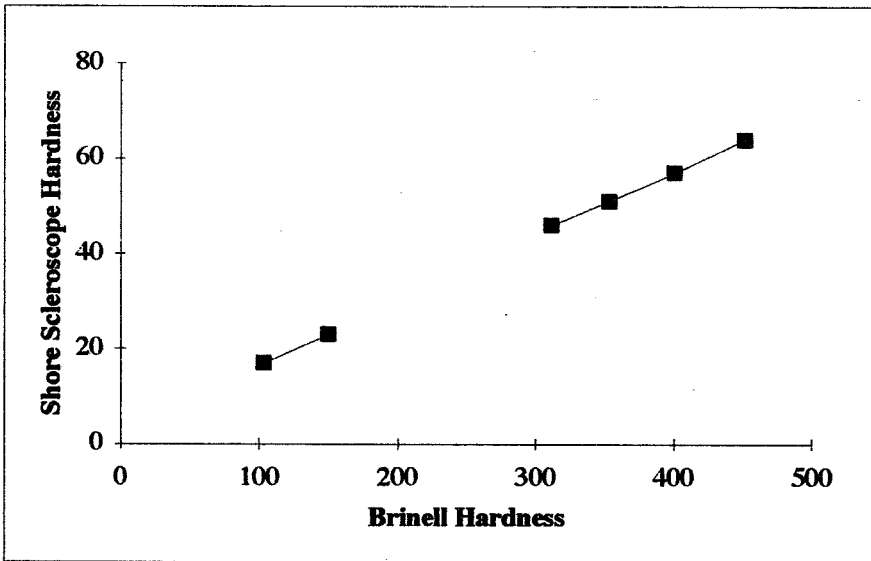


Figure 1
Scleroscope vs. Brinell
(Steel)

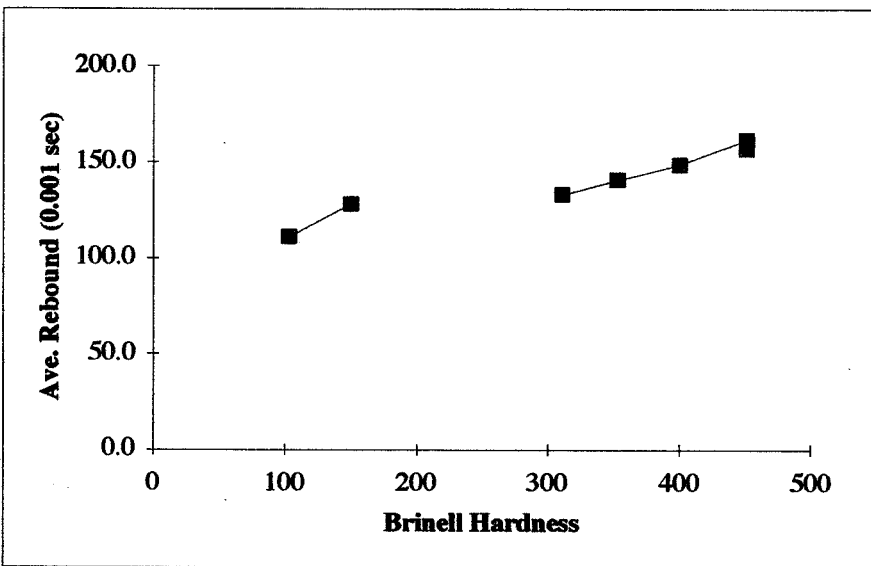


Figure 2
Rebound vs. Brinell
(Steel)

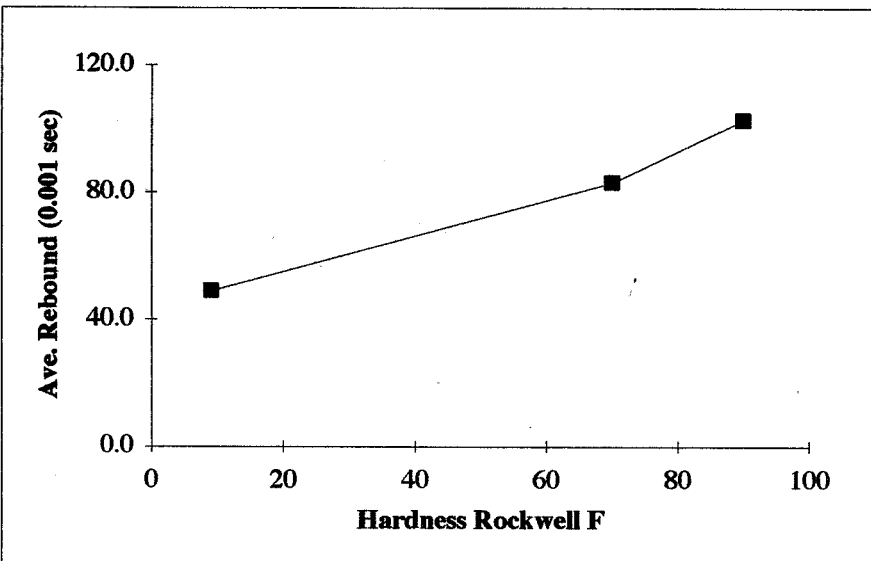


Figure 3
Rebound vs. Rockwell F
(Aluminum)

COST EFFECTIVE PROTOTYPING

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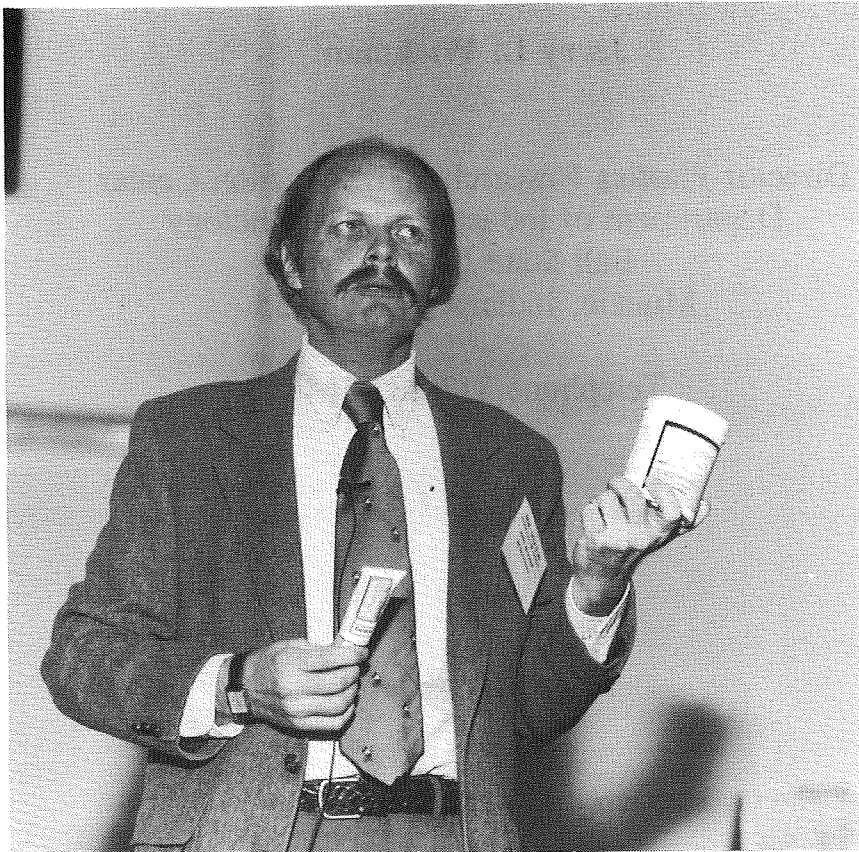
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Cost Effective Prototyping

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Key Words: Rapid prototyping (RP), Prototyping, Reverse engineering, Investment casting

Prerequisite Knowledge: Basic knowledge of part design, Computer Aided Design (CAD), prototyping, and mold flow characteristics are beneficial.

Objectives: To develop a cost effective laboratory exercise for prototype development. To develop a prototyping laboratory exercise that has the potential of linking part design, CAD, mold development, quality control, metrology, mold flow, materials testing, fixture design, automation, limited parts production and other issues as related to plastics manufacturing.

Equipment:

1. investment casting material
2. silicone rubber for casting
3. urethane elastomer for casting
4. pressurized wax injection unit
5. vacuum tank with vacuum pump
6. injection wax
7. paste floor wax
8. various tools for cutting sprue, runners, and gates
9. injection molded parts to be used as masters

Introduction:

Webster defines prototype as the first thing or being of its kind; original; model; pattern or archetype. The methods by which prototypes can be produced have changed drastically since Webster defined the term. Three dimensional models can be created in various CAD systems and an actual model produced within 24 hours. This can be done using Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), 3 Dimensional Printing (3DP), and Solid Ground Curing (SGC) to name the more common rapid prototyping methods. The cost of rapid prototyping (RP) equipment as it is known has dropped while the methods of RP have increased. Other methods of prototype development exist. They range from using Room Temperature Vulcanizing (RTV) silicone, lost foam process, and lost wax process to investment casting. These later processes are less costly and more time consuming but have the capability of helping to create a seamless education across the manufacturing curriculum.

This laboratory exercise is limited to using investment casting for mold building and a pressurized wax injection unit for the model building. The intent of the prototyping laboratory is to begin to address the issues of prototype development, materials selection, part design, mold design, CAD, quality control/metrology, cavity balancing, heating and cooling needs, cycle time calculations, and processing considerations as related to injection molding.

Plastics part design changes are occurring with greater frequency than ever before in history. The quality, accuracy, and speed of part design changes have a critical impact on the manufacturability of the final product. Global competition is forcing plastics manufacturers to utilize all available resources to ensure survival.

As a result of part design changes, it is important that students understand how a prototype is developed and can be produced. This laboratory exercise has applications in virtually any area where a product is being made; the final material (cast or machined metal, ceramic, plastic, etc.) is not critical to the prototype issue.

Procedure:

1. Select part or master. It is easier to start with an existing injection molded part as opposed to designing and fabricating your master. Small injection molded parts work well; examples may be electronic mouse parts, forks/knives/spoons, plotter components, electronic components (snap fit), etc. Using existing parts allows one to investigate the possibilities and nuances of reverse engineering.

What to avoid or consider for good part designs:

- * avoid deep cavities because part/master removal becomes more difficult and may fracture investment. Using glass reinforced investment will help if deep cavities are a necessity.
- * avoid thin wall parts if possible, they tend to be weak and difficult to fill when wax injecting.
- * avoid long material flow requirements because the wax is cooling as it flows. Long flow requirements may prevent a part from ever filling out. If necessary relocate the gating system to minimize long flow requirements.
- * consider parting line location, it is essential
- * consider parting line location, it is essential that the part can be removed from the investment. Carefully evaluate where the parting line should be on the part and how can an investment mold be made. Not all parts will easily lend themselves to this use of investment.
- * carefully consider all available options for the physical location(s) of the sprue, runner, and gate. The location, shape and size of the sprue, runner, and gate may be the difference between a successful prototype and/or one that fails.
- * draft on all parts is critical. The greater the draft the easier it is to remove the part from the investment.

- * casting and build method-develop flow charts and graphs of how the investment will be cast and the mold built. Flow charting minimizes errors in the production of the prototype and increases success rates. Also consider the process by which the vacuum is being used. Entrapped air bubbles will affect surface characteristics. If a flat back part/master is placed face down in the investment, as in Figure 1, entrapped air may not be removed.

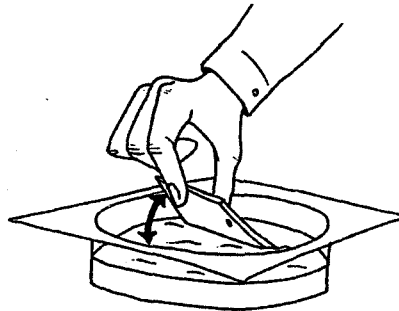


Figure 1. Flat back pattern placed into investment with detail facing down.

Consider placing the part in the bottom of the mold frame and pouring/casting investment on top of the part. If the part/master density is such that the part floats in the investment, the parting line is moved or lost. A method should be devised to temporarily secure the part to the mold frame. Conversely if the part sinks in the investment, one should devise a method of supporting the part.

- * part orientation in mold is a function of the parting line axis, size of the mold frame, and planned location of the sprue, runner and gating system.
 - * single vs. multiple cavity mold. Start building single cavity molds using simple flat back parts with a single axis parting line. In order to avoid frustration start simple and move with experience to the more complex designs.
2. Put coating of wax on plastic part or master to minimize investment adhering to part.
 3. Fabricate mold frame, depending on size of part; a plastic food container (Tupperware, Rubbermaid, etc.) works well. Some thermoformed containers work well also. Disposable mold frames can be used and are available in the shape of small fiberboard boxes.
 - * What is the size and shape of the part, this dictates the minimum dimensions of the mold frame?
 - * Where is the parting line to be located?
 - * Is draft important and how will investment be removed from the mold frame?
 - * What is the life expectancy of mold frame?
 - * What facilities are available for building mold frames?
 4. Mix investment to specifications.
 - * Check for consistency of investment.
 - * Minimize the introduction of air when blending investment.
 - * Mix sufficient quantities of investment to fill 60% of the mold.
 - * If the directions for mixing investment are followed, shrinkage of the

investment material in small volumes should be minimal. As one increases the water content of the mix, shrinkage and cracking will occur. Pulling a vacuum removes trapped air and enhances one's ability to capture detail. The investment will harden whether a vacuum is pulled or not.

5. Pull vacuum to remove air and enhance detail.

- * Possible vacuum devices (pump, chamber, gage)?
- * Optimal vacuum time?
- * Measuring vacuum?
- * Mating surfaces?

6. Cast investment to parting line.

- * Wax interior surfaces of mold frame.
- * Consider dimensional shrinkage, if any, of investment.
- * Where and how will the master be placed in the investment?
- * Density of master vs. investment?
- * What is optimal cure time?
- * Place on level surface (keep parting line level).
- * Possible sprue, runner, and gate locations?
- * Mating surfaces of the mold halves?

7. Pull vacuum to remove air and enhance detail.

8. Cleanup and/or machine mold half.

- * The investment should be allowed to cure a minimum of two hours before any machining takes place.
- * Is the meniscus of the investment going to cause a mating problem?
- * Defect identification (recast or repair), a 10x hand lens will show critical details and potential defects.
- * Investment can be easily machined depending on the tools available. Once the investment hardens it is still relatively soft. It can be worked with a variety of tools ranging from hand tools to CNC mills or lathes.
- * Locating pin placement, how will the mold halves maintain alignment when removed from the mold frame? Locating pins can be cast in or pockets can be drilled into the hardened investment. Once the opposing mold halves are cast, the alignment problems should be resolved. If pockets are to be machined in the first cavity cast, shallow (0.250"-0.500") depressions will suffice.
- * Wax mating surfaces.

9. Prepare to cast opposing half of mold (mold may be made of more than 2 parts).

- * See #4/5 for reference.

10. Pour investment into cavity

- * Place waxed master in cavity.
- * Use original mold frame.

11. Pull vacuum to remove air and enhance detail.
12. Cleanup and/or machine mold.
 - * Depending on intended use, square mold.
 - * Clean thin sections.
 - * Repair or recast sections. Repair of small voids or pockets can be accomplished by mixing the investment to specifications and filling the void or pocket. Allow the investment time to harden and machine to final size. If the section is badly damaged or cracked, recasting the mold half may be the more expedient method.
13. Per calculated specifications cut sprue, runner(s), and gates.
 - * Avoid sharp corners.
 - * Avoid thin sections (consider glass reinforced investment).
 - * Investment can be cut with hand tools.
 - * Match sprue radii on mold to that of wax injection unit.
 - * Gate size - start with 0.040" x 0.020" - keeping the cavity wall as thick as possible.
 - * Runner size - keep length as short as possible, start with 0.125" round.
14. Wax mating surfaces/cavity of mold or use mold release
15. Bring wax injection unit up to operating temperature
 - * Wax injection temperatures usually range from 140° F/60° to 170° F/77° C. The following represents a brief listing of waxes available from The Kindt-Collins Company. Your needs will dictate which wax works best for your part.
16. Produce wax prototyped parts.
 - * Fine tune process. Fine tuning of the process (investment of cavities, wax injection molding, sizing sprue, runner, and gating system) may need to take place. The investment is soft, gates can be enlarged as needed with hand tools. The viscosity of the wax varies and cavities may or may not fill the first time. The investment will typically be at room temperature. If a gate is too small or a long flow length is experienced, the wax may freeze. Depending on the level of detail required in the part and temperature of laboratory environment, it may be necessary to warm the mold. Preheating the mold to 100 - 120° F should prevent the wax from freezing at any critical points, primarily thin sections.
 - * Consider changing size of sprue, runner, and gates.
 - * Consider changing location of sprue, runner, and gates.
 - * Evaluate part characteristics
 - Form
 - Fit
 - Function

Notes to the Instructor:

This particular laboratory exercise, depending on the resources available, has the ability to create a product that has topical implications across the curriculum. The prototyping issue can be used to tie together the various technical issues. The wax injection unit is cost effective, yet simple. For impressive designs, the CAD files could be used to produce an RP model. Local industries with more costly RP facilities (SLA, SLS, FDM, etc.) are not difficult to find.

The first several castings of parts or molds should be done using investment. If the part warrants additional development, silicone or urethane can be used. The silicone and urethane are more expensive than investment, but many of the properties of the final product outweigh those of using investment. For example a small mold may require roughly 1 lb. of investment (\$1.00) whereas the same tool in silicone or urethane may cost from \$20.00 to \$30.00. Silicone rubber is available from IASCO, 5724 West 36th. Street, Minneapolis, Minnesota, 55416-2594. Urethane elastomers are available from BCC Products Inc., P.O. Box 327, Franklin, Indiana, 46131.

The injection wax varies in price depending on the type and quantity purchased. Fifty pounds of injection wax will cost approximately \$330.00 and should last several years. The wax, investment, and wax injection unit are available from Kerr Manufacturing Co., P.O. Box 455, Romulus, Michigan, 48174-0908. Investment currently costs \$70.00/100 lbs., while the injection unit is \$750.00.

The vacuum pump can be obtained from Cole Parmer Instrument Co., 7425 North Oak Park, Niles, Illinois, 60714-9930, for approximately \$200.00. The vacuum chamber (22 quart pressure cooker) with modifications can be obtained for \$70.00.

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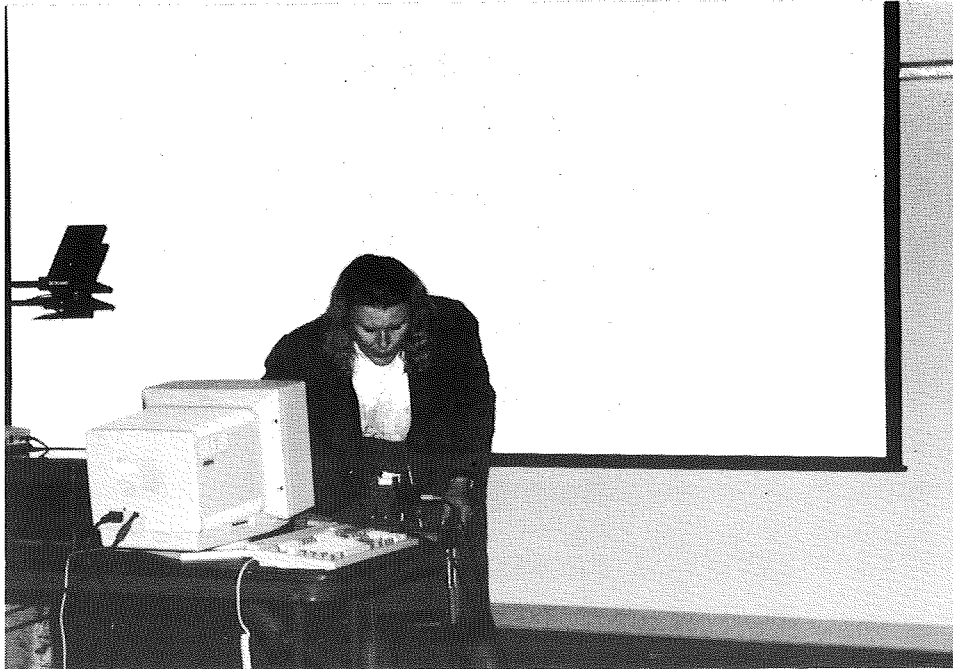
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COMPUTERIZED TESTING OF WOVEN COMPOSITE FIBERS

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Key Words: Woven Composite Fibers, fiber, glass fibers, graphite, stress, strain, modulus of elasticity, constant-rate-of-extension tensile testing machine.

Prerequisite Knowledge: Computer skills will be required to interface with the material testing center. Classroom study of the basics of stress, strain and modulus of elasticity in conjunction with or prior to the experiment.

Objective: The student will utilize the computerized testing center to perform tensile testing of the various woven composite fibers. They will interpret the graphs to provide more advanced testing results and data for stress, strain, and modulus of elasticity.

Equipment:

Unilab[®] Material Testing Center
Materials Testing Textile Accessory
Materials Testing Software
Computer (Windows[™] Software must be installed)
Computer Printer
Zirconia Scissors
Steel rule (with millimeter increments)
0-1" outside micrometer or metric equivalent
Rubber gloves
Calipers or inside micrometer
Paper, marker, calculator, pencil
Suggested woven fibers: Fine E-Glass Cloth
AS4 Graphite / E-Glass Weave

Introduction:

A composite material or composite is a structured solid material composed of two or more materials that form a useful material. The composite is designed to display the best properties or qualities of its component or once combined, display properties that neither material possesses. The existing materials are combined by physical means, as opposed to the chemical bonding that takes place in solid materials at the crystal stage.

A *fiber* is the single strand of material which threads or fabrics are made of. *Glass fibers* are produced by the process of drawing molten glass through tiny precision made openings and then lengthening them by air jet. Standard glass fiber normally used in glass-reinforced composite materials is known as e-glass. *E-glass* is the first type of fiberglass that was developed for use as a continuous fiber. It is a combination of 55% silica, 20% calcium oxide, 15% aluminum oxide, and 10% boron oxide.

Another type of fiber used in many applications is a black crystalline carbon known as graphite. *Graphite* has a very high melting point. The carbon content of graphite is 99% or greater. It is known as one of the few truly effective structural reinforcements. Cowoven fabric is a reinforced fabric woven with two different types of fibers in individual yarns, such as the AS4 graphite / E-glass Weave used in this experiment.

Woven composite materials have mechanical properties that are defined as a measure of the materials capabilities of being able to carry or resist mechanical forces or stresses. The resistance offered by a material to external forces or loads is defined as *Stress*. Stress is the amount of force (F) divided by the area (A) over which it acts. Using σ (sigma) as the universal symbol for normal stress, we have the following expression in equation 1.

$$\sigma = F / A \quad (1)$$

The corresponding SI (Systems International) units for force (F) = Newton's (N), Area (A) = square meters (m^2), and stress (σ) are Newton's per square meter (N / m^2) or Pascal (Pa). The percentage of elongation (e) or *strain* of the material is a ratio of the change in length of a specimen, from zero stress to a stressed state. Strain is the ratio of these two lengths, where l_f = final length and l_o = the original length, it is then multiplied by 100% to give the strain as a percentage. This expression can be seen in equation 2.

$$\% \text{ elongation} = \frac{l_f - l_o}{l_o} \times 100\% \quad (2)$$

The *modulus of elasticity* (E) is equal to the stress divided by the strain with corresponding SI units in Newton's per square meter (N / m^2) or Pascal (Pa).

$$E = \sigma / e \quad (3)$$

The American Society for Testing and Materials (*ASTM*) publishes standard test methods, specifications, practices, guides, classifications, and terminology for materials, products, systems, and services. The *ASTM* states that "A standard test method is a definitive procedure for the identification, measurement, and evaluation of one or more qualities, characteristics, or properties of a material, product, system, or service that produces a test result." In this experiment we will be using the tensile testing machine. According to *ASTM D 76* section 3.1.20, the tensile testing machine is

an apparatus designed to impart, or transmit, force/extension, or stress/strain, to a material and to measure the effect of the action. There are three types of tensile testing machines used for the force and elongation properties of materials. These are the constant-rate-of-traverse, CRT, constant-rate-of loading (force), CRL, and the *constant-rate-of-extension, CRE*. In accordance with ASTM standard D 1682 Section 3.6, the CRE tensile testing machine is a testing machine in which the rate of increase of specimen length is uniform with time. In this experiment we will be setting up the Unilab[®] material testing center and the materials testing textile accessory to act as a CRE tensile testing machine.

This experiment will focus on the stress, strain and modulus of elasticity of two different types of woven composite fabrics. The student will learn to transform the force/extension graph to a stress/strain graph. The computer interaction with the material testing center will automatically display the stress and strain readings when the cursor is placed at the point where the student requires the reading. The student will also perform exercises to learn how to automatically size and zoom in the graph so a more precise reading may be obtained.

Procedure:

Step 1: Producing the Fabric Sample:

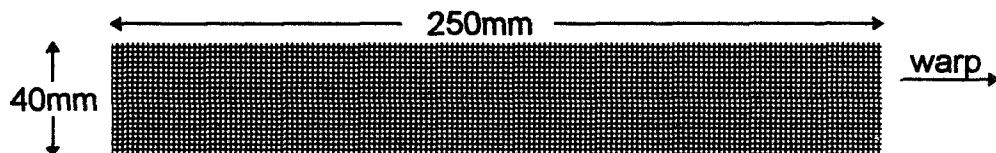
To obtain results that can be compared, it is necessary to cut the sample fabrics identically. For this experiment we will be cutting the material to be tested along the warp of the material. The warp is defined as the yarn running lengthwise in a woven fabric.

Required equipment:

- A. zirconia scissors
- B. steel rule (with millimeter increments)
- C. fine e-glass cloth or substitute
- D. AS4 graphite / e-glass weave or substitute
- E. 0-1" outside micrometer or metric equivalent

1. Cut the fabrics to be tested 250 mm long by 40 mm wide, as shown in Figure 1a.

Figure 1a



2. Using the outside micrometer, take a thickness reading of the fabric, reference Figure 1b. Record the data in Table 1. Also, record the width of the fabric sample in Table 1 (this should be approximately 40 mm). Calculate the cross sectional area in millimeters (thickness times the width) of the sample. Record in Table 1.

Figure 1b

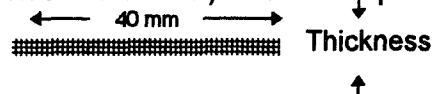


Table 1 Preliminary Measurements

Sample #	Fabric Thickness(mm)	Fabric Width (mm)	Cross sectional Area (mm ²)	Nominal gage length (mm)
1				
2				
3				
4				

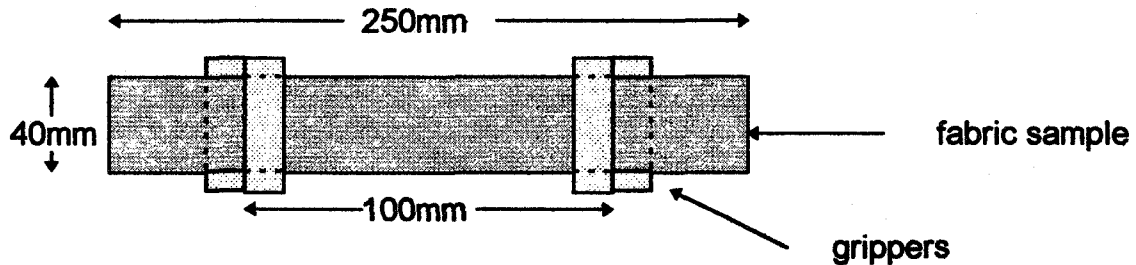
Step 2: Mounting the Fabric Sample

Required equipment:

- A. fabric samples
- B. Unilab[®] material testing center
- C. materials testing textile accessory
- D. steel rule (with millimeter increments)
- E. paper and marker

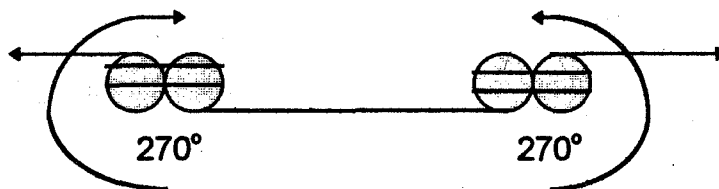
1. First, mark 100 mm out on a piece of paper. Next, lay the fabric flat on the paper, positioning the two circular grippers 100 mm apart as shown in Figure 2.

Figure 2



2. Holding the grippers and fabric, turn the grippers toward the center, 270°, as shown in Figure 3.

Figure 3



3. Pick up the sample and slide the flat sections at the end of the gripping cylinders into the slots of the textile accessories as shown in figures 4 and 5. Pull out on the loose ends to take up slack.

Figure 4

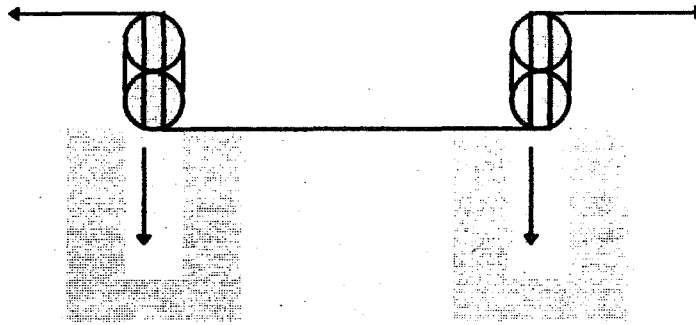
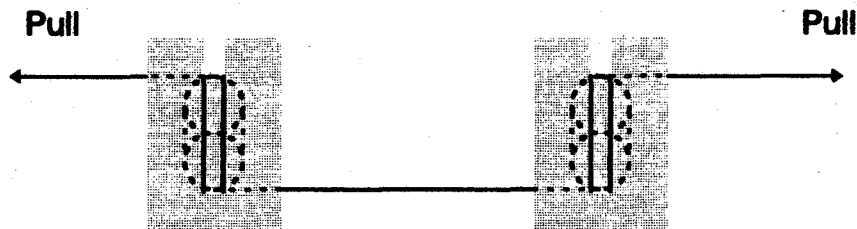


Figure 5



Step 3: Setting the Meters

Required equipment:

- A. calipers or inside micrometer
- B. steel rule (with mm increments)

1. The force meter has three range settings to choose from: 0.5 kN, 2 kN and 5 kN. Initially set the meter on its highest setting of 5 kN. Zero the force meter.
2. The displacement meter has five range settings to choose from: 0.5 mm, 1 mm, 5 mm, 10 mm, and 50 mm. Initially set the meter on its highest setting of 50 mm.
3. Slowly turn the operating handle clockwise to take up any slack in the fabric sample. Stop turning the operating handle when the force meter registers any slight reading. Zero the displacement meter.
4. At this point, take the nominal gage length of the sample. According to ASTM standard D 76 Section 9.1, the nominal gage length of a CRE type machine is the measured distance between the inner edges of the clamping surfaces of the clamps to the nearest 0.25 mm. By using a pair of calipers and a steel rule or an inside micrometer, a reading may be taken. Record this length in Table 1.
5. Do not switch from one range setting to another during a test. When you need to change scales, take the load off the sample and start a new test after you have switched range settings.

Step 4: Using the computer to plot the graph of Force (y-axis) vs Extension (x-axis)

Additional Equipment: A. Materials Testing Software
B. Computer
C. Printer (optional)

1. The initial default setting for the test time is 25 seconds. For this experiment the test time does not need to be changed.
2. Select *Configure* option menu. Select *Test Type*. Click on the *tensile* test option, then click on OK to exit the menu.
3. Using the mouse, place the cursor on the Start Sample button found to the left of the graph (this button resembles a graph). Click the mouse button once to start the test.
4. Slowly turn the operating handle clockwise until the specimen breaks. As force is exerted on the sample, a line will be plotted on the graph. If the test should finish early, the reset button can be clicked on and the test can be stopped.
5. At this point, save the data to a file or a disk to avoid loss of the data obtained.

Step 5: Automatic Sizing of the Initial Graph

1. Using the mouse and cursor, select the *Graph* option menu.
2. Select the *Scale* option (located at the bottom of the menu), to rescale the graph, and click on.
3. Select the autoscale button to provide the best fit of the graph to the screen. Click on OK to exit menu.

Step 6: Reading the Data

1. Place the cross-hairs at the highest point on the graph of the force vs extension, where the breaking point is. Click on the mouse button and a reading will appear in the information and control area of the screen display. Record the data obtained in Table 2

Step 7: Using the Zoom In Mode

1. Using the mouse and cursor select the *Graph* option menu.
2. Select the *Zoom in* option and click on. Cross-hairs will appear on the graph instead of the cursor. Zoom mode will appear in the information and control area of the screen display.

3. Position the cross-hairs on the graph near the area in which you wish to zoom in. Hold the mouse button down and drag the mouse to create a boxed area. Let up on the mouse button, and the area within the box will be enlarged to fill the screen.

4. Repeat Step 6, Reading the Data, in the zoom in mode and compare this data to the data obtained in the automatic sizing mode. The data may vary with increased magnification.

Table 2 Force / Extension Graph

Fabric Type	Sample #	Autosizing Mode		Zoom In Mode	
		Force (kN)	Extension (mm)	Force (kN)	Extension(mm)
	1				
	2				
	3				
	4				

Step 8: Transforming the Graph to Stress and Strain

1. Using the mouse and cursor, select the *Graph* option menu.
2. Select the *Zoom out* option and click on. The graph will return to the normal mode.
3. Next, select the *Transform* option menu.
4. Select the *Stress & Strain* option and click on.
5. Enter the area (mm²) and nominal gauge length (mm), from Table 1, of the sample material. Click on OK to exit the menu.
6. The graph will change to the stress/strain mode, with the y axis being stress in MPa and the x axis being strain in percent (%).

Step 9: Automatic sizing of the Stress / Strain Graph

1. Using the mouse and cursor, select the *Graph* option menu.
2. Select the *Scale* option(located at the bottom of the menu), to rescale the graph, and click on.
3. Select the autoscale button to provide the best fit of the graph to the screen. Click on OK to exit menu.

Step 10: Reading the Data

1. Place the cross-hairs at the highest point on the graph. Click on the mouse button and a reading will appear in the information and control area of the screen display. Record the data obtained in Table 3.

Step 11: Using the Zoom In Mode

1. Using the mouse and cursor, select the *Graph* option menu.
2. Select the *Zoom in* option and click on. Cross-hairs will appear on the graph instead of the cursor. Zoom mode will appear in the information and control area of the screen display.
3. Position the cross-hairs on the graph near the area in which you wish to zoom in. Hold the mouse button down and drag the mouse to create a boxed area. Let up on the mouse button, and the area within the box will be enlarged to fill the screen.
4. Repeat Step 10, Reading the Data, in the zoom in mode and compare this data to the data obtained in the automatic sizing mode. The data may vary with increased magnification.

Table 3 Stress / Strain Graph

Fabric Type	Sample #	Autosizing Mode		Zoom In Mode	
		Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
	1				
	2				
	3				
	4				

Step 12: Comparing the Data

1. For use with calculations, transfer the cross sectional area of the sample from Table 1 into Table 4 and transfer the data recorded for force in Table 2 (zoom mode) into Table 4.
2. Using equation 1 ($\sigma = F / A$) calculate the stress using this data. Record the results in Table 4.
3. Compare these results with the data obtained for stress in Table 3 (zoom mode) for the same samples. (These results should be similar).

Table 4 Comparison of the force / extension graph vs stress / strain graph

Sample #	Area (mm ²)	Force (kN) From Table 2 (zoom mode)	Stress (MPa) From Table 3 (zoom mode)	Stress (MPa) Calculated
1				
2				
3				
4				

Step 13: Calculating the Modulus of Elasticity

1. For use with calculations, transfer the data recorded for stress and strain in Table 3 (zoom mode) into Table 5.
2. Using equation 3 ($E = \sigma / e$), calculate the modulus of elasticity for each sample and record these results in Table 5.

Table 5 Calculating the Modulus of Elasticity

Sample #	Stress (MPa) From Table 3 (zoom mode)	Strain (%) From Table 3 (zoom mode)	Modulus of Elasticity (MPa)
1			
2			
3			
4			

* Repeat entire procedure for each additional sample taken.

Engineering Discussion Questions:

1. While performing Step 1.2, you were asked to calculate the cross sectional area of the sample.
 - A. From an engineering standpoint, evaluate and state the major source of error that occurred in this calculation.
 - B. How did this one error affect the rest of the experiment?
 - C. Suggest methods to overcome this error.
2. What other errors can occur in this type of experiment?

Notes to Instructor:

1. **Discussion Question 1-A:** The major cause of error occurred because the air gaps between the fibers of the sample are not taken into account.

Question 1-B: This error directly impacts the cross sectional area of the sample. The calculations performed for stress will be insufficient because they are directly proportional to the cross sectional area. This ultimately will cause the final results of the modulus of elasticity for the samples to have a large standard of deviation.

Question 1-C: Methods to overcome this include: a) using a micrometer to verify the diameter of a single fiber, then counting the number of individual fibers in the sample and multiplying them (however even then the standard of deviation may be great between each individual fiber); b) using an air permeability detection apparatus to verify the extent of the air in the sample; c) purchasing material that the manufacturer has verified the cross sectional area.

Question 2: The most common type of errors which occur in this type of an experiment include: a) the fabric slipping in the jaws of the clamps, b) failing to zero the test meters prior to each test, c) failure to properly read measuring devices (micrometers, etc.).

2. Some faculty teaching introductory courses in materials technology lack the laboratory and equipment necessary for students to have hands on experience. This experiment utilizes a very low-cost, "student friendly", multiple purpose, computerized testing device. This testing center and type of experiment works for a course even if there is no scheduled laboratory. The device and experiment are very simple to use as a supplemental outside activity set up in a computer lab.

3. The Unilab[®] Materials Testing Center is a technology education laboratory device. It is not one that is in industry to meet ASTM standards or to establish standards. However, you will note the results obtained and the graphical outputs represent the manner in which materials react when forces are applied to them. Samples of the tables, results, and graphs I obtained follow this experiment.

4. A printer may be used with this experiment to print out the resulting graphs.

5. The Unilab[®] Materials Testing Center can be obtained through Unilab[®], Inc. 1604 Walker Lake Road, Mansfield, Ohio 44906. Phone number -- (419) 747-1040. Fax number (419) 747-1041.

6. The Zirconia scissors can be obtained through Lone Peak Engineering, 12660 S. Fort St., Draper, Utah 84020-9362. Phone number -- (801) 553-1732. Fax number (801) 553-1734.

7. Rubber gloves should be worn when handling certain woven fabrics to avoid the possibility of loose fibers getting embedded into skin.

8. I found that taping the ends of the sample helped keep the sample from unraveling.

9. This experiment may be used with any type of woven composite fabric or other fabrics you choose. Woven fabrics can be purchased in your local area through various suppliers of fiberglass materials. I was able to purchase a 2' X 4' sheet of fiberglass used for automobile repair at Wal-Mart for approximately \$4.00. Prices will vary depending on the type of material you choose.

10. I experimented with aramid fabric (Kevlar[®]). I was unable to break the Kevlar[®] fabric at widths of 40mm or 20mm. I was finally able to break the Kevlar[®] by pulling one band of fibers out and testing them.

References:

American Society for Testing and Materials. 1994 Annual Book of ASTM standards. Philadelphia: ASTM, 1994. ASTM D 76 Section 3.1.20, D 76 Section 9.1, D 1682 Section 3.6.

Jacobs, James A. and Thomas F. Kilduff. *Engineering Materials Technology, 2nd ed.* New Jersey, Prentice Hall Career & Technology, 1994, pp. 119,134, & Chapter 8.

Materials Testing Kit and User Guide and Reference Manual, Unilab[®] Limited, 1994. The Science Park, Hutton Street, Blackburn BB1 3BT England. pp. 13, 24, 25.

Materials Testing Apparatus Program User Guide, Unilab[®] Limited, 1992. The Science Park, Hutton Street, Blackburn BB1 3BT England.

RESULTS OBTAINED FROM SAMPLES TAKEN

*NOTE: Excessive significant digits are used in this result section to show the student the capabilities of the computerized system. However, students should be aware that reporting of actual engineering material properties should be with appropriate significant digits.

Table 1 Preliminary Measurements

Sample #	Fabric Thickness(mm)	Fabric Width (mm)	Cross sectional Area (mm ²)	Nominal gage length (mm)
1	0.0508	40	2.032	23
2	0.1651	40	6.604	22

Table 2 Force / Extension Graph

Fabric Type	Sample #	Autosizing Mode		Zoom In Mode	
		Force (kN)	Extension (mm)	Force (kN)	Extension (mm)
fine e-glass	1	0.459	3.800	0.459	3.809
graphite / e-glass weave	2	3.360	3.613	3.347	3.510

Table 3 Stress / Strain Graph

Fabric Type	Sample #	Autosizing Mode		Zoom In Mode	
		Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
fine e-glass	1	226.063	16.522	226.108	16.512
graphite / e-glass weave	2	507.497	15.358	507.044	15.289

Table 4 Comparison of the Force / Extension Graph vs Stress / Strain Graph

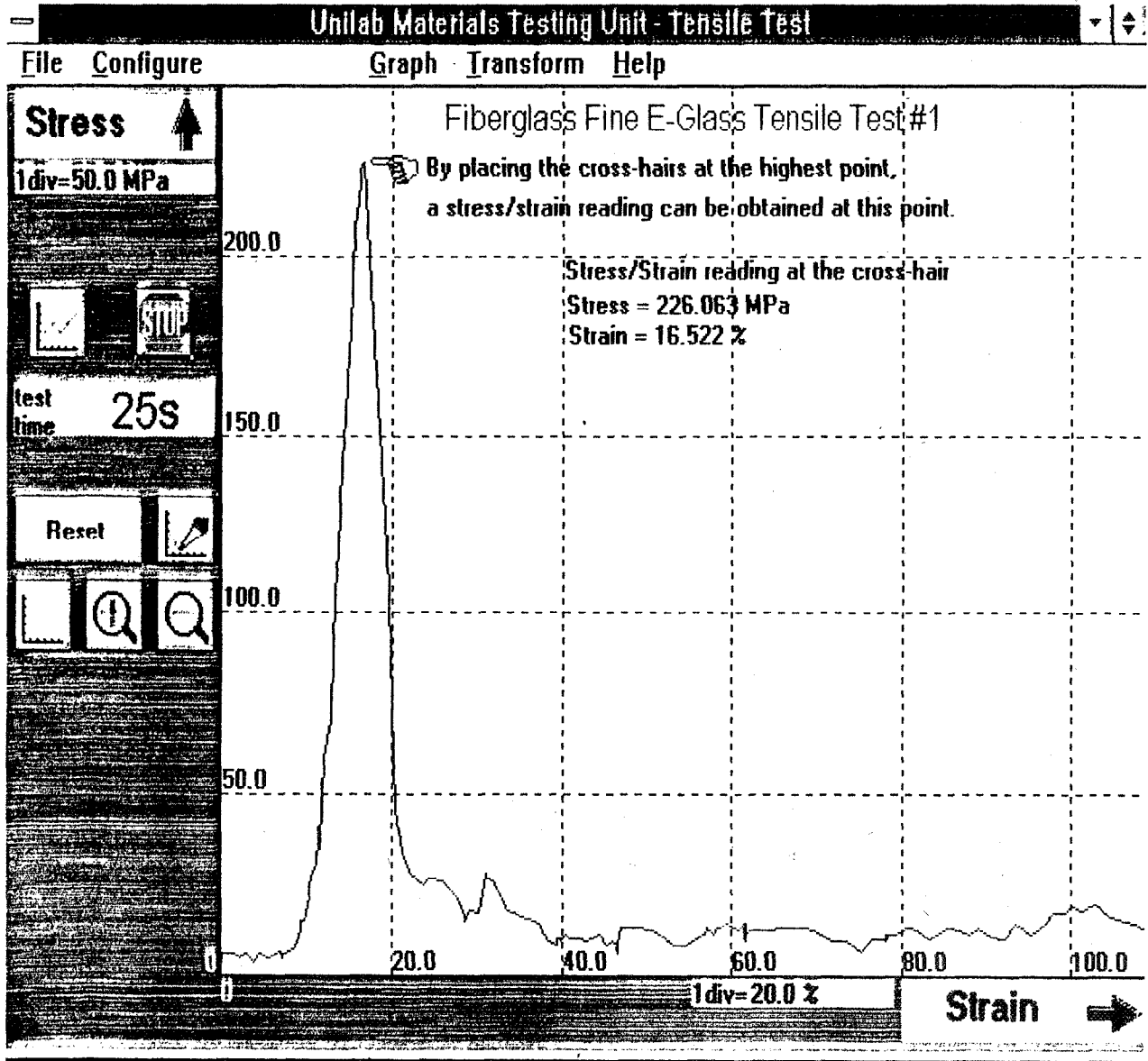
Sample #	Area (mm ²)	Force (kN) From Table 2 (zoom mode)	Stress (MPa) From Table 3 (zoom mode)	Stress (MPa) Calculated
1	2.032	0.459	226.108	225.88
2	6.604	3.360	507.044	508.78

Table 5 Calculating the Modulus of Elasticity

Sample #	Stress (MPa) From Table 3 (zoom mode)	Strain (%) From Table 3 (zoom mode)	Modulus of Elasticity (MPa)
1	226.108	16.512	1369.35
2	507.044	15.289	3316.397

See Steps 9 and 10: Automatic Sizing of the Stress/Strain Graph and Reading the Data

The following is a copy of the screen you will see for Step 9 and Step 10



*NOTE: The actual graph on this screen will be the print mode output..

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 1996	3. REPORT TYPE AND DATES COVERED Conference Publication		
4. TITLE AND SUBTITLE National Educators' Workshop: Update 95 Standard Experiments in Engineering Materials Science and Technology		5. FUNDING NUMBERS 243-10-01-01		
6. AUTHOR(S) James E. Gardner, Langley Research Center, Hampton, VA; James A. Jacobs, Norfolk State University, Norfolk, VA; Michael A. Karnitz, Oak Ridge National Laboratory, Oak Ridge, TN, Compilers				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-0001		8. PERFORMING ORGANIZATION REPORT NUMBER L-17561		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration, Washington, DC 20546-0001; Norfolk State University, Norfolk, VA 23504; National Institute of Standards and Technology, Gaithersburg, MD 20899; U.S. Department of Energy, Oak Ridge, TN 37831-6132		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CP-3330		
11. SUPPLEMENTARY NOTES American Society for Engineering Education; ASM Foundation; Battelle Pacific Northwest Laboratories; Fernald Environmental Restoration Management Corp.; Martin Marietta Energy Systems, Inc.; Materials Education Council				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 23 Availability: NASA CASI (301) 621-0390		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) This document contains a collection of experiments presented and demonstrated at the National Educators' Workshop: Update 95, held at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, on November 5-8, 1995. The experiments related to the nature and properties of engineering materials and provided information to assist in teaching about materials in the education community.				
14. SUBJECT TERMS Materials; Experiments; Education		15. NUMBER OF PAGES 404		16. PRICE CODE A18
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102