N72-18899

NASA SP-5944 (01)

TECHNOLOGY UTILIZATION

TESTING METHODS AND TECHNIQUES: STRENGTH OF MATERIALS AND COMPONENTS

A COMPILATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Foreword

The National Aeronautics and Space Administration and the Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace community. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the public investment in aerospace and nuclear R&D programs.

The methods, techniques, and devices presented in this compilation are used in testing the mechanical properties of various materials. Although metals and metal alloys are featured prominently, some of the items describe tests on a variety of other materials, from concrete to plastics. Many of the tests described are modifications of standard testing procedures, intended either to adapt them to different materials and conditions, or to make them more rapid and accurate. In either case, the approaches presented can result in considerable cost savings and improved quality control.

The compilation is presented in two sections. The first deals specifically with material strength testing; the second treats the special category of fracture and fatigue testing.

This compilation is not a complete survey of the field of materials testing. Rather, its sampling of many diverse activities is intended for the interest of mechanical engineers and materials testing technicians. At the same time, it may serve as an introduction to the field for those unfamiliar with the principles and practices of materials testing.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader Service Card enclosed in this compilation.

Unless otherwise stated, NASA and AEC contemplate no patent action on the technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

Technology Utilization Office
National Aeronautics and Space Administration

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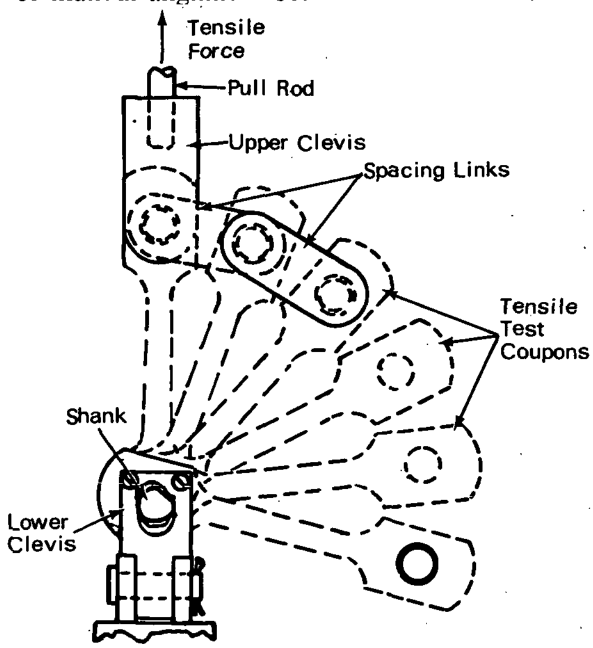
Section 1. Material Strength Testing

TENSILE TESTER ACCEPTS MULTIPLE COUPONS

A novel device permits rapid, sequential testing of up to 6 tensile coupons without interruption for manual alignment between tests. This feature is especially useful when testing is to be performed under controlled environmental conditions, where time would be lost in regaining the proper environment after the interruption.



The device differs from a similar, commercially available system in that it provides positive coupon alignment prior to test, and is much less apt to jam and cause premature failure. As shown in the figure, the device consists of radially arrayed tensile coupons, connected at the upper end by high-strength spacing links (two links per gap) and mounted at the lower end on a special shank. The upper end of the first coupon is attached to the upper mounting clevis, which is attached to the pull-rod of the testing machine. The shank is retained in the lower clevis by keeper plates, and the lower clevis is screwed into the base of the tester. Strain gages are bonded to each specimen, enabling separate stress-strain plots to be made.

As the pull-rod moves upward, the first specimen is stressed to the breaking point. Further vertical movement of the rod causes the linkage connecting the first and second specimens to rotate the lower mounting about the shank and align the second specimen. Tension is then applied to the second coupon across the first pair of spacing links. Progressive rotation of the plate after each failure of a specimen allows complete testing of all specimens.

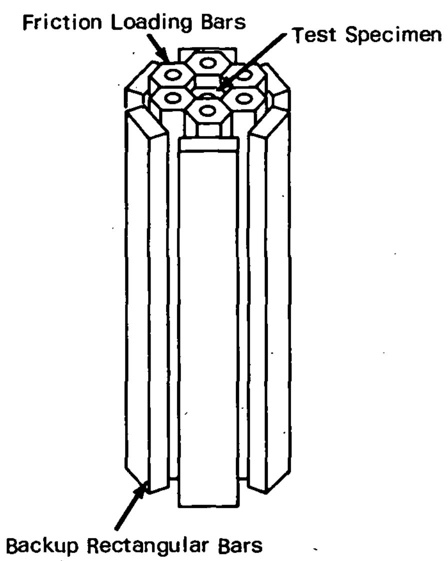
Source: R. T. Hartunian of
McDonnell Douglas Co.
under contract to
Marshall Space Flight Center
(MFS-2067)

Circle 1 on Reader Service Card.

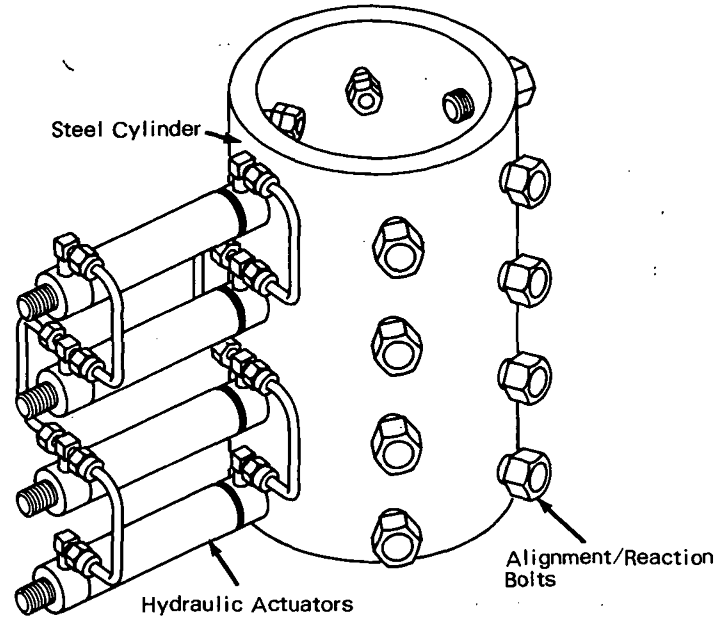
PORTABLE TENSILE TESTING UNIT

A commercially available, portable, tensile testing unit has been improved by adding an hydraulic accumulator to the tester's hand-pumped load cell. The accumulator allows test loads to be applied at a constant strain rate, thereby improving the accuracy and repeatability of test results obtained.

The addition of the accumulator to the unit provides two separate test systems. The operator can (1) bypass the accumulator and use the hand steel cylinder whose diameter and length are consistent with the size of the specimens to be tested. Six equally spaced rows of radially tapped holes are cut into the walls of the cylinder. These holes accept either hydraulic actuators or alignment/reaction bolts. This arrangement permits six-faced loadings of specimens that have a hexagonal cross section.



Specimen Assembly



Test Chamber

The test specimen assembly is prepared by surrounding the specimen proper with six frictional loading bars that are slightly longer in length than the test specimen. Backup rectangular bars are added to distribute the lateral loading uniformly. The mating faces of loading bars are machined to provide a small clearance, so that the full lateral load is carried by the test specimen.

The bundled specimen is centered in the test chamber, which is then positioned on a universal testing machine (not shown), with a compression loading block supporting the friction loading bars. Lateral loading is provided through the hydraulic actuators. With a very light lateral pressure applied, the frictional loading bars are compressed by a predetermined amount. The hydraulic actuators are then pressurized to a preset pressure and the compression on the loading bars is released at a uniform rate. As the load is released, the test specimen is placed in tension. Compression release continues until the test specimen fractures.

Source: T. F. Hengstenberg and G. Zibritosky of
Westinghouse Astronuclear Laboratory
under contract to
AEC-NASA Space Nuclear Systems Office
(NUC-0051)

No further documentation is available.

TENSILE TESTING GRIPS ENSURE UNIFORM LOADING OF TUBULAR SPECIMENS

A new design, double-grip fixture for attaching tubular specimens to a tensile testing machine solves the problem of unequal stress distribution across the tube cross section.

Standard grips used in the tensile testing of bimetal tube specimens allow tensile loading

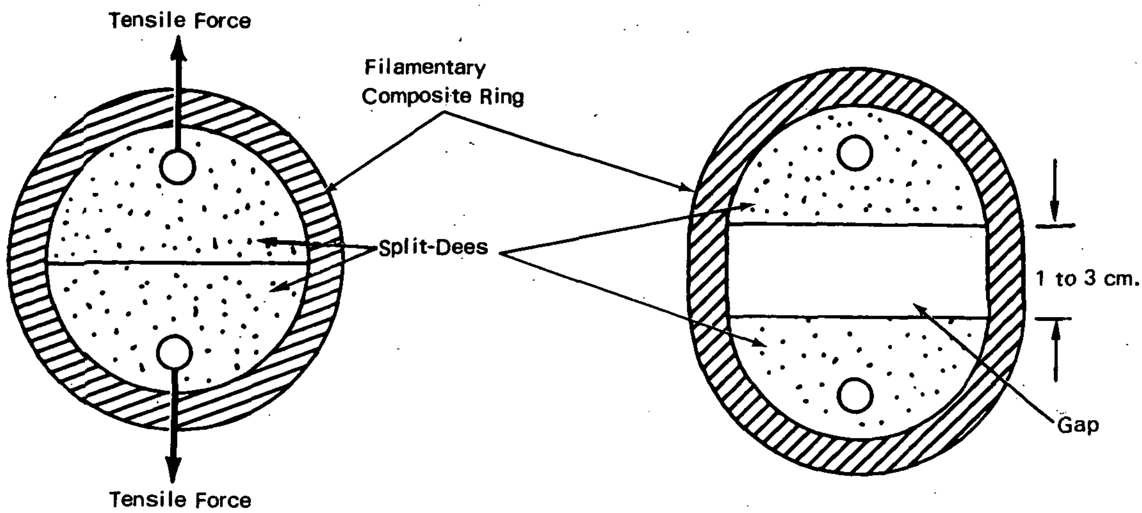


Figure 1. Split-Dee Tensile Test

Figure 2 "Racetrack" Filament-Wound Tensile Specimen

corners of the dees. This generates bending moments of a sufficient magnitude to throw doubt on the validity of the test data.

A straight section was added, adjacent to the split in the dees, in an attempt to eliminate the bending moment. Mathematical analysis of the resulting "racetrack" specimen and comparison of test results achieved with it and the ring specimen indicate that, while bending is not eliminated by this addition, it is substantially reduced. Even a relatively short (1 cm) section reduces the bending moment to less than one-half that of the circular ring.

A further advantage of the "racetrack" specimen is that strain gages may be readily attached to the composite material in the center of the straight section.

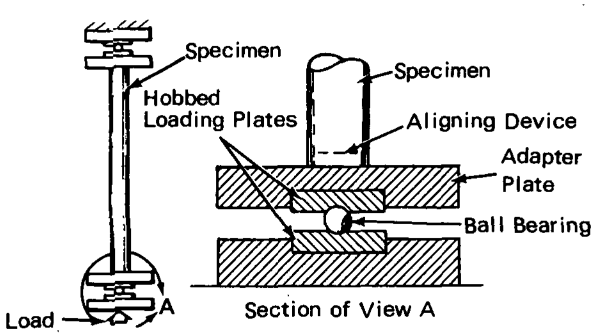
The following documentation may be obtained from:

National Technical Information Service
Springfield, Virginia 22151
Single document price $3.00
(or microfiche $0.65)

Reference:
NASA-CR-66518 (N68-13926), Design Criteria and Concepts for Fibrous Composites Structures

Source: B. W. Rosen and N. F. Dow of
General Electric Co.
under contract to
NASA Headquarters
(HQN-10268)

PIN-ENDED COLUMN LOADING DEVICE



An inexpensive, simple-to-make device can apply a load to a round- or pin-ended column in a universal testing machine and can yield an end-fixture constant near unity. The device allows universal movement, has very low friction under heavy load, and has a maximum end-fixture constant of 1.08.

The device (see fig.) enables a specimen to be loaded between two small steel ball bearings.

MODIFIED TECHNIQUE FOR ELONGATION MEASUREMENT OF THIN METAL STRIPS

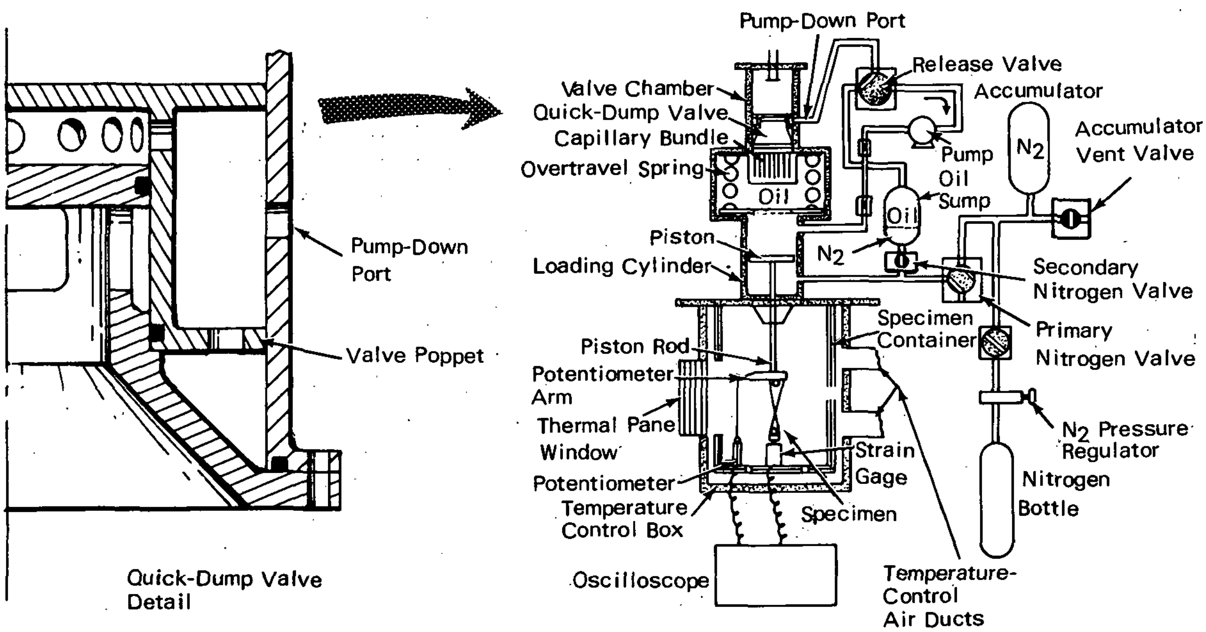
The scribing technique discussed in the previous item will not work reliably when very thin specimens are to be tested, because the inscribed marks themselves may act as points of stress concentration in the specimen and cause premature fracture.

A solution to this problem is achieved by applying a thin gold plating to the test coupons before scribing. After test, the specimen may be pieced back together and photographed along with an accurate scale. The specimen should be obliquely lighted in order to reveal the scribe marks in the gold layer.

Source: I. M. Rehn of
Aerojet-General Corp.
under contract to
AEC-NASA Space Nuclear Systems Office
(NUC-10076)

No further documentation is available.

TENSILE-STRENGTH APPARATUS APPLIES HIGH STRAIN-RATE LOAD WITH MINIMUM SHOCK



The apparatus shown in the diagram can apply tensile test loads at relatively constant, very high strain rates (up to 8.5 m/s), with minimal shock and vibration to the tensile specimen and apparatus.

The apparatus consists of two primary assemblies, a strain generator and a specimen container, separated by a strain wall. The specimen container is enclosed in a temperature-control box, and the specimen is connected directly to the strain generator through a piston rod.

To ready the system for test, oil is pumped from the pump-down port to the top side of the loading-cylinder piston. This transfer of oil automatically seats the quick-dump valve poppet and also drives the loading-cylinder piston to its lower position. The primary nitrogen valve is opened to pressurize the underside of this piston. The secondary nitrogen valve is then

FLEXURE TEST APPARATUS FOR ELECTRICAL CONDUCTORS

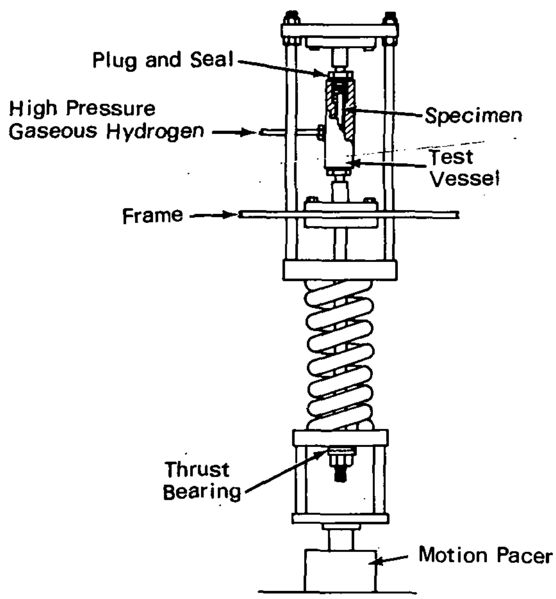
A flexure testing machine simultaneously subjects up to four insulated electrical wire specimens to repeated bending stress, and positively indicates failure of the conductor. The wire is repeatedly bent over mandrels at a controlled rate, through a bend angle of $\pm\pi/4$ rad ($\pm 45°$). A relay-actuated control circuit stops the machine upon fracture of any single conductor. Indicator lamps are lighted to reveal the failed specimen. The control and indicator circuitry is needed because many present day insulation materials are capable of bearing the load weights by themselves after conductor fracture.

An alternate mode of operation allows measuring and recording any change in conductor resistance during test. The machine may be programmed to discontinue the test after any resistance value or resistance change ratio is reached.

Source: E. U. Baker of
McDonnell Douglas Corp.
under contract to
Marshall Space Flight Center
(MFS-13572)

Circle 6 on Reader Service Card.

CONTROLLED HYDRAULIC LOADING DEVICE



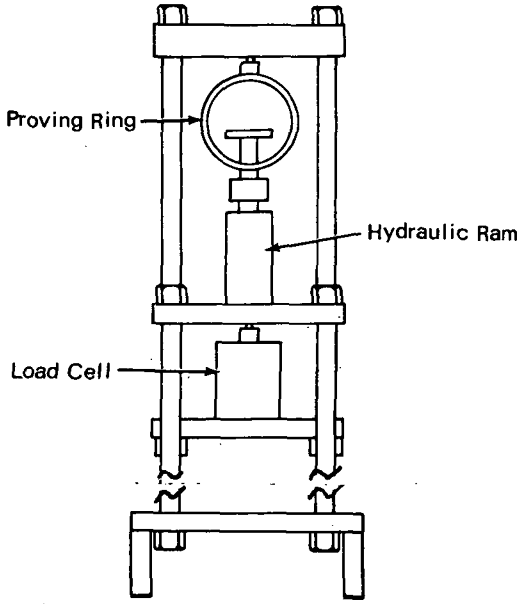
The hydraulic loading device shown in the figure provides either load- or strain-rate control for testing critical tensile specimens. Designed to provide loading at linear strain rates from 0.1 to 0.5 m/m/min, the device effectively paces both load-application and strain-rate from zero to a maximum load of 26.6 kN (6000 lb).

For load-rate control, a commercially available, motion pacer unit is attached to the bottom spring plate of the static loading device. The pacer is used in conjunction with a manual hydraulic flow control valve, which controls the rate at which the hydraulic ram compresses the spring of the static loading device. For specimen strain-rate control, the motion pacer is attached to the top plate of the static loading device. In this mode of operation, cross-head motion is paced.

Source: R. D. Lloyd and G. V. Sneesby of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-2000)

No further documentation is available.

LOAD CELL CALIBRATOR



The illustrated device permits the use of a standard proving ring as a calibration transfer device for calibrating load cells of 220 to 2200 N (50 to 500 lb) capacity. Prior to the construction of this device, such low-capacity load cells were calibrated using weights as transfer standards. The device, similar, except in size, to a commercially available force calibrator, is small enough to permit handling low-capacity load cells conveniently.

Source: S. C. Stene and E. R. Lebs of North American Rockwell Corp. under contract to Manned Spacecraft Center (MSC-11865)

Circle 8 on Reader Service Card.

TESTING WELD STRENGTH AND MECHANICAL PROPERTIES OF 2219-T81 ALUMINUM ALLOY

Welding, fracture, tensile-strength, and fatigue tests performed on 2219-T81 aluminum alloy have resulted in improved knowledge of the mechanical properties of this alloy. Among the important results are the following: (1) The yield strength of 2219-T81 sheet and plate decreases significantly when welded. The reduction of yield strength is much greater than the corresponding reduction in ultimate strength. (2) Toughness of base metal 2219-T81 sheet and plate increases with a decrease in temperature. Plane stress and plane strain fracture toughness of the heat-affected zone (HAZ) increases with a decrease in temperature; the HAZ is less tough than the base metal but tougher than any other zone. The weld metal region has the lowest fracture toughness of any of the regions tested. (3) The weld area fracture toughness (plane stress or plane strain) of automatically welded 2219-T81 sheet or plate decreases significantly between 78 and 20 K. (4) The behavior of welded 2219-T81 aluminum plate is quite erratic after three repair welds have been made. The toughness values of repair welded 2219-T81 aluminum can be substantially lower than those of the new welds. (5) Cyclic flaw growth rates are generally higher on the weld metal than on any other region tested. (6) At normal operating stresses, the critical flaw size for 2219-T81 parent metal and welds is quite large, given the standard 2:1 weld land buildup. (7) Due to the very low possible toughness of repair welds, it is recommended that repair welding be kept to a minimum with 2219-T81 aluminum, because serious material property degradation is possible. All repair welds (except for the flaw simulation tests) on this program meet all government specifications for welds. (8) Tungsten inclusions considerably reduce the fracture toughness of the welds. Such inclusions should be removed wherever possible.

Strength—Grade 1" castings. The castings were all produced with the same mold design and from the same ladle of metal. The machined test bars were solution heat treated for 12 hours at 865 K and then oil quenched. Two test bars were used for each test. The first two bars were tested after 30 minutes and the last two bars were tested after 24 hours.

The results indicated that room temperature aging of Tens 50 alloy is a slow process, probably requiring several days before minimum strength requirements are met or exceeded.

Source: R. E. Zuech of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-18931)

No further documentation is available.

Section 2. Fracture and Fatigue Testing

FATIGUE TESTING OF 1100-H14 ALUMINUM ALLOY

An investigation of the fatigue properties of pure (1100) aluminum in various gaseous environments has shown that the fatigue life of the metal is greater in vacuum than it is in air, by a factor of about 3:2. The effects of residual concentrations of oxygen, water vapor, and hydrogen on fatigue life have also been investigated.

Fatigue tests were conducted in partial pressure and vacuum environments, using modified ASTM constant stress bend specimens in the cantilever mode of reverse bending. The fatigue life data were plotted as a function of surface strain amplitude calculated from fixed deflection amplitudes. Outer surface stress amplitudes were calculated from the elastic strain levels, assuming negligible fatigue hardening. Preliminary studies have shown that the 1100-H14 aluminum used in this series of fatigue tests exhibits very little strain hardening and maintains an essentially elastic stress-strain response in bending.

Source: M. J. Hordon, M. A. Wright and
M. E. Reed of
National Research Corp.
under contract to
NASA Headquarters
(HQN-10197)

Circle 10 on Reader Service Card.

LOW-CYCLE FATIGUE TESTS ON NICKEL ALLOYS 625 AND HASTELLOY C

Low-temperature, low cycle, flexural fatigue tests have been performed on two prominent nickel alloys to determine short-term deformation and change in load-carrying ability. Flexural reverse-bending fatigue tests were conducted on Alloy 625 and Hastelloy C at speeds up to 30 cycles per minute, with maximum deflections of ±2.41 cm in a total specimen length of 12.7 cm.

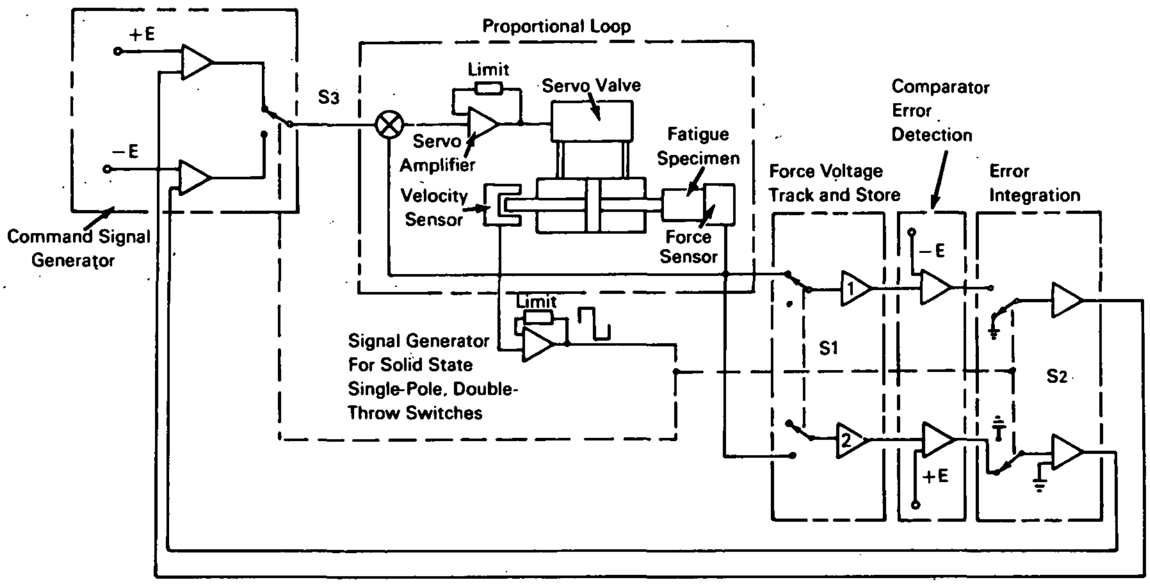
For each alloy, two strain gages were cemented to each of two specimens, at 8.1 cm and 3.45 cm from the moving end of the specimen. With the first specimen of each pair, the gages were connected to an X-Y recorder; the second set of gages was connected to an oscilloscope. A standard tensile testing machine was used to deflect each specimen 2.41 cm in tension and in compression.

and a calibration readout unit, together with the signal from a second strain-gage bridge. The section also includes readout instrumentation needed to calibrate and monitor performance.

Source: W. T. Davis
Langley Research Center
(LAR-10042)

Circle 12 on Reader's Service Card.

HYDRAULIC SERVO SYSTEM INCREASES FATIGUE-TESTING ACCURACY



The fatigue testing system shown in the figure has improved the accuracy of loads applied to a standard fatigue specimen. The system consists of a proportional loop hydraulic system and an error-sensing electronic control loop.

The proportional loop contains a servo amplifier with a limit control, a servo valve which drives a piston, a velocity sensor, a force sensor, and the fatigue specimen. Frequency control is obtained by setting the limits on the servo amplifier. This is the normal assembly used for fatigue loading of a specimen.

To increase the accuracy of the system, an error-sensing electronic control loop is added to the proportional loop. This control loop consists of a signal generator, a force voltage tracker and storer, an error detection comparator, an error integrator, SPDT switches, and a command signal generator.

The electronic error sensor tracks and stores the force sensor's output voltage to the point where the velocity changes sign (i.e., the point of maximum force). The stored output voltages are then compared with the desired command reference voltages in the error detection comparator. An error signal generated for each peak is integrated and added to the appropriate command voltage level, and the composite command signal is fed to the proportional loop hydraulic system.

The velocity sensor of the proportional loop system triggers the signal generator which drives the SPDT switches. These switches, S1 and S2, appropriately channel the inputs and outputs of the error sensing electronic control loop to achieve two proper feedback voltages. One of these is selected by switch S3 and fed into the proportional loop.

Source: G. V. Dixon and K. S. Kibler
Langley Research Center
(LAR-217)

No further documentation is available.

a flexible shaft, guides the transducer across the specimen.

Tests were conducted on a specimen into which a slot was being machined to simulate the propagation of a fatigue crack. Increments as small as 0.003 cm were detected and automatically tracked. The repeatability of the system was ±0.013 cm for a number of specimens tested.

Source: F. Hoppe and N. S. Inman of
Fairchild Hiller Corp.
under contract to
Langley Research Center
(LAR-10091)

Circle 14 on Reader Service Card.

FATIGUE CRACKS DETECTED AND MEASURED WITHOUT TEST INTERRUPTION

An ultrasonic flaw detector, involving modified transducers clamped to the specimens, nondestructively detects fatigue cracks. The system provides a permanent, continuous record of cracks encountered throughout fatigue tests, without any need to interrupt or interfere with the tests.

Detecting fatigue cracks by the reflection of ultrasonic energy is similar to detecting distant objects by using radar. Acoustic energy generated by an ultrasonic transducer is transmitted into the test specimen in the form of pulsed envelopes of high-frequency waves. After the pulse is transmitted, the same transducer acts as a receiver for energy reflected from any discontinuity, such as that formed by the metal-air interface of a fatigue crack. The amount of energy reflected from a crack is related to the crack area, the intensity of the incident ultrasonic wave, and the orientation of the crack.

The oscillograph readout is coupled to a gating circuit, permitting a permanent record to be made of signals received from flaws in a selected portion of the specimen while the test is running.

Source: S. J. Klima, D. J. Lesco, and
J. C. Freche
Lewis Research Center
(LEW-266)

Circle 15 on Reader Service Card.

ANALYSIS OF FLOW-INDUCED FATIGUE IN BELLOWS

An investigation of bellows failure caused by flow-induced fatigue has yielded increased understanding of the mechanism of vibration generation and amplification in bellows, and has pointed the way toward a solution to the problem of bellows fatigue.

Fatigue failures are experienced in bellows carrying fluids at high speed. Such failures commonly occur when bellows are subjected to flow speeds around Mach 0.3, but the principles governing this behavior are not well understood. Although a rigorous analysis of this problem is difficult, much insight can be obtained qualitatively.

It can be assumed that flow through a bellows generates random sound waves in the fluid from repeated sources. For example, sound generated by the disturbance in flow past a convolution root will be generated at repeated intervals, corresponding to the convolution spacing, along the bellows. Under these conditions, certain wavelengths of sound will be amplified and others cancelled. Because the sound travels along the bellows in both directions, standing waves can be produced.

Because convolutions are essentially springs, they must be affected to some extent by any varying force such as sound waves. The extent load the specimen during test. Automatic control of liquid level in the Dewar, and a shut-off switch actuated by test specimen failure, permit unattended operation for considerable periods.

Source: T. F. Durham of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-435)

No further documentation is available.

FATIGUE IN REINFORCED CONCRETE BEAMS UNDER DYNAMIC LOAD

Investigation of the strength properties of reinforced concrete beams subjected to vibrational stresses has led to increased knowledge of the dynamic properties of concrete. Such knowledge is needed for the design of buildings frequently subjected to high-intensity vibrations. Buildings located near missile launching pads and jet air fields are obvious examples.

One hundred specially designed, scaled, reinforced concrete beams were tested. Fifteen were tested to determine their static strengths. The remaining beams were tested under sinusoidal and random vibrations to determine their dynamic fatigue characteristics. The beams were mounted, one at a time, on an electromagnetic shaker and were vibrated at their supports. Desired stress levels were maintained by monitoring the input signal to the shaker. The number of vibration cycles was established up to the moment of the specimen's failure. The reinforcing wires imbedded in the concrete beams were also tested by a tensile machine to determine their yield and ultimate tensile strengths and to obtain a better analytical understanding of the strength of the reinforced concrete specimens.

The following documentation may be obtained from:

National Technical Information Service
Springfield, Virginia 22151
Single document price $3.00
(or microfiche $0.65)

Reference:
NASA-CR-79530 (N67-11684) Fatigue of Reinforced Concrete Due to Sinusoidal and Random Loadings

Source: G. C. Chan of
Wyle Laboratories
under contract to
Marshall Space Flight Center
(MFS-14980)

SURVEY OF FRACTURE TESTING METHODS

A comprehensive survey has been prepared on current fracture-toughness testing methods that are based on linear-elastic fracture mechanics. General principles of the basic, two-dimensional crack, stress-field model are discussed in relation to real three-dimensional specimens. The designs and necessary dimensions of specimens for mixed mode and opening mode (plane strain) crack-toughness measurements are considered in detail. Test procedures and instrumentation methods are described, and expressions for the calculation of crack-toughness values are given for the common types of specimens.

Source: J. E. Srawley, M. H. Jones, and
W. F. Brown, Jr.
Lewis Research Center
(LEW-10379)

Circle 17 on Reader Service Card.

spanning the machined crack, and knife-edge clips on the bracket engage the notched arms of the holders. When the precracked joint is placed under load, the gage measures displacements which are primarily due to the behavior of the crack, with the parent metal acting essentially as rigid material.

Source: J. E. Collipriest and D. E. Kizer of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-16786)

Circle 18 on Reader Service Card.

ACCELERATED STRESS CORROSION TEST FOR STEELS AND NICKEL ALLOYS

The stress corrosion susceptibility of a wide variety of steels and nickel alloys can be rapidly evaluated using a new laboratory test procedure.

Single-edge-notched specimens are fatigue-cracked, loaded in plane tension, and immersed in 20% by weight NaCl solution at room temperature. A computer program is used to calculate approximate loading parameters, and required testing time is limited to a maximum of 1000 hours. Times as short as 100 hours may be used under some circumstances.

The test can be used to determine: (1) the stress-corrosion susceptibility of many common high-strength alloys; (2) the effects of processing parameters on the susceptibility of these alloys; and (3) the acceptance level for stress corrosion resistance of the alloys. Preliminary seacoast trials have verified the validity of the test.

The same basic approach to the development of a stress-corrosion test has been used before. However, earlier tests were based on the use of fatigue-cracked cantilever bend specimens, which required individual loading fixtures. Using edge-notched tensile specimens allows a large number of specimens to be loaded in series and tested simultaneously in a single, dead-weight, lever-arm loading system.

Source: A. H. Freedman of
Northrop Corp.
under contract to
Marshall Space Flight Center
(MFS-13701)

Circle 19 on Reader Service Card.

FAILURE MODES IN POLYTETRAFLUOROETHYLENE EXAMINED USING FRACTOGRAPHY

Fractographic principles, long used in metallurgy, can now be applied to the analysis of the microstructure and fracture characteristics of polytetrafluoroethylene (PTFE). Fractography is a common analytical technique for studying the fracture face of a failed metal by means of both macro- and microphotography. The minute topographical features revealed in the fractographs are then compared with standards prepared from specimens fractured under controlled conditions. Similarity between a standard and a fractograph that represents an actual service failure is used to determine the failure mode.

Notched and unnotched samples of 0.65 cm thick PTFE were tested in tensile and fatigue testing machines, both at room temperature and at the temperature of liquid nitrogen. The test conditions approximated the most extreme stress and cryogenic environments to which the PTFE would be exposed during use. Replicas of the fractured surfaces were prepared by the commonly used, two-stage, acetate replica technique. All fractures were studied in two magnification ranges: the macrorange, from 1 to 10×; and the microrange, from 3500 to 15,000× (with the electron microscope). The various rosion of the specimens. Failure of highly stressed susceptible alloys and tempers generally occurs during the first few hours of testing. Therefore, specimens should be inspected at least once during the first four hours' exposure, and twice a day thereafter.

Source: W. J. Helfrich of
Kaiser Aluminum and Chemical Corp.
under contract to
Marshall Space Flight Center
(MFS-20175)

Circle 21 on Reader Service Card.

CHEMICAL MILLING REVEALS STRESS CORROSION CRACKS IN TITANIUM ALLOYS

A solution of the type used for the chemical milling of titanium alloys may be used to reveal stress corrosion cracks, without special surface preparation. The solution consists of 10 parts HF (concentrated), 60 parts H_2O_2 (30% concentration), and 30 parts H_2O, by volume. The surface is simply rinsed in water and dried, swabbed with the solution for 10 to 30 seconds, and rinsed again in water. The cracks can then be observed by the naked eye or at low magnification. The technique is especially useful with large specimens or hardware, where polishing would be impractical. The solution may also be useful in revealing small machining cracks or fatigue cracks, but should not be used when the examination must be totally nondestructive.

Source: D. N. Braski
Langley Research Center
(LAR-10077)

No further documentation is available.

NASA-Langley, 1971

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