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Lewis Research Center

Report Title:

"Composites Research in Support of the NASP Institute for Composites (NIC)"

NCC3-218

Period Covered:

June 1, 1991 through August 31, 1994

Submitted by:

T. Michael Knasel
Director for Research
Ohio Aerospace Institute
22800 Cedar Point Road
Cleveland, OH 44142
216/962-3040

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Unclas

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NASA GRANTEE SUBCONTRACTOR
NEW TECHNOLOGY REPORT

NASA requires each research grantee, research contractor and research subcontractor to report new technology to the NASA Technology Utilization Office. The required reports and corresponding schedules for researach grantee subcontractors are as follows:

Title of Report	Form Number	Timetable
Individual Disclosure	NASA 666A	The grantee subcontractor discloses each discovery of new technology individually, at the time of its discovery.
Interim Report	LeRC-GSNTR	For multi-year grant subcontracts, the subcontractor summarizes the previous year's disclosures on an annual basis. The first Interim New Technology (NT) Report is due exactly 12 months from the effective date of the subcontract.
Final Report	LeRC-GSNTR	The grantee subcontractor submits a cumulative summary of all disclosed discoveries. This Final NT Report is submitted immediately following the subcontract's technical period of performance.

Subontractor Name and Address: Massachusetts Institute of Technology
Department of Materials Science and Engineering
77 Massachusetts Ave.
Cambridge, MA 02139

Report Submitted by: R. M. Pelloux
Telephone Number: (617) 253 - 3314

NASA Grant Title: NASP Institute for Composites (NIC)

NASA Grant Number: NCC 3- 218

NASA Grant Monitor: OAI Mike Knasel

Subcontract Completion Date: 8 / 31 / 94

Today's Date: 9 / 22 / 94

New technology may be either reportable items or subject inventions.

A reportable item is any invention or discovery, whether or not patentable, that was conceived or first actually reduced to practice during the performance of the contract or subcontract. Large business contractors and subcontractors must disclose reportable items as they are discovered and submit a noncumulative list of these new technology items on an annual basis [ref: Interim NT Report] and a cumulative list at the completion of the contract (or subcontract) period [ref: Final NT Report].

A subject invention is any invention or discovery, which is or may be patentable, that was conceived or first actually reduced to practice during the performance of the contract or subcontract, Small business contractors and subcontractors must, at a minimum, disclose subject inventions as they are discovered and submit a cumulative list of these new technology items on an annual basis [ref: Interim NT Report] and at the completion of the contract (or subcontract) period [ref: Final NT Report].

Grantees, small business contractors and subcontractor are only required to disclose and report patentable items (subject inventions). We request, however, that small business contractors and subcontractors disclose both patentable and nonpatentable (reportable) items, both of which are automatically evaluated for publication as NASA tech briefs and considered for NASA *Tech Brief* awards.

PLEASE COMPLETE THE REVERSE SIDE OF THIS FORM AND MAIL TO THE FOLLOWING ADDRESS:

NASA LEWIS RESEARCH CENTER
ATTN: KATHY KERRIGAN
TECHNOLOGY UTILIZATION OFFICE; MAIL STOP 7-3
CLEVELAND, OHIO 44135

NASA National Aeronautics and Space Administration

New Technology Report

Form Approved
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NT CONTROL NO. *(Official use only)*

INSTRUCTIONS

This form may be used when reporting inventions, discoveries, improvements or innovations to NASA. Use of this report form is optional; provided, however, that whatever report format is used contain the essential information requested herein.

In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure," as required by the New Technology or Property Rights in Inventions clause. For further guidance as to what constitutes a satisfactory report, please refer to NHB 2170.3, Documentation Guidelines for New Technology Reporting.

Available additional documentation which provides a full, detailed description should be attached, as well as any additional explanatory sheets where necessary.

1. TITLE

Elevated Temperature Tensile and Creep Deformation of a SiC Fiber-Reinforced Titanium Metal Matrix Composite

2. INNOVATOR(S) *(Name and Social Security No.)* *

R. M. Pelloux - SS 534 42 3580
Rita Thurston - SS 357 68 9567

3. EMPLOYER *(Organization and division)*

Massachusetts Institute of Technology
Dept. of Materials Science and Engineering

4. ADDRESS *(Place of Performance)*

77 Massachusetts Ave.
Cambridge, MA 02139

SECTION I — DESCRIPTION OF THE PROBLEM THAT MOTIVATED THE TECHNOLOGY DEVELOPMENT *(Enter A.—General Description of Problem Objective; B.—Key or Unique Problem Characteristics; C.—Past History/Prior Techniques; D.—Limitations of Prior Techniques)*

The main goal was to measure the elevated temperature tensile and creep properties of a SiC fiber-reinforced titanium metal matrix composite.

* Supplying this information is voluntary, in accordance with Public Law 93-579 (Privacy Act of 1974). However, it is required for eligibility in the establishment of Space Act monetary awards.

SECTION II *(Con.)*

SECTION III — UNIQUE OR NOVEL FEATURES OF THE TECHNOLOGY AND THE RESULTS (OR BENEFITS) OF ITS APPLICATION *(Enter as appropriate A.—Novel or unique features; B.—Development or conceptual problems; C.—Operating characteristics, test data; D.—Analysis of capabilities; E.—Source of error; and F.—Advantages/shortcomings)*

C. - Test data results are given in attached report and in MS thesis.

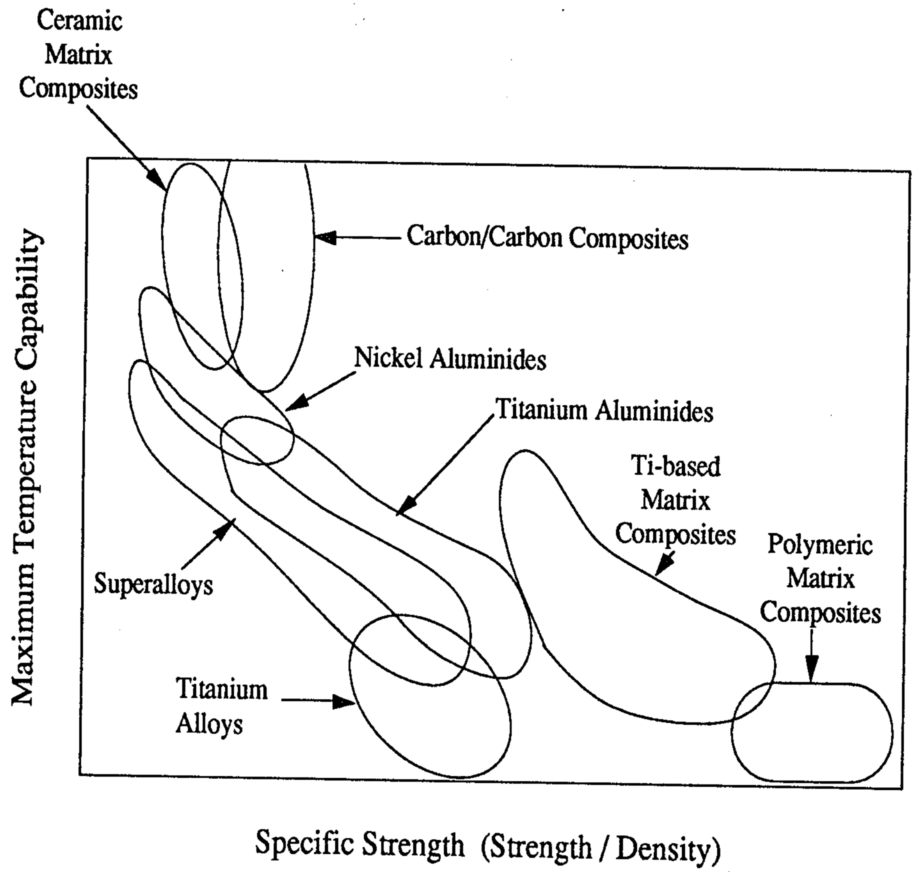
ELEVATED TEMPERATURE TENSILE AND CREEP DEFORMATION OF A SiC FIBER-REINFORCED TITANIUM METAL MATRIX COMPOSITE

Research Sponsored by the National Institute for Mechanics and Life Prediction of High Temperature Composites (NIC) at the Wright Laboratory Materials Directorate, Wright-Patterson AFB, OH

Additional assistance provided by: Instron Corporation, Canton, MA
and GE Aircraft Engines, Lynn, MA

Massachusetts Institute of Technology
Department of Materials Science and Engineering
Professor R. M. Pelloux
Research Assistant: Rita J. Thurston
September 30, 1994

Relative Capabilities of Several Conventional and Advanced Materials



Outline of Presentation

- Research Objectives
- Material
- Experimental Results
    - (1) Monotonic Tensile Behavior and Strain Rate Sensitivity
    - (2) Creep Behavior
    - (3) Creep Tests with DCPD Technique
- Conclusions
- Recommendations for Future Work

Research Objectives

- Develop a comprehensive understanding of the tensile and creep behavior of continuous fiber-reinforced metal matrix composites, including damage accumulation and failure mechanisms

- Evaluate test methodologies and equipment for evaluation of high temperature composites

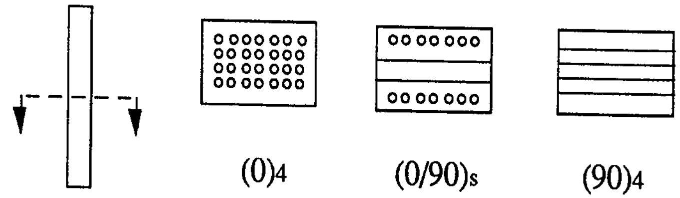
- Generate mechanical property data for analytical models and design and life prediction techniques

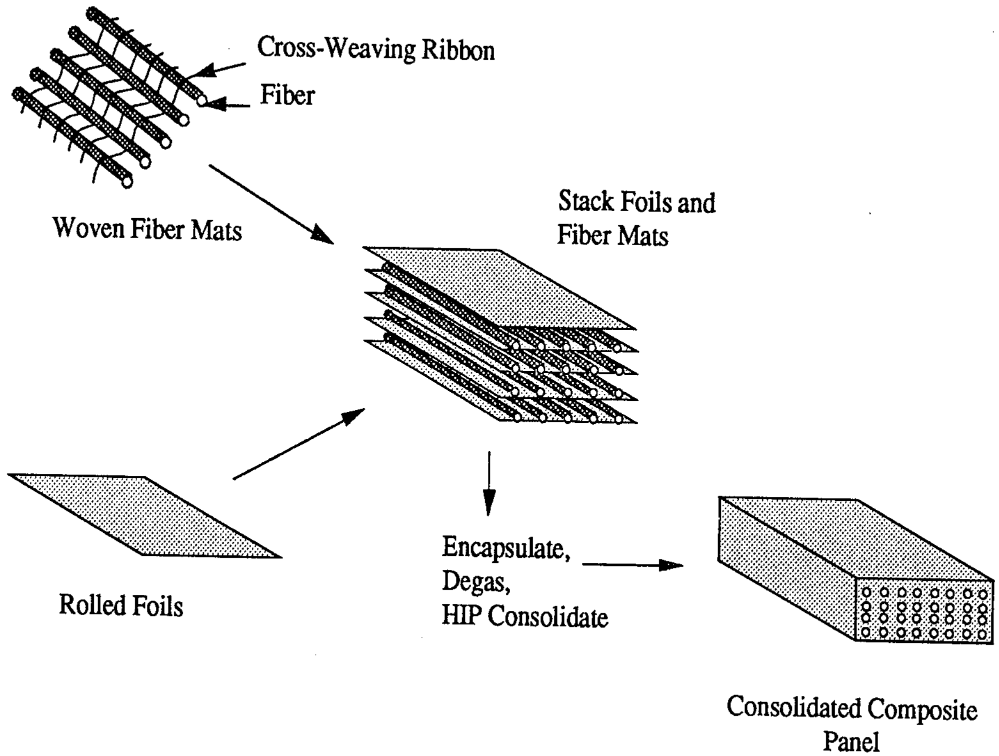
SCS-9/Beta 21S Composite

Beta 21S: Ti-15Mo-2.7Nb-3Al-0.2Si
(weight percent)

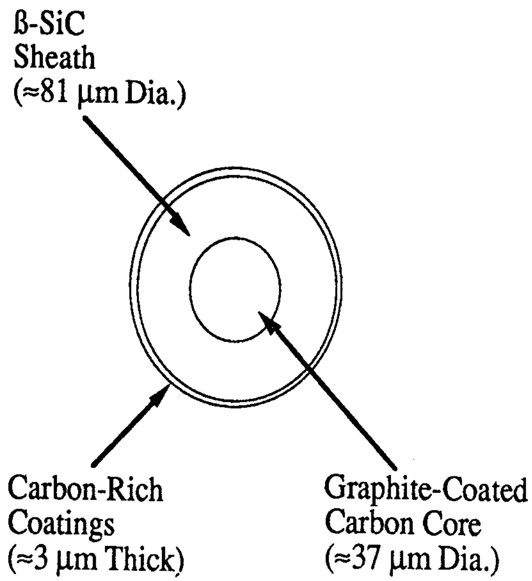
SCS-9: SiC fiber

Composite: 0.24 fiber volume fraction

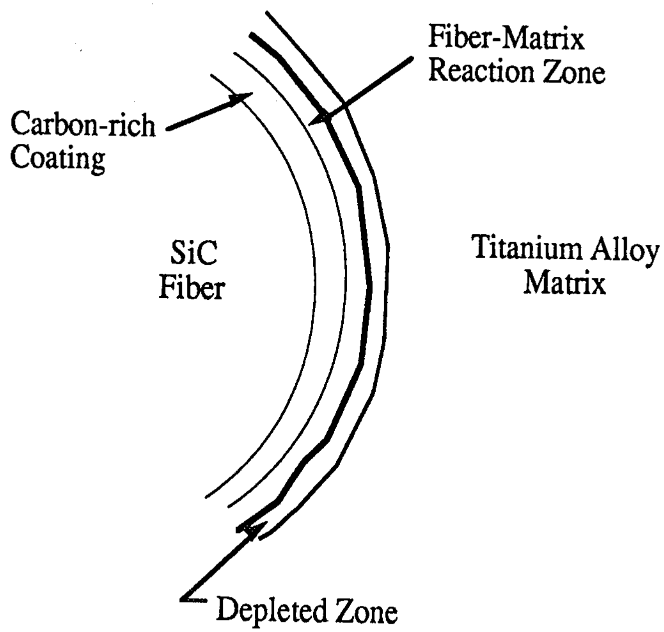




Cross Sections of SCS-9 Fiber and Fiber-Matrix Interface

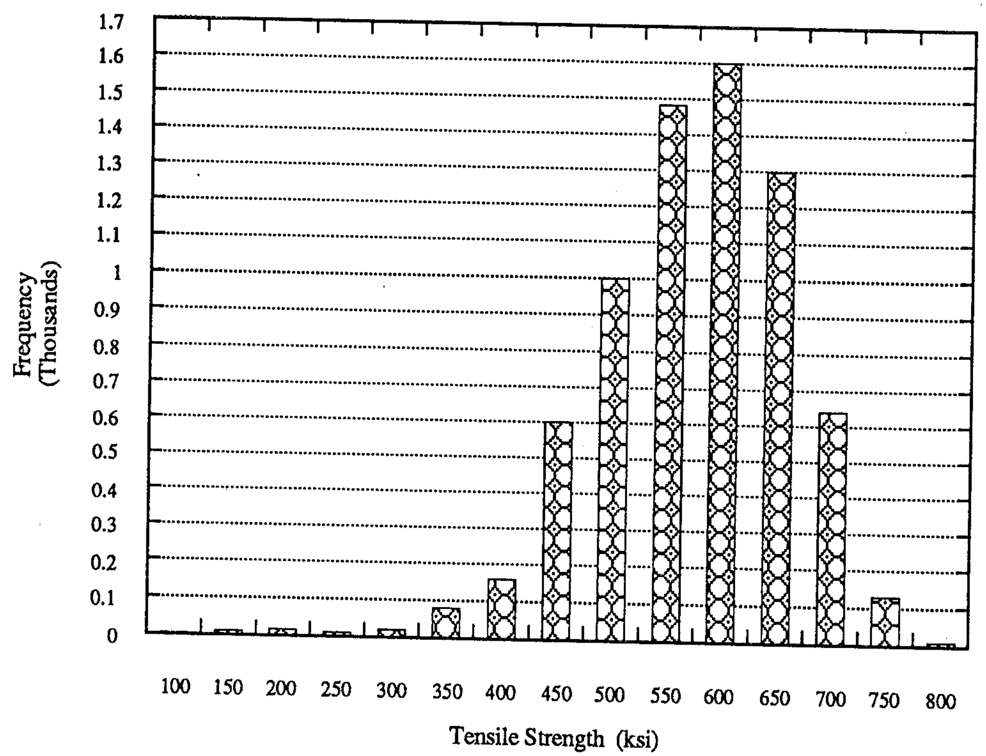


(a)



(b)

Histogram of SCS-9 Fiber Tensile Strength



Tensile Behavior

Test Equipment

- Instron Model 8502 dynamic test system with automatic data collection
- Modular hydraulic grips with side-entry wedge grip heads
- 1-zone (25.4 cm) furnace
- Strain gage extensometer for RT tests (25.4 mm gage length)
- Instron capacitive extensometer for ET tests (24.8 mm gage length)

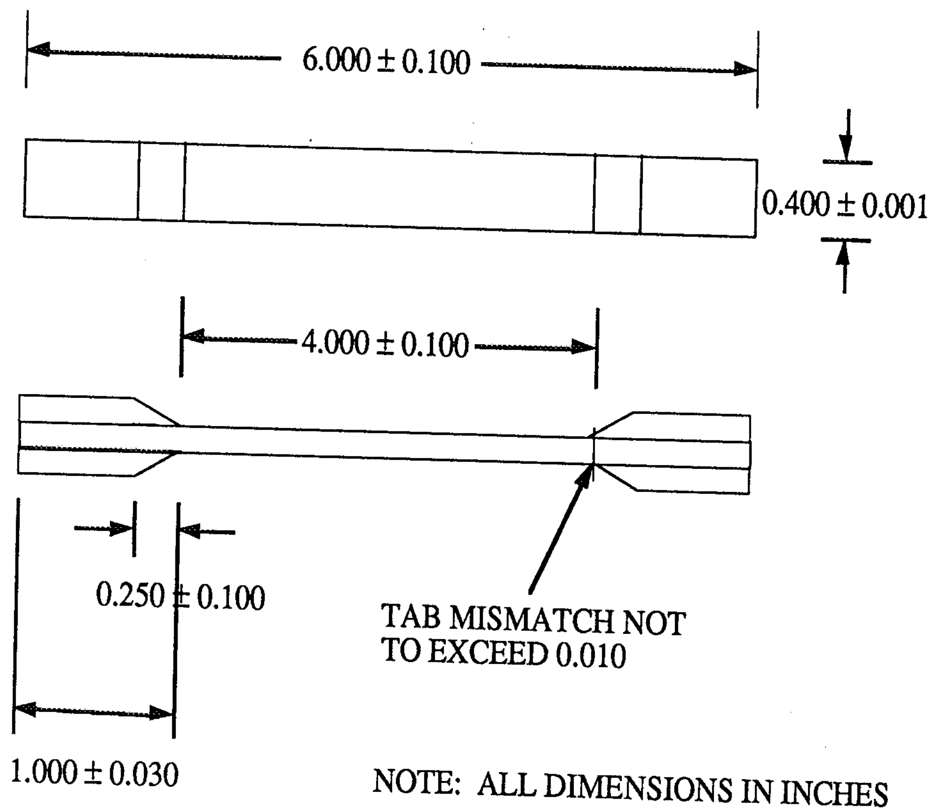
Tensile Test Parameters and Specimen Geometry

Constant Strain Rate Tests

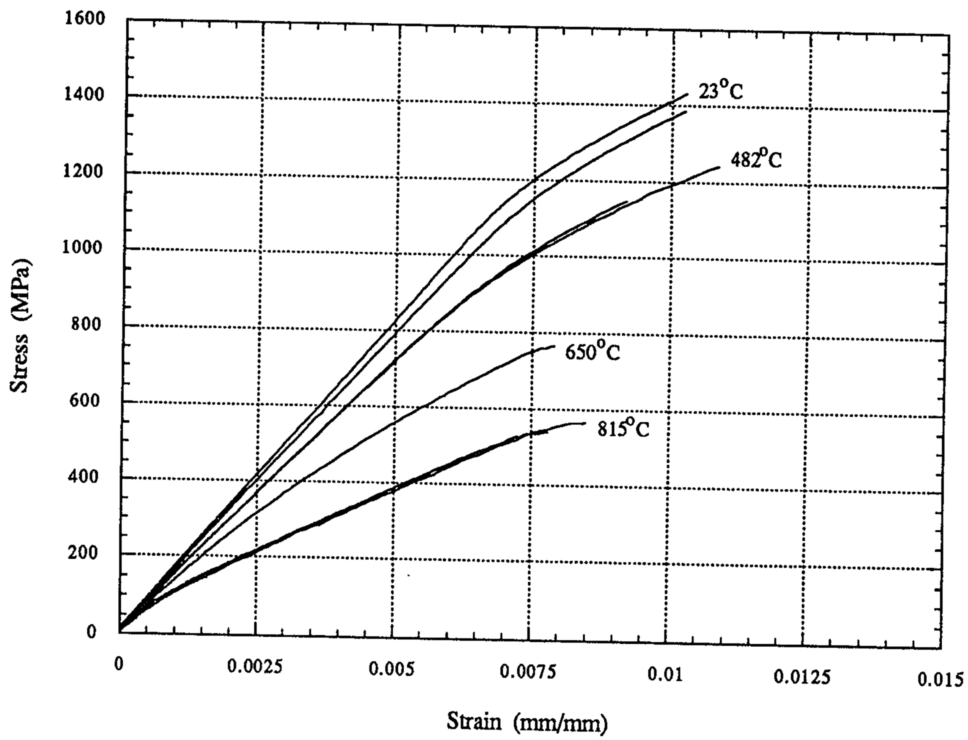
- RT, 482, 650, 815°C
- 0.01 mm/mm/min.

Strain Rate Sensitivity Tests

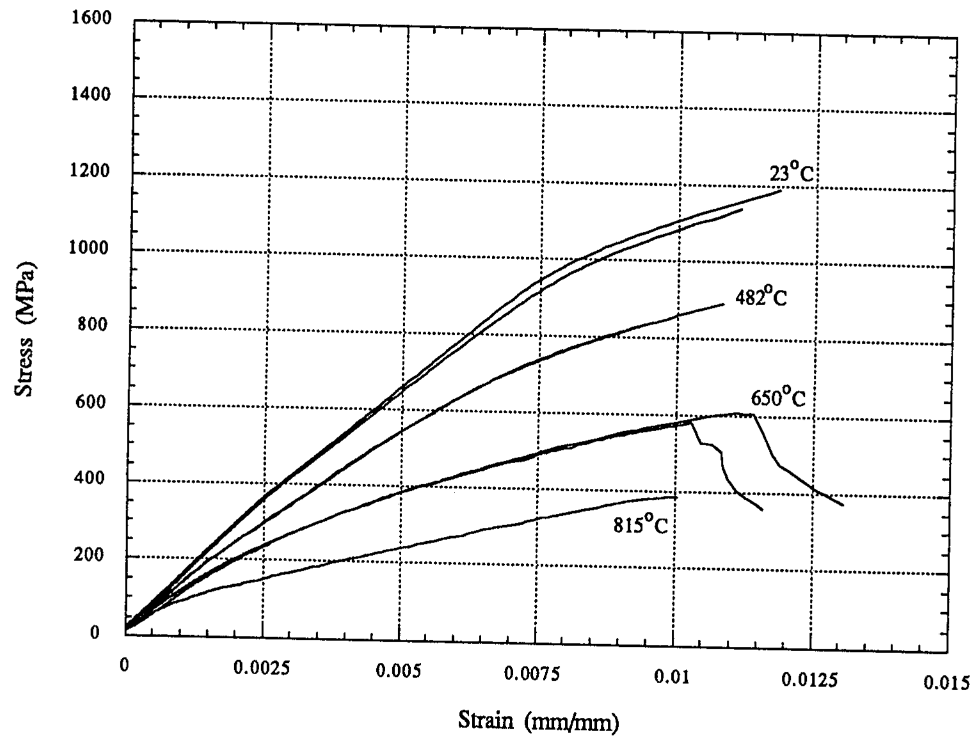
- 482, 650, 815°C
- 0.001, 0.01, 0.1 mm/mm/min.



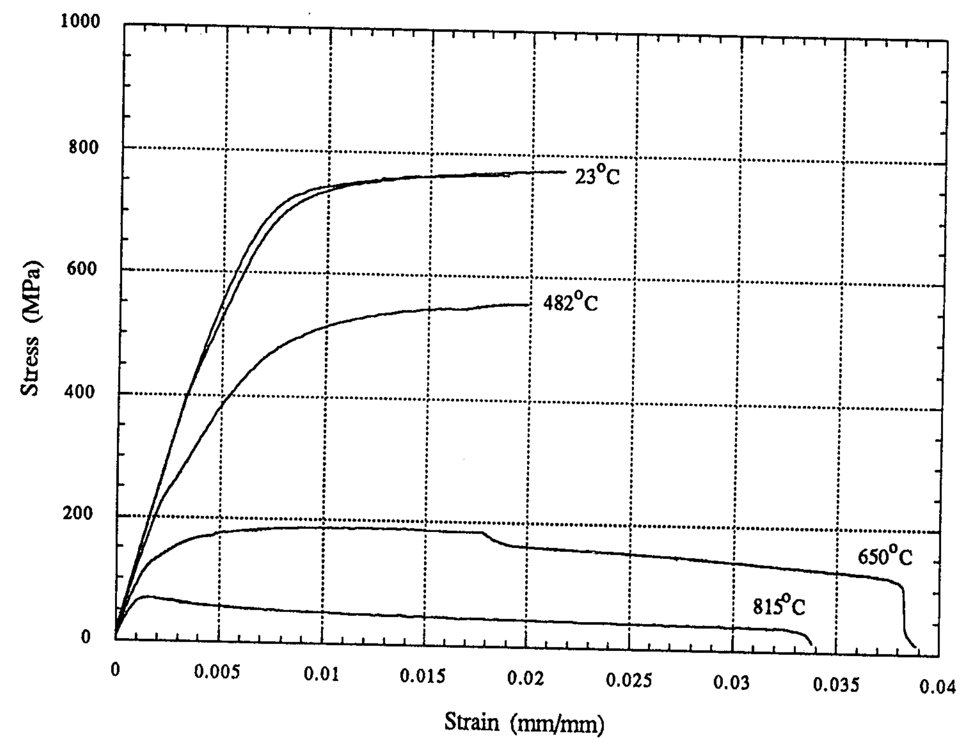
$(0)_4$ SCS-9/Beta 21S Stress-Strain Curves



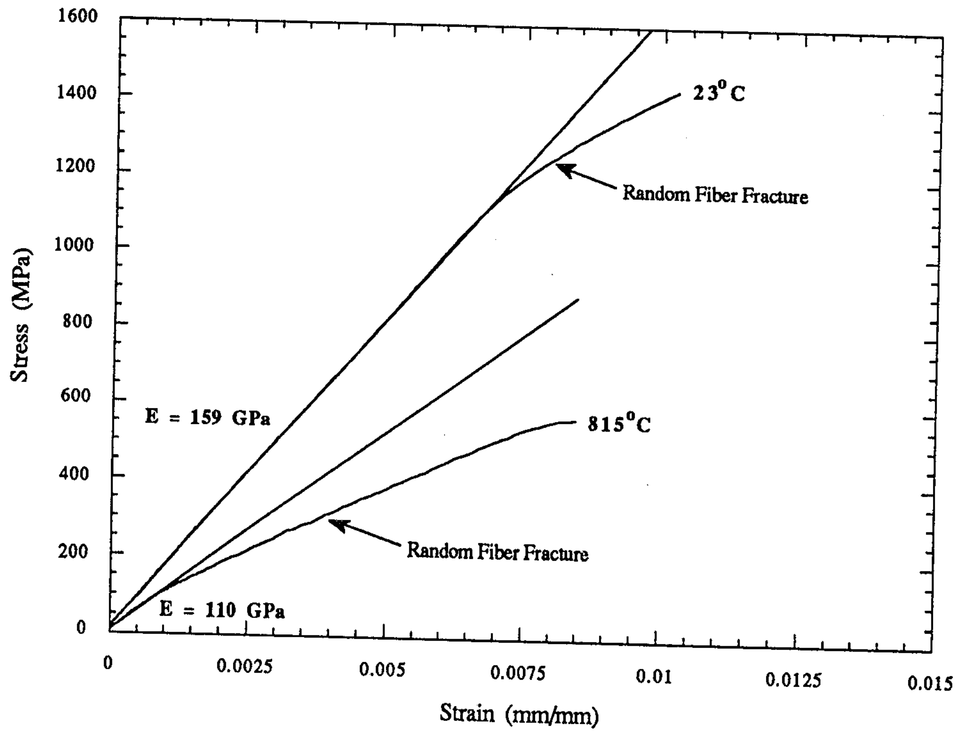
$(0/90)_s$ SCS-9/Beta 21S Stress-Strain Curves



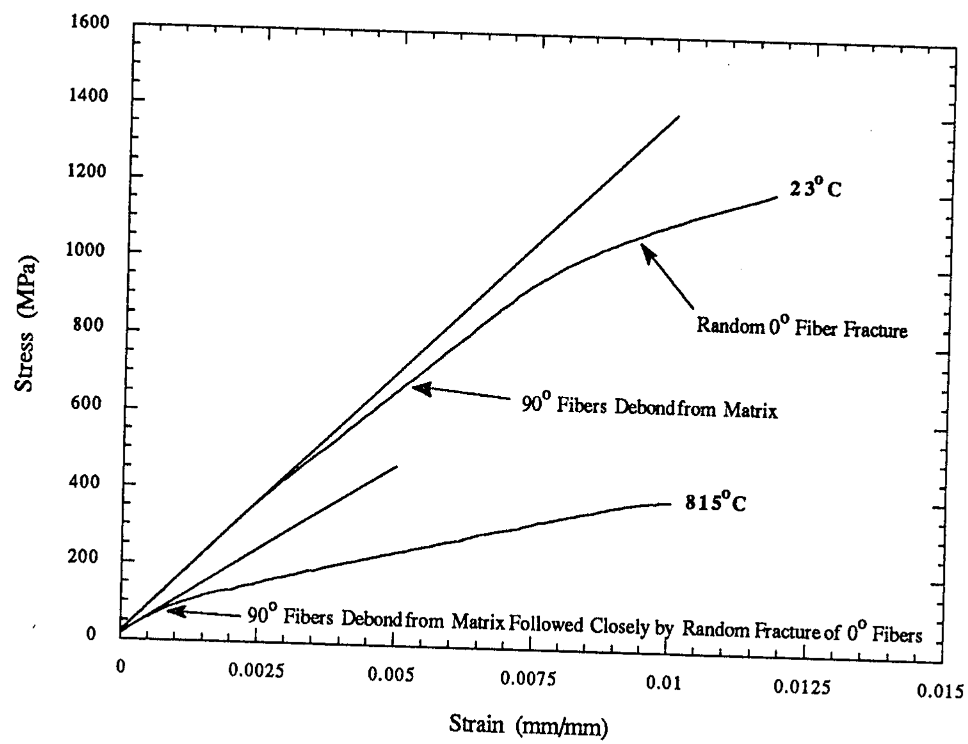
$(90)_4$ SCS-9/Beta 21S Stress-Strain Curves



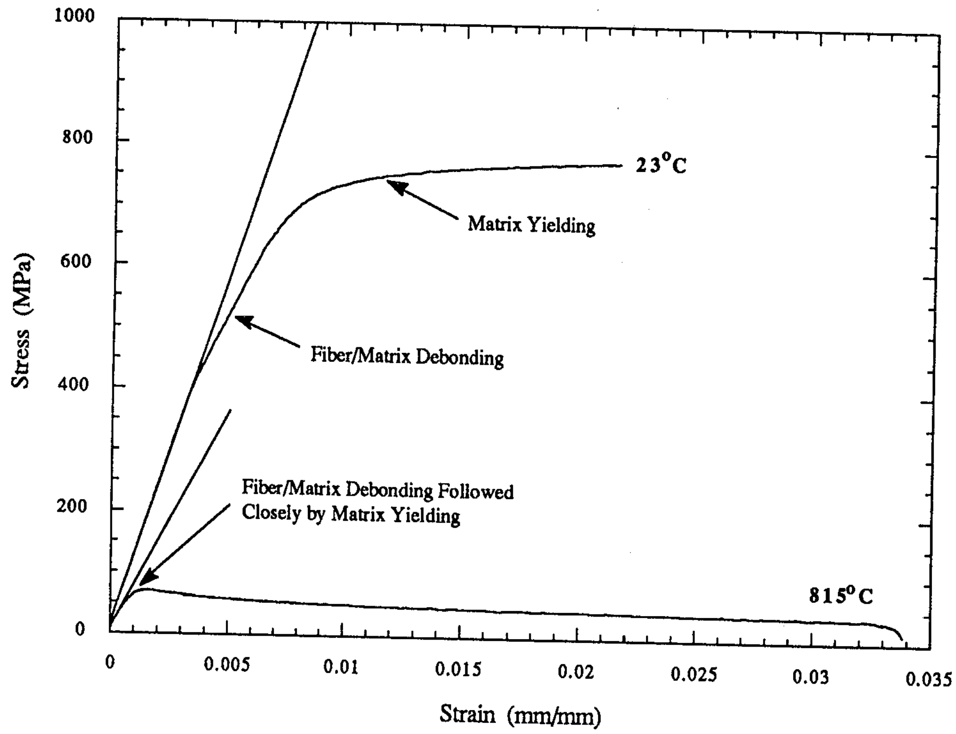
$(0)_4$ SCS-9/Beta 21S RT and 815°C Stress-Strain Curves



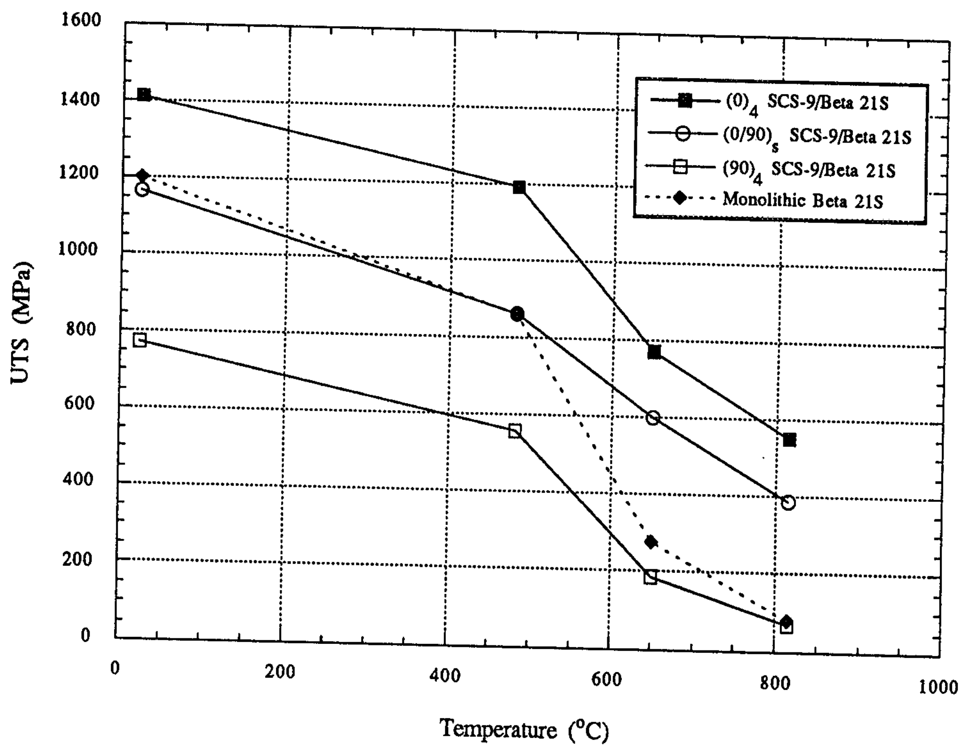
(0/90)$_s$ SCS-9/Beta 21S RT and 815°C Stress-Strain Curves



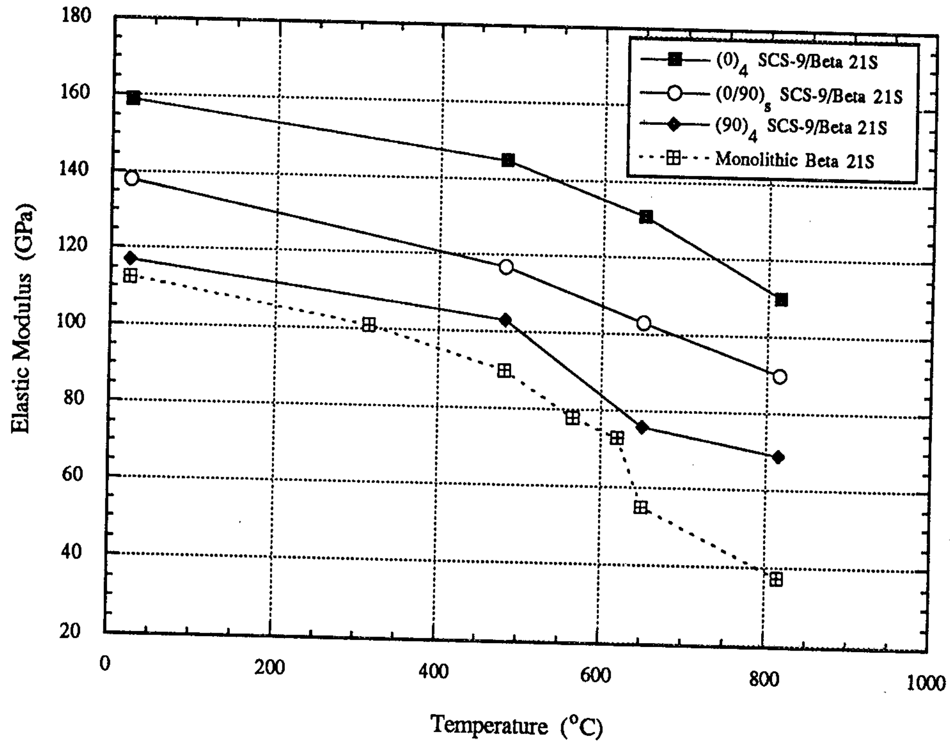
$(90)_4$ SCS-9/Beta 21S RT and 815°C Stress-Strain Curves



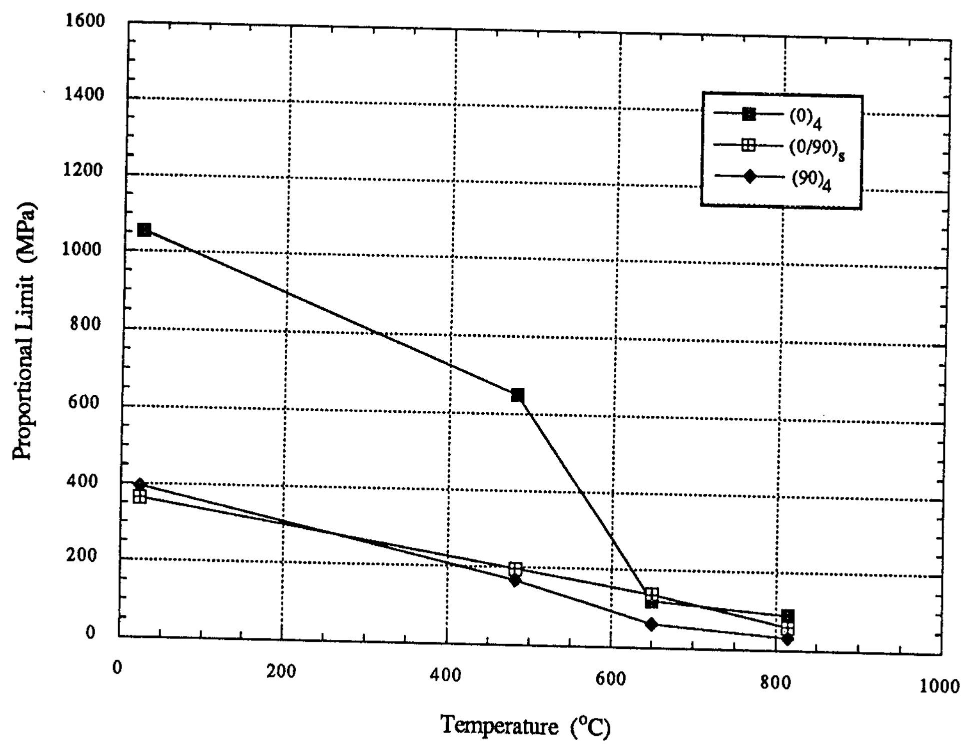
Temperature Dependence of the UTS of SCS-9/Beta 21S Composite Layups



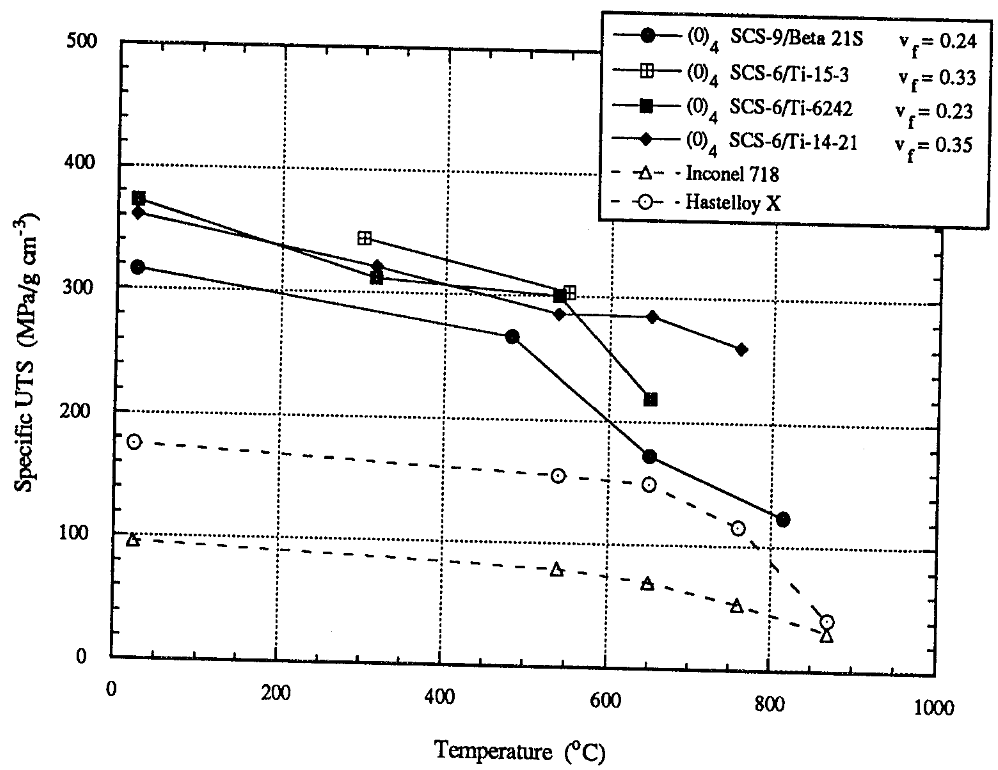
Temperature Dependence of the Elastic Modulus of SCS-9/Beta 21S Composite Layups



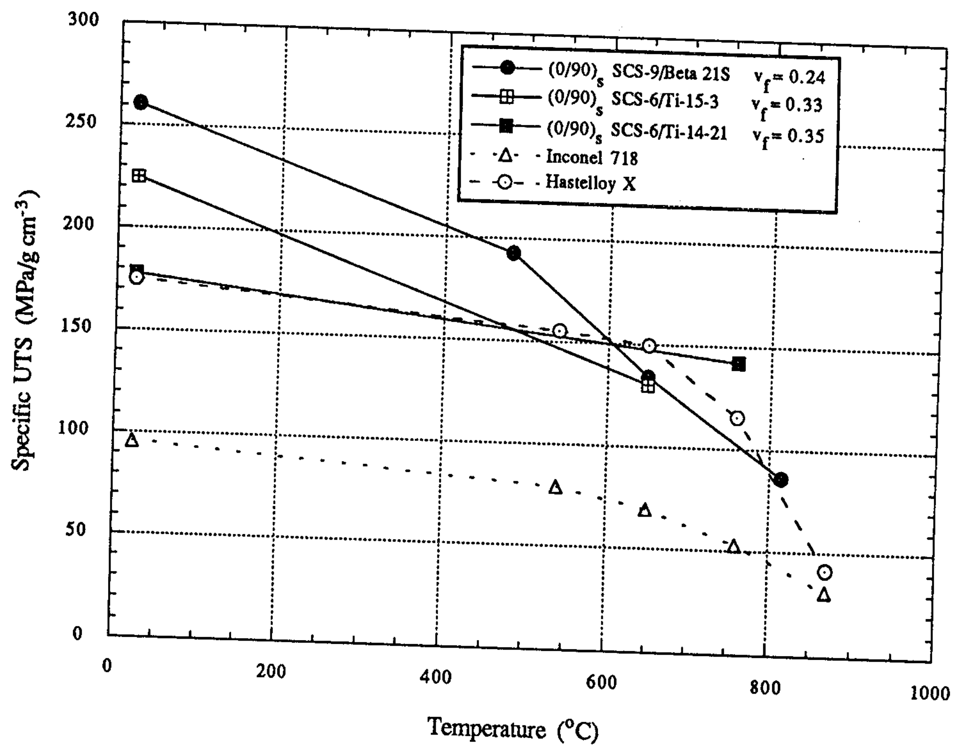
Decrease in Proportional Limit With Temperature



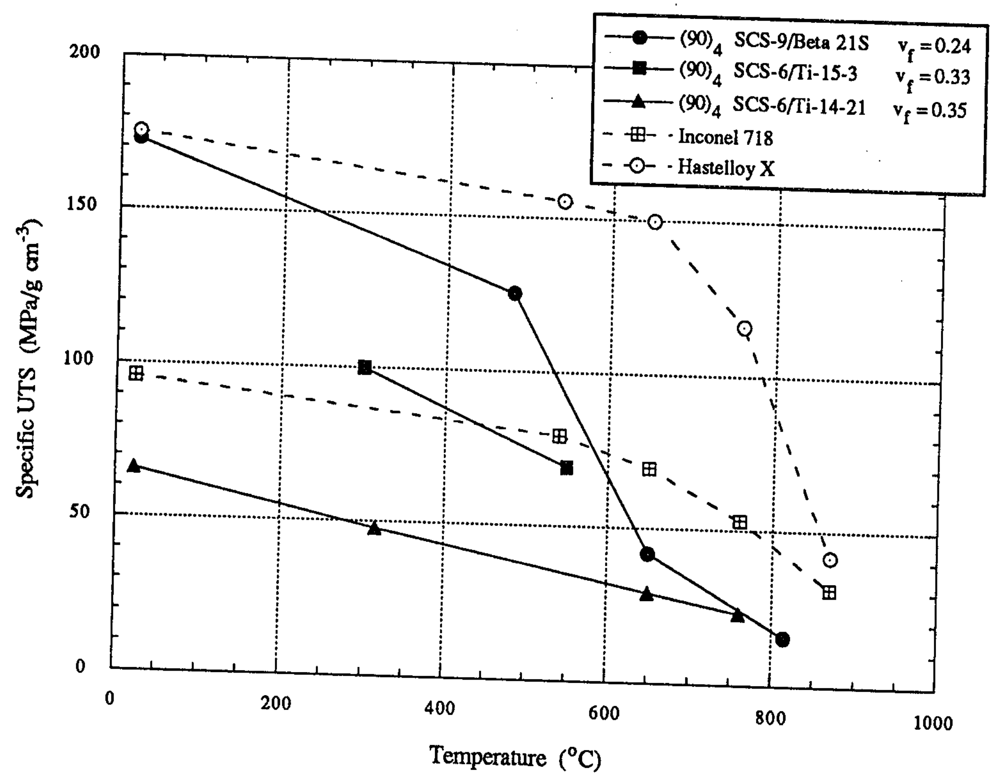
Specific UTS of $(0)_4$ Composites and Two Nickel-base Alloys



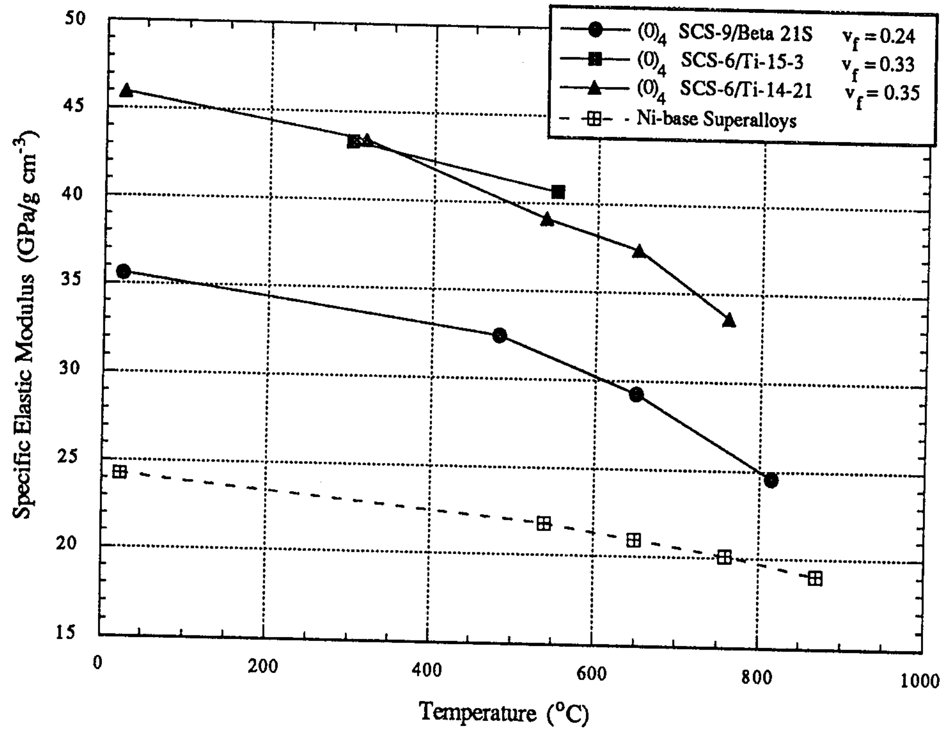
Specific UTS of $(0/90)_s$ Composites and Two Nickel-base Alloys



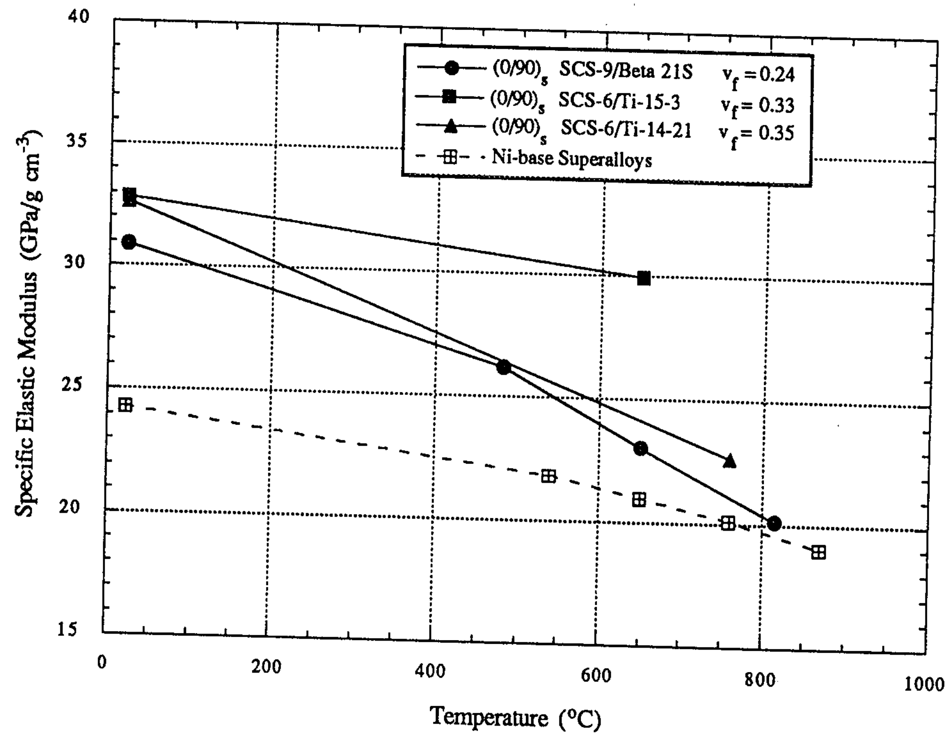
Specific UTS of $(90)_4$ Composites and Two Nickel-base Alloys



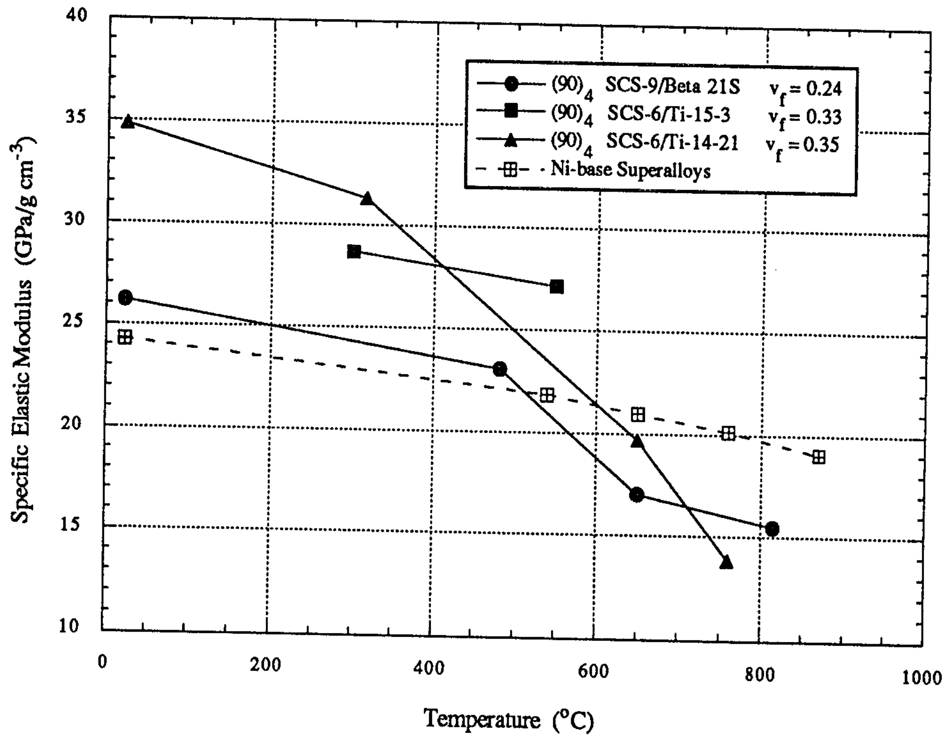
Specific Elastic Modulus of $(0)_4$ Composites and Nickel-base Superalloys



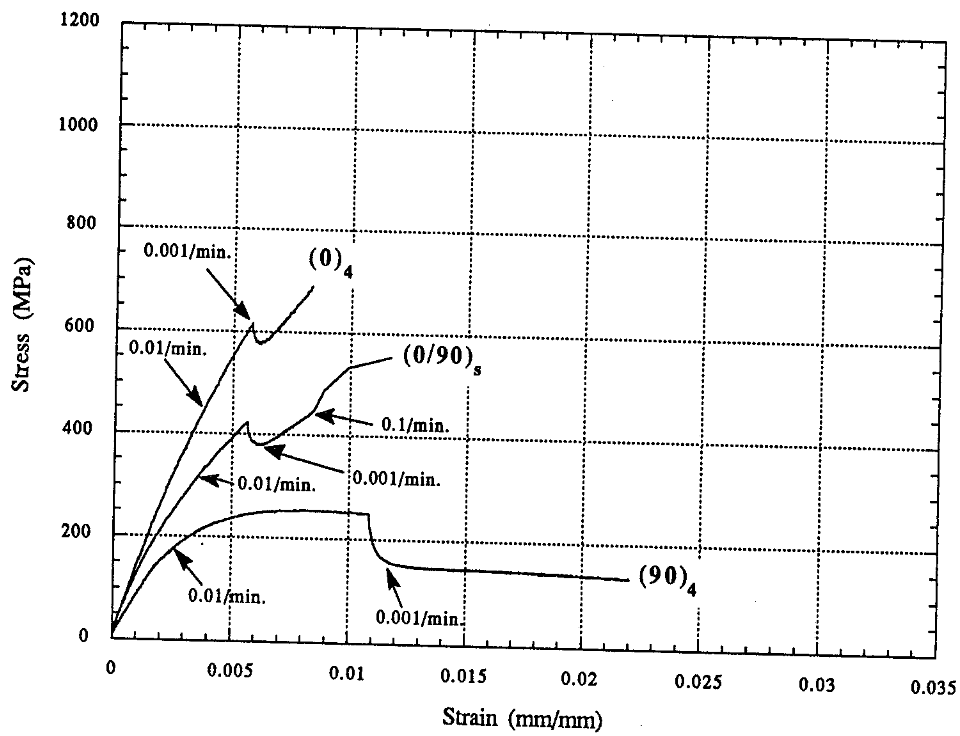
Specific Elastic Modulus of $(0/90)_s$ Composites and Nickel-base Superalloys



Specific Elastic Modulus of $(90)_4$ Composites and Nickel-base Superalloys



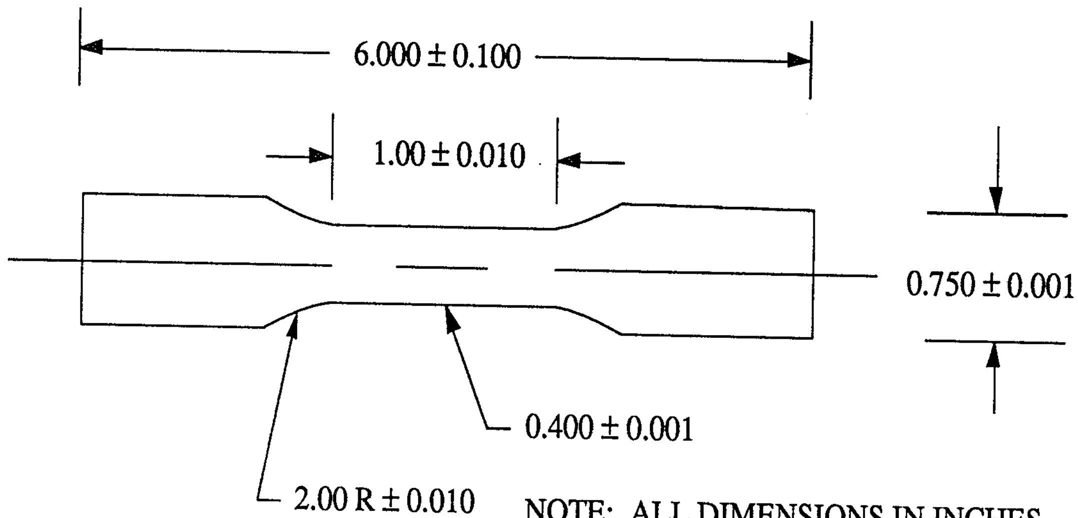
Stress-Strain Curves Obtained from Tensile Tests Conducted at 650°C with Instantaneous Changes in Strain Rate



Creep Test Parameters and Specimen Geometry

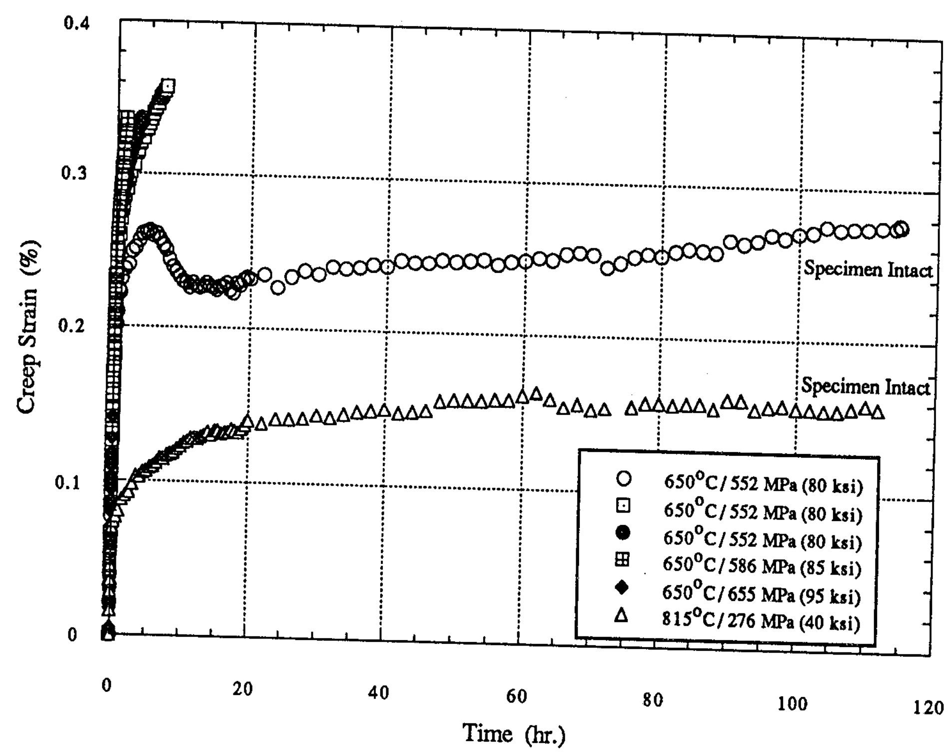
Test Parameters

$(0)_4$	650°C	552, 586, 655 MPa
	815°C	276 MPa
$(0/90)_s$	650°C	276, 345, 414 MPa
	815°C	103 MPa
$(90)_4$	650°C	34, 69, 138 MPa
	815°C	21, 34 MPa

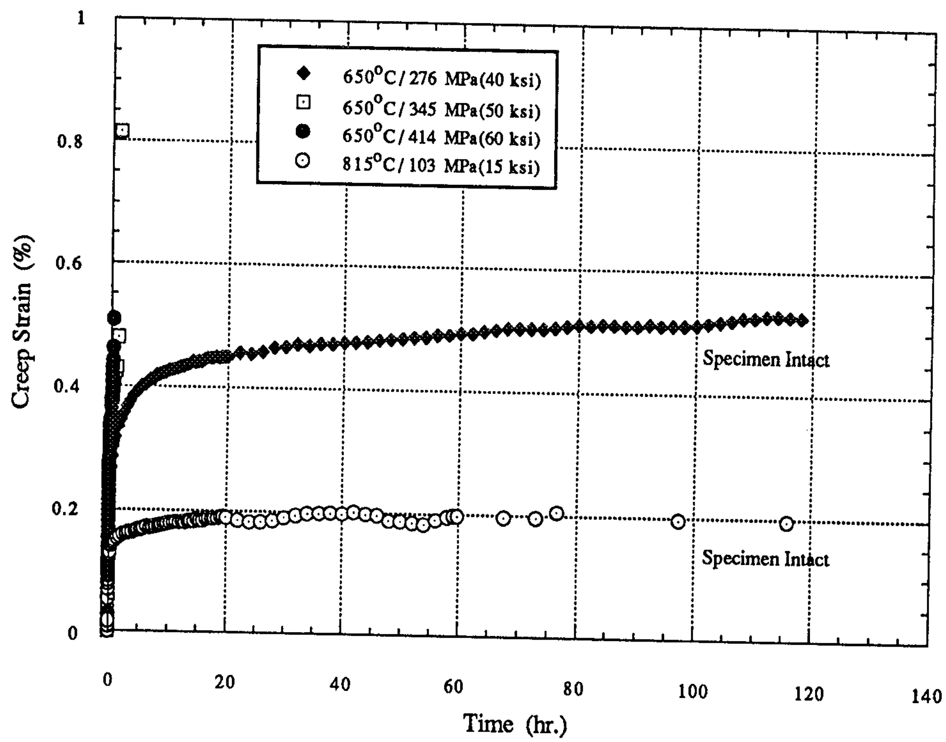


NOTE: ALL DIMENSIONS IN INCHES

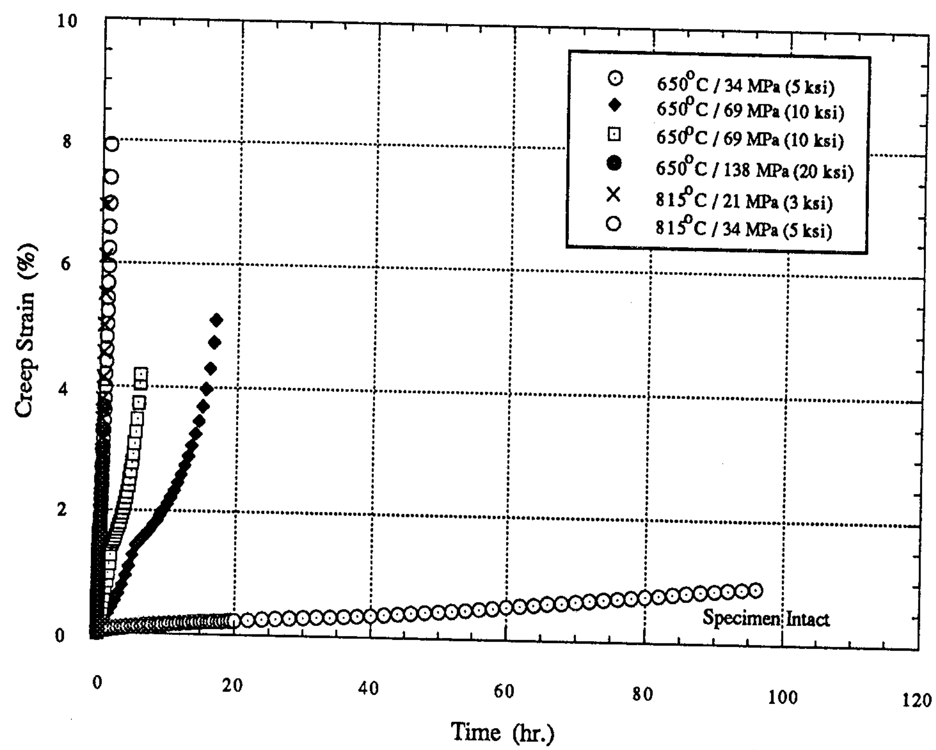
Creep Curves for $(0)_4$ SCS-9/Beta 21S



Creep Curves for $(0/90)_s$ SCS-9/Beta 21S

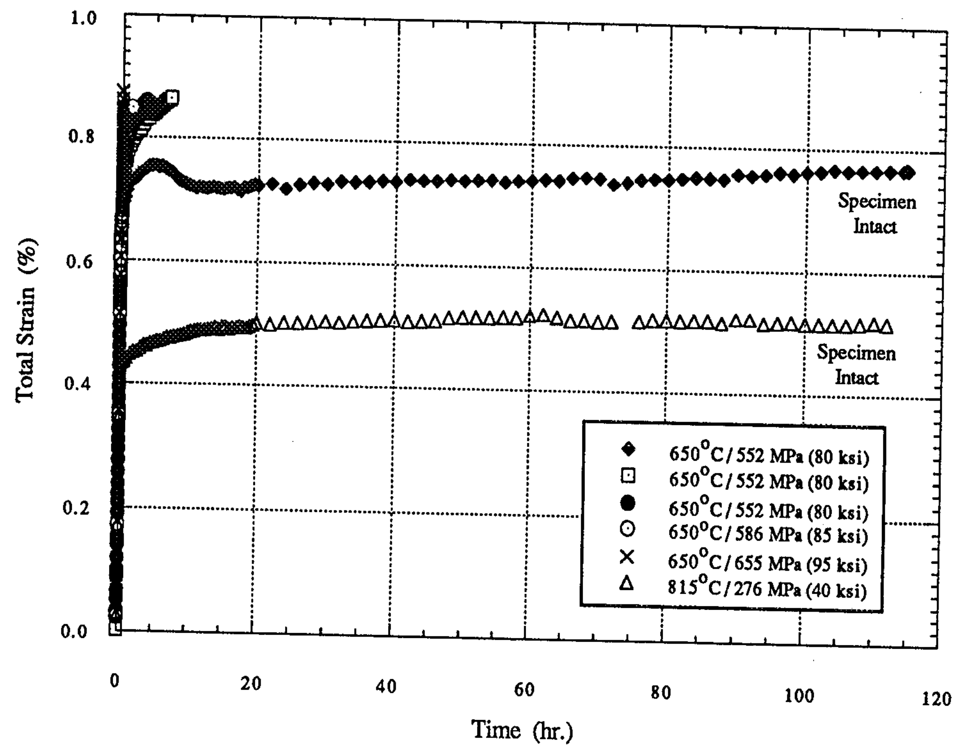


Creep Curves for $(90)_4$ SCS-9/Beta 21S

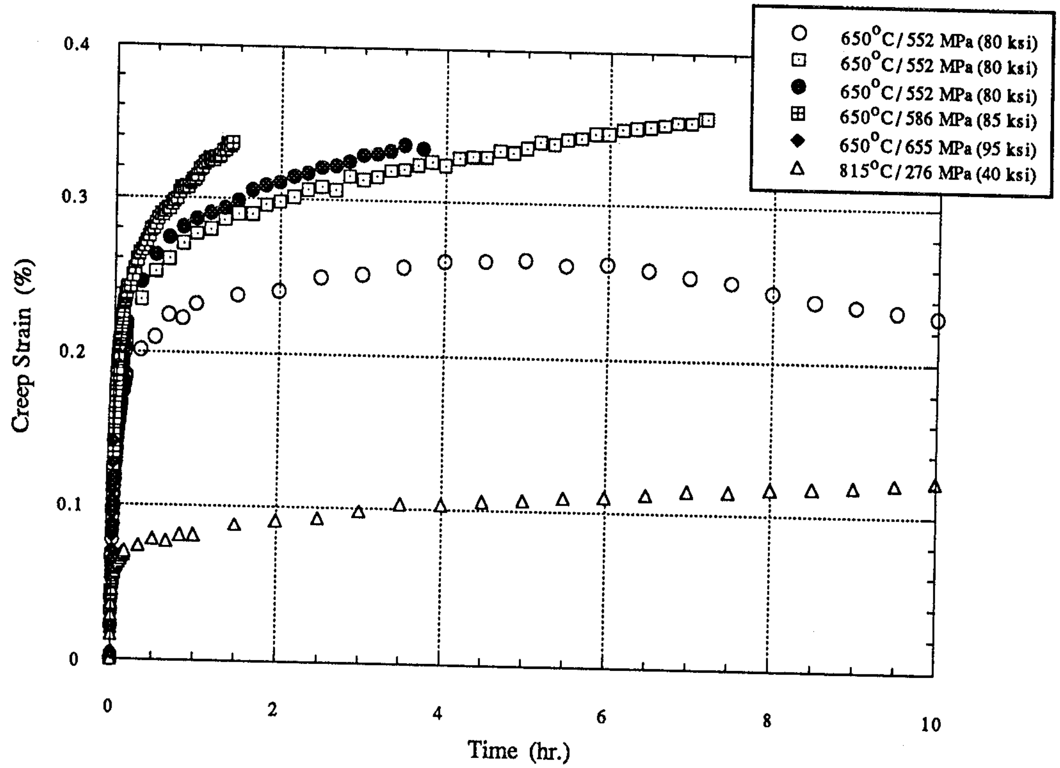


Total Strain for $(0)_4$ SCS-9/Beta 21S

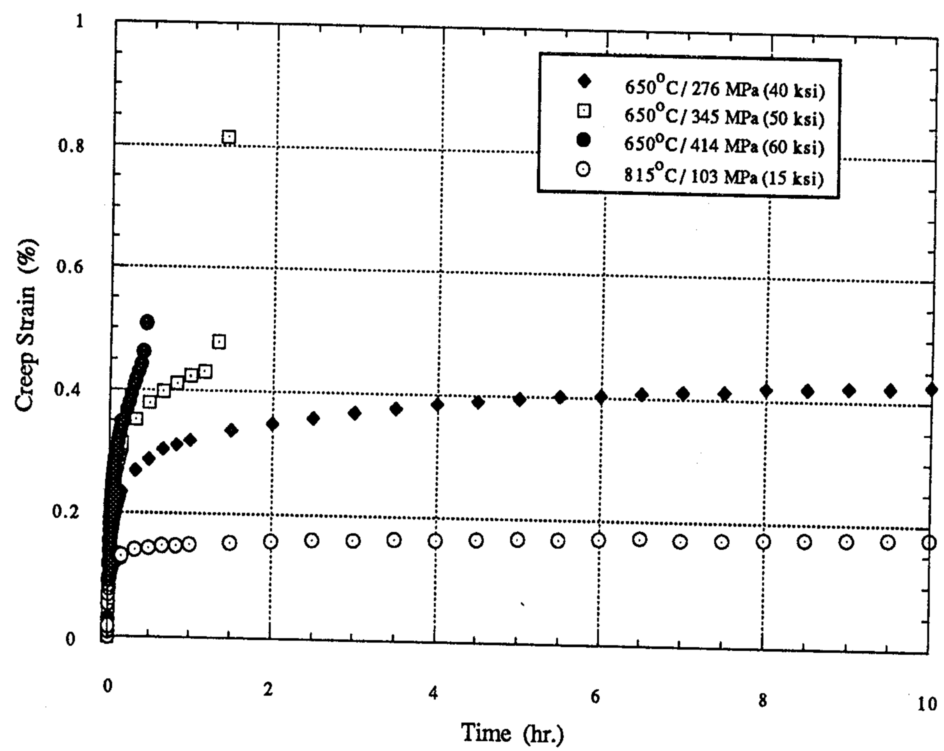
$$\varepsilon_c = \frac{\sigma_c}{E_f v_f}$$



Highlight $(0)_4$ SCS-9/Beta 21S Creep Curves

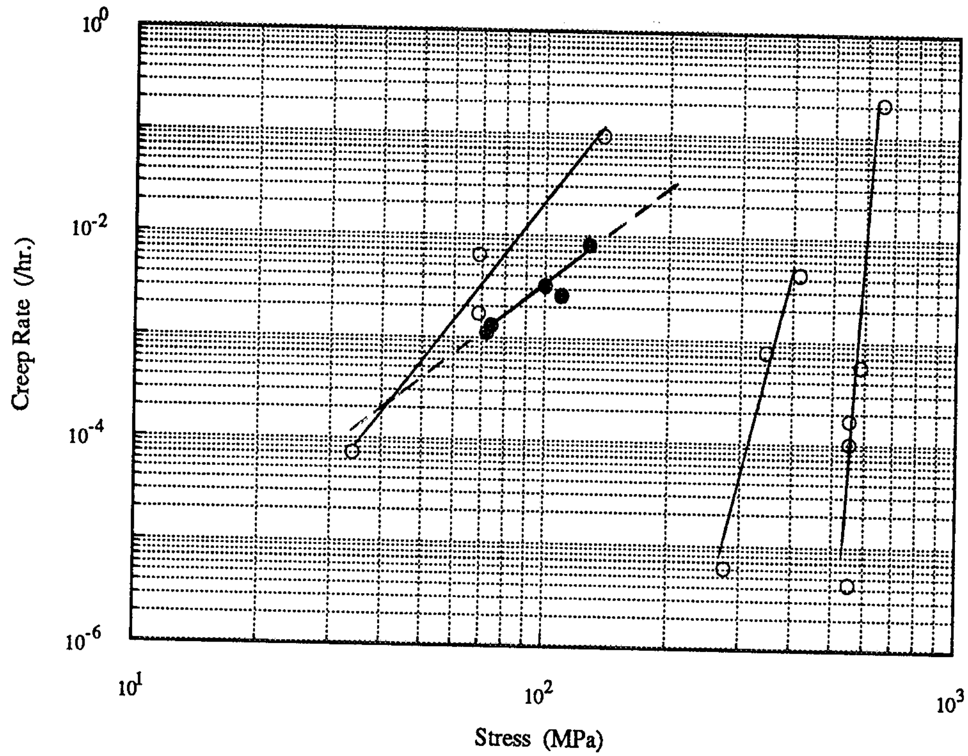


Highlight $(0/90)_s$ SCS-9/Beta 21S Creep Curves

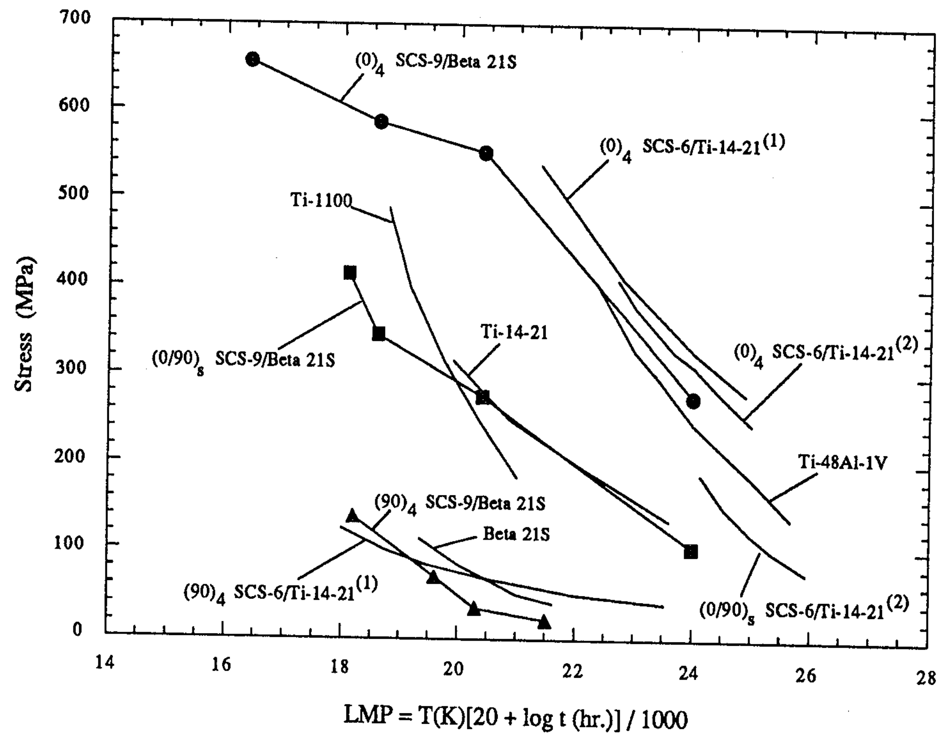


Creep Rate Dependence on Applied Stress

$$\dot{\varepsilon}_{ss} = A\sigma^n$$



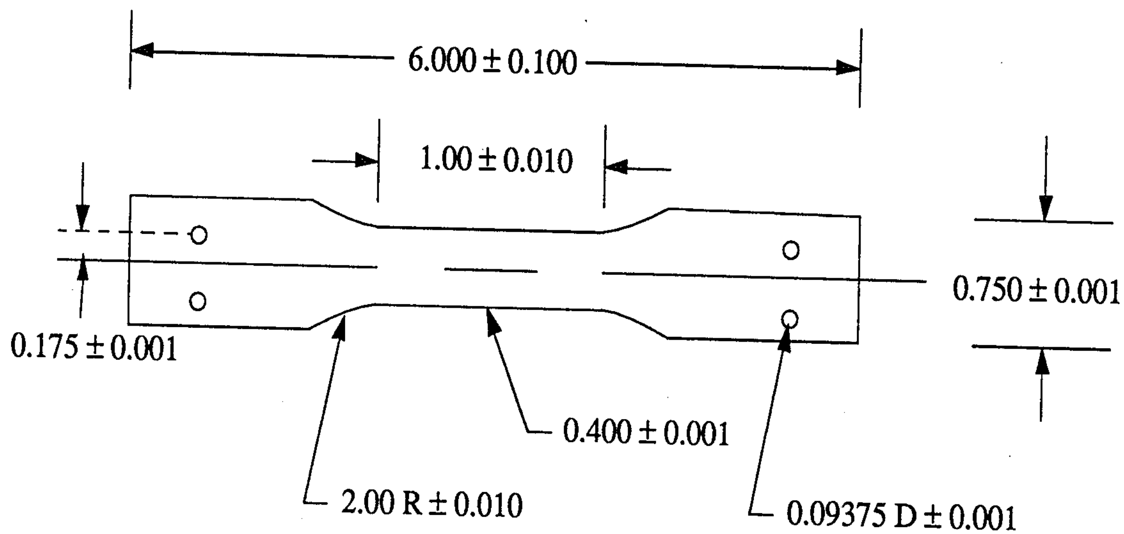
Larson - Miller Plot



Creep Tests with DCPD Technique

Test Equipment

- ATS 2410 lever arm creep tester with automatic data collection
- ATS wedge coupling grips with flat face inserts
- Double knife-edge alignment couplings
- 3-zone slip round test furnace



NOTE: ALL DIMENSIONS IN INCHES

Creep Tests with DCPD Technique

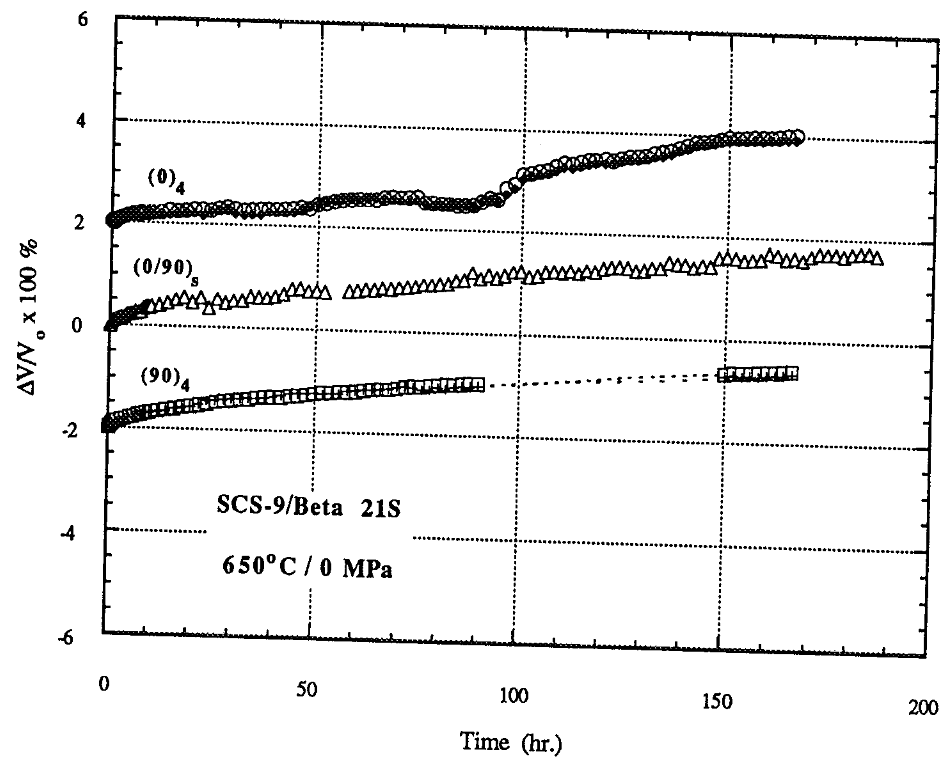
$$V(t) = I(t)\rho(t)G(t) = I(t)\rho(t)\frac{L(t)}{A(t)}$$

Assumptions:

- Constant resistivity
- Constant current
- Constant volume

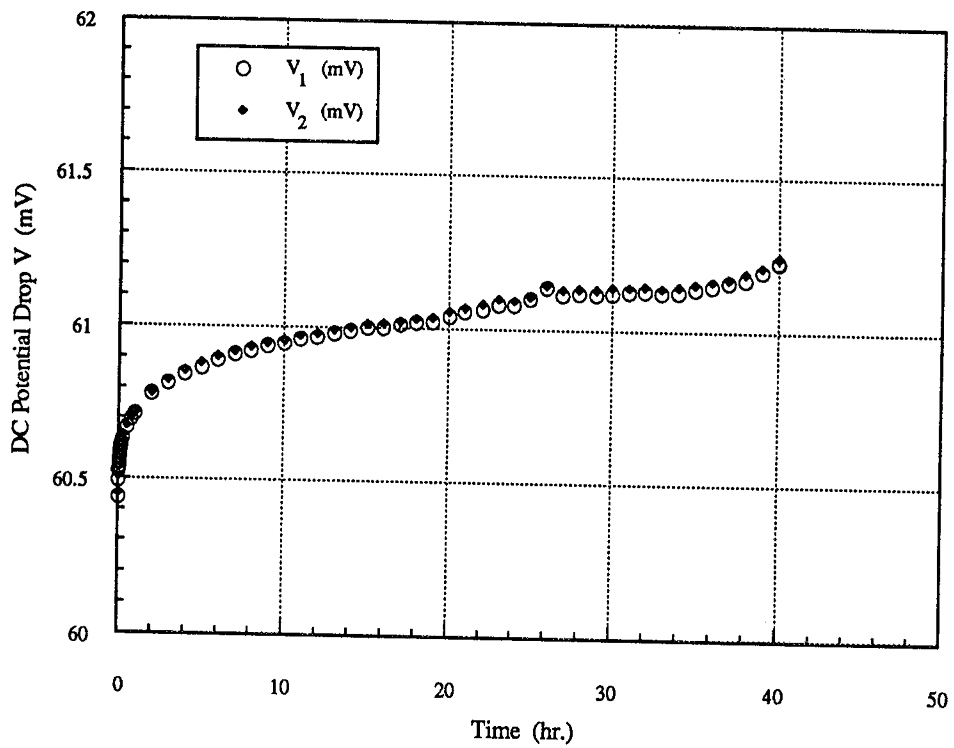
Verifying Assumptions

650°C / No Load Tests



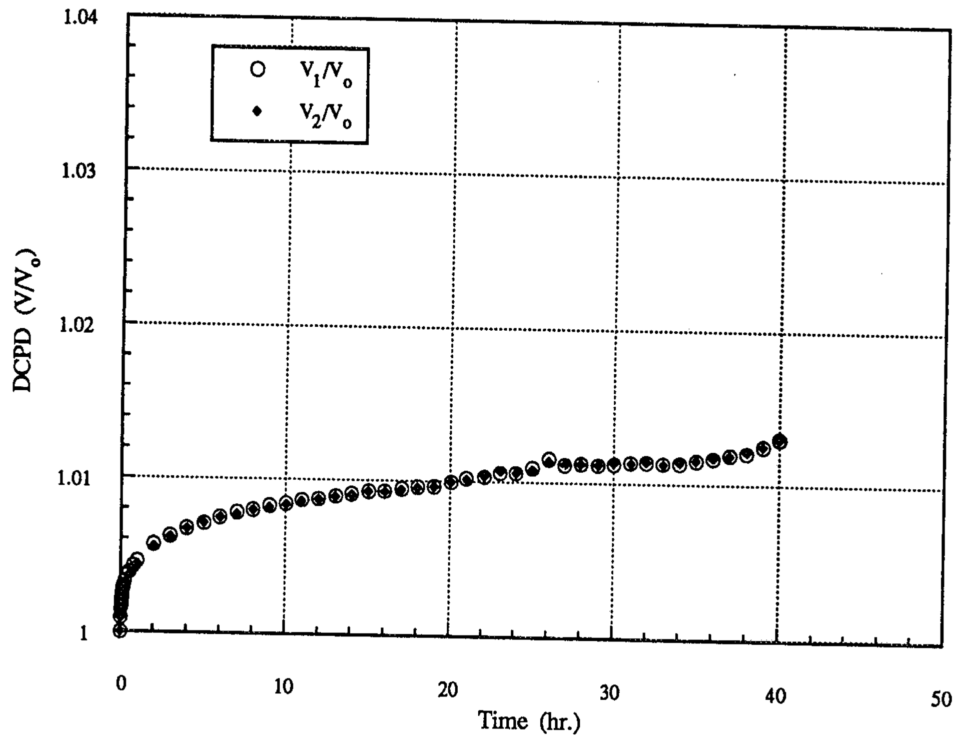
DCPD Curves for $(0)_4$ SCS-9/Beta 21S

650°C / 276 MPa



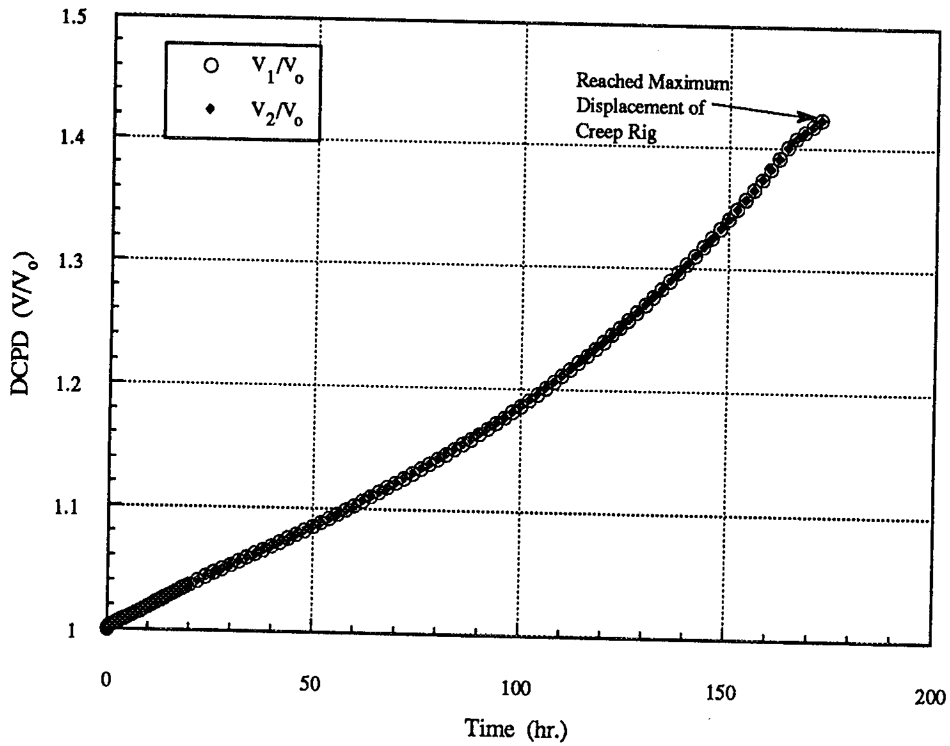
Normalized DCPD Curves for $(0)_4$ SCS-9/Beta 21S

650°C / 276 MPa



Normalized DCPD Curves for $(90)_4$ SCS-9/Beta 21S

650°C / 21 MPa

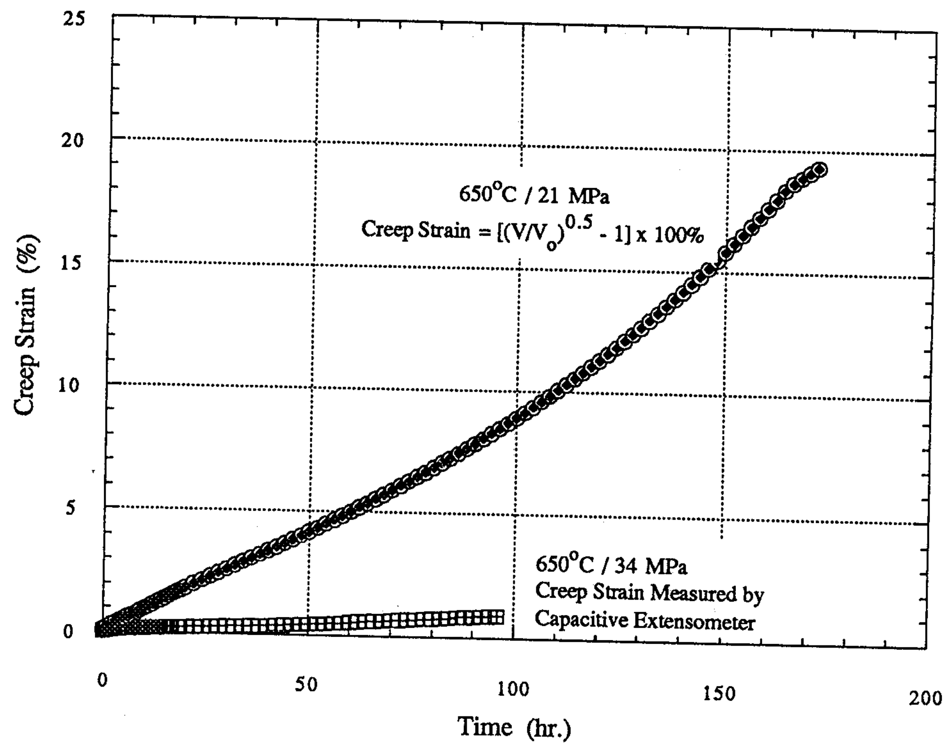


Quantitative Correlation of DCPD Readings to Creep Strain

$$\ell n\left(\frac{V}{V_o}\right) = 2\ell n\left(\frac{A_o}{A_t}\right)$$

$$\varepsilon = \ell n\left(\frac{A_o}{A_t}\right) = \frac{1}{2}\ell n\left(\frac{V}{V_o}\right)$$

$$\delta = \frac{\Delta L}{L} = \left[\left(\frac{V}{V_o}\right)^{\frac{1}{2}} - 1\right] x\ 100\,(\%)$$



Conclusions

- At 650°C, the UTS of $(0)_4$ and $(0/90)_s$ SCS-9/Beta 21S decreases by almost 50% from the room temperature values, indicating that operating temperatures should be less than 650°C to take advantage of the specific strength as well as the specific elastic modulus of these composite layups.

- The tensile properties of SiC fiber-reinforced titanium composites are dependent on the properties of the fiber reinforcement as well as the fiber volume fraction.

- Fracture mechanisms in $(0)_4$ SCS-9/Beta 21S are a combination of random fiber failure throughout the specimen and matrix microyielding around fractured fibers.

  Failure of $(90)_4$ SCS-9/Beta 21S is dominated by the properties of the metal matrix.

  Fracture mechanisms in $(0/90)_s$ SCS-9/Beta 21S are a combination of fiber-matrix debonding, random fiber fracture of the 0° fibers and matrix microyielding around debonded 90° fibers and fractured 0° fibers.

Conclusions

- The $(0)_4$ and $(0/90)_s$ SCS-9/Beta 21S composites are highly creep resistant when the applied stress on the 0° fibers is below the fracture strength of the fibers. At 650°C, the threshold stress levels of the $(0)_4$ and $(0/90)_s$ layups are approximately 552 MPa and 276 MPa, respectively. Below these stress levels, the creep rate approaches zero as the applied stress is transferred to the 0° fibers. Above these stress levels, the 0° fibers are loaded to fracture during transfer of the applied stress, which leads to high creep rates and a much shorter creep life.

- At 650°C and near-threshold stress levels, there is a small but steady accumulation of creep strain with time in the $(0)_4$ and $(0/90)_s$ composites. This is believed to be due to environmental degradation of the fiber and matrix near the specimen edges. Failure of all three composite layups in long creep tests in air is expected to initiate from the edge of the specimen due to environmental degradation.

- Fiber reinforcement parallel to the stress axis or at an angle less than 90° is necessary to enhance the tensile strength and creep resistance of the monolithic matrix material.

Conclusions

- The servohydraulic test system is capable of instantaneously changing the strain rate during a tensile test, thereby allowing the strain rate sensitivity of a material to be determined in a single test. The system was also capable of running constant load creep tests.

  The capacitive extensometer was capable of measuring the small strains in $(0)_4$ and $(0/90)_s$ composite specimens during both tensile and creep tests.

- The $(0)_4$ and $(0/90)_s$ SCS-9/Beta 21S composites are practically insensitive to strain rate at 650°C and 815°C. The $(90)_4$ composite exhibits significant strain rate sensitivity which increases with increasing temperature.

- DC potential recordings of creep deformation of the three composite layups revealed that creep damage and deformation could be detected by the change in potential across the specimen gage length. The task of quantitatively relating changes in potential to creep deformation processes has to be approached differently compared to monolithic materials due to the difference in creep deformation mechanisms.

Future Work

- Conduct creep rupture tests below threshold stress levels to determine the effects and degree of environmental degradation.
- Evaluate whether there is effective transfer of the applied stress from the matrix to the fibers in creep tests in which the fibers do not extend into the grips.
- Evaluate the creep recovery behavior of SiC fiber-reinforced titanium composites, including the effects of different creep loading cycles.