FRACTURE & DEFORMATION DIVISION

An Overview of Research Activities

FRACTURE & DEFORMATION DIVISION

Center for Materials Research
National Measurement Laboratory
National Bureau of Standards

Boulder, Colorado
Gaithersburg, Maryland

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CONTENTS

1. INTRODUCTION

Fracture and Deformation Division personnel are located in both Boulder and Gaithersburg. Although separate geographically, these two groups complement each other. The Boulder group has emphasized low-temperature properties, especially mechanical, of metals, alloys, and composites. The Gaithersburg group has emphasized high-temperature mechanical properties, especially of ceramics, and failure analyses. Together these groups represent most of NBS's expertise in mechanical properties and all its expertise in fracture mechanics, a research activity now expanding at NBS.

The division's special strengths fall mainly into six categories:

1. deformation and fracture of ceramics
2. failure analysis
3. low-temperature mechanical and fracture properties
4. test-standard development
5. fracture control
6. weld-defect effects

Recent ceramics studies include creep rupture at elevated temperatures; erosive wear and strength degradation from particle impact; high-temperature, high-pressure compressive strengths of castable refractories; flexural-strength and compressive-strength characterization of geothermal cements; microstructural effects on stress-corrosion cracking of aluminum oxide for prosthetic applications; and electron microscopy.

Special failure-analysis tasks this past year included: the second Silver Memorial Bridge failure (Pt. Pleasant, West Virginia); a seamless, welded steel pressure vessel that ruptured while being filled with natural gas; and railroad-wheel and tank-car failures.

Low-temperature research included: an assessment of carbon and nitrogen additions to the strength and toughness of austenitic stainless steels at liquid-helium temperature (4 K); the tensile, shear, and compressive characterization of fiberglass-epoxy composites at low temperatures; characterization of the temperature dependence of the flow strength of austenitic stainless steels from 4 to 100 K; and further development of welding alloys and processes for the use of stainless steels in cryogenic applications.

Recent research on test-standard development and fracture control has progressed on J-integral, precracked Charpy impact tests and on assistance to ASTM in establishing standard test procedures and standard-specimen parameters.

For weldments, research is now progressing to establish alternative allowable-defect-size standards, based on fitness-for-service. Such studies, conducted previously for the trans-Alaska oil pipeline, are now progressing for the Alaska Natural Gas Transportation System and include pipe and weldment material properties, elastic-plastic-model development and verification, and nondestructive inspection to measure defect length and depth.

The division's technical outputs reach many government agencies, including the Departments of Energy, Transportation, and Defense.

Recent emphasis on fusion, magnetohydrodynamics (MHD), coal gasification, and geothermal energy by the Department of Energy has led to several efforts: low-temperature research for structural containment of the large magnetic fields produced by superconducting magnets; an assessment of future low-temperature material requirements for superconducting MHD magnets; characterization of castable refractories at high temperatures and pressures; development of an *in situ* evaluation test for metal susceptibility to high-temperature, high-pressure environment-assisted metal cracking; and property characterization of geothermal cements.

Transportation-related research includes establishing inspection and alternative allowable-defect-size standards for pipeline girth welds, mechanical-property and microstructural characterization of pressure-tank-car steels and railroad wheels, fracture-mechanics assessment of tank-car behavior, and numerous structural metal-fracture analyses.

Research for the Department of Defense is diverse. We assist the Navy in upgrading its fracture-control plans, identifying material limitations in ultrasensitive inertial-guidance-system gyroscopes, studying the applicability of proof testing to nitride and carbide ceramics that may be used in gas-turbine engines, conducting erosion and wear experiments of ceramics to reduce machining costs, and examining the low-temperature material properties related to superconducting motors and generators for ship propulsion. We assist the Air Force in using advanced composities in lightweight superconducting-magnet, airborne power packages.

The division emphasizes technology transfer. Two books are in preparation. "Materials at Low Temperatures" contains tutorial chapters on mechanical and physical properties and on various types of materials. The second book is a "Survey of Fracture Toughness Testing and Data with Reference to Meaning and Applications." Collaborating with the DoE, the division holds annual workshops on "Materials at Low Temperatures" at Vail, Colorado. Four ceramics-related workshops were held this year at Gaithersburg. The division actively leads in managing the annual International Cryogenic Materials Conference. It participates actively in the US/USSR Science and Technology Joint Exchange Program on Electrometallurgy. Collaborating with the DoE and Battelle, the division maintains a Failure Information Center. The division provides technical assistance to the Assistant Secretary for Science and Technology, Department of Commerce, in the area of steelmaking technology and technology transfer. As a follow-on to last year's efforts, division members are advising the Office of Science and Technology on the progress of a $1 million study being carried out at Lehigh University on the "Potential for Alleviation of the Adverse Trade Impact on the U.S. Steel Industry".

New opportunities for research are provided to the division by the current NBS Durability Initiative. Increased emphasis will occur on elastic-plastic fracture mechanics. Workmanship codes need to be extended to fitness-for-service alternatives to reduce repair welds, to assess specific defects in critical structures, to formulate fracture-control plans for critical structures, and to estimate structural-integrity lifetimes. Elastic-plastic fracture-mechanics models and methodologies are needed to replace the traditional linear-elastic fracture-mechanics approach because most structural alloys for critical applications are selected to ensure against crack instability preceding plastic deformation. Therefore, research will begin on test methodologies, model development and verification, and effects of defects and subcritical crack growth; all of these relate to elastic-plastic or all-plastic conditions.

New studies are also expected on high-temperature or time-dependent properties of metals. Such research is timely because new energy-conversion systems, plasma-containment systems, and nuclear systems all have serious material-selection and durability problems associated with understanding and characterizing the time-dependent fracture processes in structural alloys. Study of crack-tip fracture mechanisms, characterization of fracture processes, and generation of property data (emphasizing creep and fatigue), will provide new insights to assist in high-temperature design and material selection.

2. PERSONNEL AND THEIR RESEARCH

2.1. In Boulder

John M. Arvidson	friction fracture and mechanical properties low-temperature testing
Bruce W. Christ	failure analysis microcreep plastic deformation
Maurice B. Kasen	composites flaws in welds grain-boundary impurity segregation nonmetallics
Hassell M. Ledbetter	Debye temperature elastic constants internal friction phase transitions tensor-property averaging
Harry I. McHenry	elastic-plastic fracture mechanics fracture control welding
David T. Read	elastic-plastic fracture mechanics fracture mechanics of weldments physics of mechanical deformation ultrasonics
Richard P. Reed	fracture mechanics at low temperatures low-temperature materials research martensite transformations
Raymond E. Schramm	composites nonmetallics superconductors x-ray diffraction
Ralph L. Tobler	fracture mechanics mechanical properties at low temperatures

2.2. In Gaithersburg

Roland deWit	dislocation theory fracture mechanics
Ronald C. Dobbyn	failure information materials-performance data mechanical-properties-data systems

James G. Early	fracture and mechanical properties hydrogen in metals powder metallurgy
Richard J. Fields	deformation-and-fracture mechanism maps quantitative metallography fracture processes at high temperatures
Stephen W. Freiman	ceramics and glasses fracture mechanics mechanical properties, environment effects
Edwin R. Fuller, Jr.	atomistic models of fracture fracture mechanics of ceramics fracture, environment-assisted mechanical properties at high temperatures
George E. Hicho	failure analysis hydrogen embrittlement mechanical testing testing methods transmission electron microscopy
Bernard J. Hockey	ceramics deformation and wear scanning and transmission electron microscopy
Charles G. Interrante	ferrous alloys hydrogen embrittlement impact testing test methods and standardization welding metallurgy
Ralph J. Krause, Jr.	chemical equilibria geothermal cements, mechanical properties high-pressure, high-temperature systems vapor-pressure measurements
Clyde McDaniel	ceramics creep x-ray diffraction
Robert S. Polvani	creep dimensional stability mechanical processes at high temperatures transmission electron microscopy

John H. Smith	ferrous alloys failure analysis and fracture mechanics test methods structural reliability welding
T. Robert Shives	failure analyses fatigue of metals
Nancy J. Tighe	ceramics creep at high temperatures mechanical properties, high-temperature scanning and transmission electron microscopy
Sheldon M. Wiederhorn	ceramics erosion fracture processes mechanical properties at high temperatures and high pressures
William A. Willard	failure information mechanical testing

3. CURRENT STUDIES

3.1. Fracture Mechanisms and Analyses

For structural materials, the basics of crack-tip processes are essential to understanding fracture and predicting its long-term effects. Influences of atomic structure and chemical reactions at the crack-tip have been demonstrated with atomistic models of fracture in a solid, but these influences have not yet been confirmed quantitatively by experimental studies of subcritical crack growth and environmental effects. Ductile processes in the high-stress region of the crack tip must be introduced into these atomistic models to assess the role of plastic deformation and to extend the theoretical models to describe crack-growth phenomena such as fatigue. High-temperature fracture is complex: competitive fracture mechanisms, such as subcritical crack growth, cavity nucleation and growth, and grain-boundary sliding, are affected by microstructure, impurity content and segregation, processing history, and environment.

Failure-analysis studies perform a valuable service for those government agencies that have no testing facilities and require research on the safety of structural materials. By using modern metallographic, x-ray, fractographic, and chemical-analyses techniques, and maintaining a Failure Information Center, our division serves as a focal point for analyses and compilation of many critical structural failures.

The NBS Materials Durability Initiative will provide funding for increased emphasis on high-temperature fracture processes and mechanisms. Our understanding of the fracture of metals under time-dependent conditions will be increased by research on crack-tip theory coupled with high-temperature tensile, creep, and fatigue properties.

Research in Fracture Mechanisms and Analyses is divided into four areas: Fracture Theory, Plastic Deformation of Metals, Failure Information Center, and Failure-Avoidance Services.

3.1.1. Fracture Theory

E. R. Fuller, R. M. Thomson, S. W. Freiman, and R. de Wit

Lattice theories of fracture were extended to include the effect of corrosive environment on the simple, one-dimensional model of a crack. The solid in which the crack is enclosed consists of two one-dimensional chains of atoms that form a border for the crack and the projected crack plane. The two chains are bonded in the projected crack plane by linear springs; the atoms within each chain are bonded by bendable springs. At the tip of the crack is a nonlinear spring that can also react with the corrosive environment, which is composed of diatomic molecules. Predictions of the stress dependence of the activation energy for crack motion indicate a power-law dependence whose exponent varies from 1.5 to 2 depending on the form of the atomic bonds of the solid. General conclusions are: (1) chemical activity accentuates and extends the intrinsic, slow crack-growth phenomenon because of the surface-absorption activation barrier, and (2) the "chemical" and "mechanical" contributions to the activation energy for slow crack growth are not separable.

Tensile experiments are now being conducted on silicon to attempt to correlate chemical activity, mechanical stress, and crack-tip opening. Optimum selection of environment and temperature is necessary to ensure chemical absorption and yet to prevent crack-tip blunting from dislocation processes.

3.1.2. Plastic Deformation of Metals

B. W. Christ and R. S. Polvani

Tensile microcreep in various metals and alloys is being measured currently on instrument-grade beryllium. The overall goals of this study are: (1) to develop a data base on microcreep (10^{-12} cm/cm·s) for improved design of gyroscopes used in inertial-guidance systems for naval applications, and (2) to develop a fundamental understanding of microcreep. This program involves combined efforts of two NBS groups and the Draper Laboratory, Cambridge, Massachusetts.

Microcreep testing of instrument-grade beryllium has been carried out at about 63°C (145°F), and temperature control is held to ± 0.005°C (0.01°F) on a testing system designed to detect strains in the range of 10^{-7}. A major finding is the phenomenon of microcreep exhaustion, i.e., loss of the ability for continued microcreep. This phenomenon is attributed to the exhaustion of glide dislocations through an as-yet-to-be-identified microstrain-hardening process. The potential of microcreep exhaustion for promoting ultradimensional stability in gyroscope structural components will be explored.

The building of a second testing system designed like the first is nearing completion. A third testing system designed to detect strains in the range of 10^{-8} has been completed. Zero-applied-stress dimensional stability of instrument-grade beryllium is now being tested. A fourth testing system is being designed to obtain biaxial microcreep data. A review paper surveying the micromechanical properties of beryllium is near completion.

3.1.3. Failure Information Center

R. C. Dobbyn and W. A. Willard

The Failure Information Center assists the coal-conversion industry in extending the useful life and reliability of plant components by maintaining a central source of information on the performance, especially failures, of materials and components used in coal-conversion environments. It provides an integrated material-properties data base for construction materials to aid in the design, contruction, and operation of coal-conversion plants. Finally, it collects and evaluates the information, maintains computer files for convenient retrieval, and disseminates the data in convenient form to the users.

Sources of the information compiled by the Failure Information Center include operators of all gasification and liquefaction processes, from bench-scale units through operating pilot plants participating in the DoE voluntary failure reporting program. Informational detail varies from one-page failure-occurrence reports to final reports of laboratory analyses of failed parts.

A computerized data base of approximately 500 reported failures has been established and is continually being updated, refined, and increased as additional failure reports are received. Separate information items addressing the same failure are collated when possible. In addition, direct contact with operating personnel at the various process locations and with failure-analysis laboratory staff has enhanced the quality and the flow of information and has assisted plant operators in problem solving.

Several draft reports have been assembled and other dissemination methods are being explored. The failure-experiences feature in DoE's Materials and Components Newsletter, to which NBS and Battelle-Columbus contribute, has been a successful method of sharing information. Requests for additional details are received regularly from Newsletter readers.

At present, the center produces sets of abstracts covering all reported incidents. The abstracts are intensive summaries constructed from the source document, and they contain all reported data. They are sorted according to material, component type, failure mode, and conversion process, or any combination of these factors.

During the past year, the Failure Information Center has completed a detailed study of the performance of materials used in the Conoco Lignite Gasification Pilot Plant (CO_2 Acceptor Process). The study is based on the information contained in plant operating records and is not limited to reported failures. In addition, the center responded to 68 requests for information and supplied over 2800 reports and abstracts summarizing the details of in-service materials performance.

3.1.4. Failure-Avoidance Services

B. W. Christ, C. G. Interrante, J. G. Early, T. R. Shives, and G. E. Hicho

Failure-avoidance services provided to other government agencies and other NBS divisions include diagnostic failure analysis, mechanical testing, metallographic analysis, and metallurgical consultation. Sponsoring agencies include the Office of Pipeline Safety Regulation and other branches of the Department of Transportation, the National

Transportation Safety Board, the Department of Defense, the Consumer Product Safety Commission, the Bureau of Engraving and Printing, and the Department of Agriculture. These sponsoring agencies have responsibilities in matters of public safety, productivity, national defense, and the promotion of effective and responsive regulations. When structural failures occur or when metallurgical problems arise, NBS responds immediately to help the sponsoring agency. NBS provides a prompt and objective assessment of the cause of failure based on metallurgical evaluation and nondestructive examination of the material and a structural analysis based on mechanical-property measurements and fracture-mechanics concepts.

This past year, 15 reports were issued to sponsoring agencies. These are reports of structural failures that occurred in pressure vessels, aircraft components, railroad tank cars, gas distribution lines, amusement-park rides, seat belts, fuel pumps, printing plates, bicycle parts, and building-construction materials.

3.2. Durability of Ceramics and Composites

The Fracture and Deformation Division program on ceramics and composites is divided into five parts: fracture fundamentals, fracture and fracture-mechanics information on structural materials, development of new engineering data for design purposes, the investigation of processes that result in erosive and abrasive wear, and the investigation of the microstructure of composites and ceramics through the use of light and electron microscopy. Experimental techniques developed by the division permit us to conduct measurements on the mechanical properties of composites and ceramics over a wide range of experimental conditions: in vacuum at temperatures to 2700°C, in corrosive environments at temperatures that range from room temperature to 1000°C, in air at temperatures that range from room temperature to 1500°C, and at cryogenic temperatures as low as -269°C. This range of experimental capabilities is unique.

Ceramic materials are used in many critical applications where special properties, such as chemical resistance to corrosive environments, mechanical resistance to erosion and wear, and physical resistance to temperature extremes, are required. Ceramics, such as glasses, refractory concretes, geothermal cements, porcelains, and high-density ceramics, are used in many commercial applications, for example: containers for nuclear-waste disposal, linings for geothermal wells, components for high-temperature gas turbines and heat exchangers, thread guides and wear surfaces for the manufacture of paper and clothing, cutting tools and cutoff wheels for the shaping and finishing operations used in the manufacture of various machines and tools, and insulating linings for the coal-conversion and petrochemical industries. In defense applications, these materials are used as radomes, missile nose cones, turbine components in portable electric-generating facilities, and bearing surfaces in gyroscopes. In many applications, resistance to mechanical abuse is crucial. Because they are brittle, structural ceramics are usually overdesigned to satisfy engineering requirements or are not used, even though they have other outstanding properties. The investigation of the fracture and deformation properties of these materials may overcome many of the difficulties associated with their brittleness.

In contrast to metals or ceramics, composite materials are highly engineered, heterogeneous materials designed to impart unique, superior properties not achievable with conventional materials. Composites offer the possibility of high-strength, lightweight, durable structures. In typical advanced composites, the strength-to-weight ratio is an order of magnitude larger than normal grades of steel. Extensive commercialization of composites will realize major energy and materials savings, increased productivity, improved product safety, and improved U.S. technological innovative capabilities. The solution to effective industrial utilization of composite materials is a better understanding of their wear-out and fracture mechanisms. By investigating the mechanical strength and fracture behavior of a variety of composite materials (ceramic/ceramic, ceramic/ metal, ceramic/polymer, and metal/polymer), many of the problems associated with mechanical degradation will be solved, and composites will be used in a wide variety of industrial applications for their unique properties.

3.2.1. Fundamentals of Fracture

S. W. Freiman, B. J. Hockey, S. M. Wiederhorn, and E. R. Fuller

The effects of proof testing on the strength of materials were investigated. A theoretical study was conducted to evaluate the effect of single-region and multiregion crack propagation on the strength of components after the proof test. In this study, two single-region Weibull-type strength distributions were studied: one with a slope of m at high-cumulative-failure probability levels; the other with a slope of R = 2 at low-failure probability levels.* Truncation of the strength distribution always occurs as the result of proof testing; the truncation strength depends on the rate of unloading. In contrast to these results for single-region crack propagation, multiregion crack propagation results in a more complicated strength distribution after proof testing. Bimodal strength distributions occur as a consequence of region-II-type crack growth (i.e., R = 0). Theoretical results confirm experimental findings that proof tests must be conducted at rapid unloading rates and with good environmental control to be effective. Experimental investigations are currently underway to check the predictions of this theoretical model of proof testing.

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*m is the shape factor of the Weibull strength distribution before proof testing; R is the exponent of the stress-intensity factor, K_I, assuming that the crack velocity can be expressed as a power function of the stress-intensity factor: $v = AK_I^n$.

A new analytical technique, electron scanning for chemical analysis (ESCA), was applied to analyze the type of chemical reactions that occur during the stress corrosion of ceramic materials. This, coupled with other techniques, will enable analysis of chemical species that form on freshly fractured surfaces that are exposed to active environments. During the past year, the surface analysis system, which includes ESCA, SIMS, and Auger spectroscopy, arrived and was put into operation. The thin-film deposition system, which will be used to make test specimens, is being attached to the surface analysis system so that fresh uncontaminated surfaces of ceramic material can be analyzed when the equipment is fully operational. To study the effect of stress on the chemical reactions, a specimen holder that can stress the thin film has been designed and built. The holder is held in a shuttle that goes between the film-deposition chamber and the analysis chamber. A thin film of ceramic is formed on a substrate, which is then stressed using a micromanipulator, reacted with an environment, and transferred into the analysis chamber for examination. To date, thin films of aluminum oxide have been deposited on aluminum using an electron-beam deposition system that is part of the apparatus. In the coming year, we hope to use the apparatus for chemical analysis of stressed ceramics and glasses. This project is being conducted jointly with the Ceramics, Glass, and Solid State Science Division (D. M. Sanders).

3.2.2. New Approaches To Fracture and Deformation Information

E. R. Fuller, S. W. Freiman, S. M. Wiederhorn, R. J. Fields, and N. J. Tighe

Fracture mechanics provides engineers with new design techniques for estimating the total allowable lifetime under load when mechanisms of failure are well understood. For ceramic materials, the primary mechanism of failure at low temperatures is subcritical crack growth, whereas that occurring at high temperatures is creep and creep cracking. By characterizing creep and fracture processes in ceramic materials, estimates of the creep rate or the crack-growth rate can be made, and the lifetime of structural components can be determined. The success of this approach depends, in part, on the quality of the creep and crack-growth data used to characterize the fatigue behavior of structural materials.

To improve our ability to collect useful data for lifetime predictions, a new type of loading apparatus was developed for dead-weight loading of structural ceramic materials. The technique involves the use of pneumatic loading as a substitute for the dead-weight loading usually used for constant-load experiments. The pneumatic system has several advantages over the dead-weight system. It is inexpensive and compact; a number of systems can be used simultaneously for experimental purposes without requiring a great deal of space for operations. The advantage of space efficiency was used in the construction of a high-temperature fracture-mechanics facility, which was designed so that three loading fixtures were operated within each furnace. A similar facility is now under construction for evaluating the creep resistance of refractory materials for regenerative heat exchangers in large MHD facilities. The pneumatic test facilities have the further advantage that when the static load test has been completed it is possible to load the specimens pneumatically so the strength can be measured. A pneumatic-loading facility is also being constructed as an integral part of our bioceramic test program. Here the compactness of the system has an advantage for the construction of a multiple-test facility that has the proper biological environment for testing materials that are intended for use as prosthetic devices.

Often our ability to assess materials in new environments depends as much on the way we view the engineering information available on a material as it does on the information itself. In the past year, a new method of expressing crack-growth data has been developed that clearly delineates mechanisms of crack growth as a function of temperature and stress-intensity factor. The experimentally controllable parameters, K_I and T, are plotted as ordinate and abscissa related by contours of constant material response, i.e., crack velocity. This sort of map emphasizes changes in the fracture resistance of a material as either the temperature or the stress-intensity-factor change. In general, the resistance of a material to slow cracking or fracture depends upon the temperature and the load level. Any change in the mechanism of cracking or fracture will manifest itself as a change in dependence on these two controlling parameters. On the map, such a change would be indicated by an abrupt change in slope of the constant-velocity contour lines. The loci of such slope changes define boundaries between different mechanisms of slow crack growth or fast fracture. The boundaries may be sharp or diffuse, but within a set of boundaries exists a region in which one mechanism of slow crack growth or fracture is dominant. This new type of map has been applied to high-temperature fracture data on hot-pressed silicon nitride, providing a clear picture of the regions over which each mechanism of crack growth is dominant. During the coming year, this new mapping procedure will be applied to other ceramic and metallic materials to see if mechanisms for crack growth can also be clearly represented for these materials.

3.2.3. Engineering Evaluation of Ceramics

E. R. Fuller, N. J. Tighe, S. M. Wiederhorn, S. W. Freiman, D. E. Roberts, C. L. McDaniel, and R. F. Krause, Jr.

Extensive studies are being conducted on the strength of ceramic materials that are intended for use in a number of important commercial and defense applications. Materials being studied include: castable refractories for coal-gasification application, geothermal cements that will be used to line the wells that tap hot reservoirs of water deep within the earth, specialty ceramics that are intended for use in heat engines, dense ceramic materials for prosthetic devices, alkali halides for scintillation counters in deep-space NASA gamma-ray observatories, dielectric materials for ceramic capacitors intended for defense applications, and refractories for regenerative heat exchangers used in MHD applications.

Work on castable refractories is being conducted because of the intended use of three refractories in coal-gasification applications where strength must be maintained under severe environmental conditions. The objectives of the project are: (1) to characterize the mechanical properties (strength, erosion resistance, and fracture toughness) that relate to the structural integrity of refractory concretes intended for use in coal conversion systems, (2) to correlate these mechanical properties with microstructural changes that are induced by the reactive environment, and (3) to develop equipment and test procedures to assess the reliability and durability of castable refractories. Our major accomplishment last year was the completion of a high-pressure, high-temperature mechanical test machine that is capable of measuring strength in coal-gasification environments at extreme temperatures (100°C) and pressures (7 MPa, 1000 psi). The unit has been operated at design conditions Initial experiments were conducted in steam at temperatures as high as 1000°C on both a low (56%) aluminum-oxide refractory and a high (94%) aluminum-oxide refractory. Results of these initial experiments are consistent with results from previous experiments in which the strength was tested after high-temperature, high-pressure exposure. Results indicate that the lower purity (less expensive) 56%-aluminum-oxide refractory is superior for coal-gasification reactor linings. This result should contribute to substantial savings in the construction costs of gasifiers through the use of the less-expensive refractory.

The program on geothermal cements was initiated to develop a laboratory test facility for screening candidate cementing materials that are to be used in finishing operations of geothermal well holes. The program will provide the technical data necessary for an evaluation of the structural integrity of these cements after they have been exposed to high-pressure, high-temperature brine. The suitability of these cements for more costly tests in down-hole facilities will be evaluated for the Department of Energy. The program is divided into several tasks aimed at establishing the mechanical and physical properties of cements after they have been exposed to simulated geothermal environments. Properties to be measured include flexural and compressive strengths, strengths of cement pipe interfaces, and cement permeability at elevated pressures and temperatures. The equipment for this study has been designed and is being built. Proposed procedures for these tests have been drafted and submitted to an American Petroleum Institute Task Group for evaluation.

For the Department of Energy, a special series of screening tests was conducted on geothermal cements to evaluate the performance of a special group of cements. The structural stability of the cements was evaluated after exposure to water at temperatures of about 200°C and pressures of $\sim$ 20 MPa ($\sim$2800 psi) for extended intervals of time. Among the cements that were tested were candidates that had been proposed for use in a remedial cementing operation of a hot-dry-rock well at Los Alamos Scientific Laboratory. A series of shear-bond strength tests was also conducted to examine the influence of thermal cycling on the interfacial bond between a steel rod and the cement.

Because ceramic materials offer the potential for significant increase in operating temperatures and efficiency for gas turbine engines, silicon nitride is being considered by the Department of Defense and the Department of Energy for application in heat engines. Work at NBS on the subject of proof testing as a method of ensuring the reliability of this material at high temperatures is being conducted under the auspices of the Department of Energy. The objective of this study is to determine if the strength distribution of a population of test specimens can be truncated by proof testing. Earlier studies for the Department of Defense showed that truncation as a practical technique was acceptable at room temperature and, for rather large cracks, at high temperatures. In addition, there is an upper limit to the proof-test load that can be used to achieve reliability without destroying too many specimens. During the past year, this work was expanded to include reaction-sintered silicon nitride and hot-pressed silicon-nitride doped specimens. During the past year, this work was extended to include reaction-sintered silicon nitride and hot-pressed silicon nitride doped with yttrium oxide. Work on the reaction-bonded silicon nitride indicates that proof testing as a means of ensuring component reliability will be applicable to this material. Results at room temperature and at 1200°C show that, regardless of test conditions, the strength distribution of the reaction-bonded silicon nitride is truncated by proof testing. This conclusion is based on several hundred strength tests conducted on this material after exposure to 1200°C at load for periods as long as 1000 h. We conclude that, when subjected to stress at 1200°C, the material will either fail upon loading or will support its load indefinitely at elevated temperatures. This conclusion is consistent with the fact that subcritical crack growth, as determined by fracture-mechanics techniques, does not occur in this material at 1200°C. At room temperature, subcritical crack growth does occur, but in a predictable manner, so that the framework of fracture mechanics can be used to predict lifetime. These conclusions do not seem to be applicable to yttria-doped, hot-pressed silicon nitride, which can fail unpredictably when subjected to high temperatures (1200°C) under sustained load conditions. Flaw generation and subcritical crack growth are a considerable problem with the hot-pressed material. Work is continuing on this material to determine the causes of failure.

Another new and interesting application of ceramic materials is in the field of medicine. Certain types of ceramic materials (aluminum oxide, glass ceramics) are useful as structural components of prosthetic devices because they are biologically inert to the body environment and are relatively strong compared with bone. As a consequence, these materials are being introduced into the body in several applications: total hip replacements, anchors for artificial teeth, and artificial knee joints. In these applications, ceramic materials will have to sustain structural loads for periods that may last for forty years or longer. Given the tendency for ceramic materials to undergo stress-corrosion cracking owing to water in the environment, there is concern over the ability of these materials to perform their function in the body environment for extended periods. Because of this concern, the Fracture and Deformation Division has been conducting a study to determine the effect of microstructure on stress-corrosion cracking of aluminum oxide.

During the past year, one of the major tasks has been to assemble the test rigs to perform long-term delayed-failure studies on biomaterials. This setup is nearly completed. It consists of 10 pneumatically loaded test rigs. The specimens will be held in tanks through which the selected liquid environment will be peristaltically pumped. We are in the process of assembling a microcomputer system that will monitor the stresses on the test specimens and provide information from which the failure times can be determined. Data will be displayed on a video screen in the laboratory.

Initial data have been obtained in air on 30 to 50 specimens of the Friedericksfeld Al_2O_3. The crack-growth parameters calculated from these data agree with those obtained at the University of Florida under the same conditions.

Considerable discussions have been carried out with Dr. Larry Hench of the University of Florida and Dr. Jerry Klawitter of Tulane University regarding a joint research program with NBS. The result of discussions with Dr. Klawitter is a proposal summary that has been submitted to FDA. In this study, Tulane University would perform the *in vivo* studies on stressed ceramic specimens. NBS would conduct the accompanying mechanical-property experiments before and after implantation. Discussions with Dr. Klawitter have also been held regarding the development of an ASTM standard on the strength and mechanical testing requirements of Al_2O_3 for implants. We plan to write a draft standard within the coming year.

A new project for the coming year is the evaluation of the mechanical properties of alkali halides to be used as scintillation material for the NASA Gamma Ray Observatory. Data on mechanical properties are needed by NASA to aid in the efficient design of the support housings for the scintillation materials. Materials to be studied include NaI and CsI, both of which will be used in the observatory. The type of information needed includes compressive and flexural strength measurements for the NaI and the CsI, creep measurements for the CsI, and fracture-toughness and static-fatigue measurements for the NaI. Equipment is currently being designed and constructed to perform the required mechanical tests. The work is expected to be completed by the end of the 1980 fiscal year.

Another new project for the coming year is the development of screening tests to assess the performance and expected lifetime of ceramic capacitors for defense applications. These studies will be conducted on multilayered ceramic capacitors that are currently being used in a number of critical military applications, which include the guidance system for the Trident missile. These systems require the maximum mechanical and electrical reliability achievable. Studies on this project will involve the use of ultrasonic signals combined with sophisticated computer-analysis techniques as a means of detecting delaminations and cracks in capacitor parts. In support of this screening development, studies will be concluded to characterize the microstructure of ceramic capacitors and to establish the susceptibility of the ceramic material in the capacitor to strength degradation resulting from internal stresses and subcritical crack growth. This research is a joint effort with Division 564 to provide technical assistance to the Navy to improve the reliability of chip capacitors for defense applications.

The final project on our program of engineering evaluation of ceramic materials is concerned with refractory materials for MHD air preheaters. The high-temperature plasma (2400-2700°C) necessary for operable and economically attractive open-cycle MHD power generation is achievable through the combustion of fossil fuels using air preheated to about 1500°C. Temperatures of this level require the operation of regenerative heaters at temperatures as high as 1650°C; the heaters require refractory materials that are capable of maintaining their mechanical integrity at this extreme temperature. Creep resistance is one of the primary properties that will determine the ability of refractories to perform adequately as components in regenerative heaters. Although several types of commercial refractory bricks have been selected to serve in this application, creep data on these materials are not available at temperatures in excess of 1500°C. The objective of this research project is to obtain the necessary data on the high-temperature compressive creep of the refractories being considered for use in MHD air preheaters and to rank the proposed refractories in terms of their creep resistance at the service temperature of 1400 to 1650°C. To date, equipment has been designed for multiple creep experiments at temperatures as high as 1650°C in air. The equipment uses the pneumatic loading fixtures described in section 3.2.2. When completed, the test facility will be capable of measuring creep on 12 specimens simultaneously. All components for the test facility are currently being ordered or constructed at NBS. An existing dead-weight loading apparatus was modified to obtain preliminary data on candidate materials and to eliminate any potential problems that might arise in the study.

3.2.4. Friction and Wear of Ceramics

S. M. Wiederhorn, B. J. Hockey, and H. Johnson

Friction and wear are important phenomena that determine the cost and reliability of precision-ground ceramic parts. Since machining often accounts for 90% of the cost of these parts, a considerable reduction in costs may be achieved by improving the machining process.

Furthermore, since machining and erosion leave residual damage that reduces the strength of ceramic components, an understanding of these processes may lead to improvement in the strength of these materials. To achieve these ends, this project has been initiated to study the friction, wear, and erosion resistance of commercially important ceramic materials.

In an extension of work conducted last year on sharp particles, impact data (SiC grains against glass) were collected to evaluate the effect of impact angle on contact-induced strength degradation. These studies were conducted to determine if impact at oblique angles leads to local damage that is greater than that predicted by elastic-plastic strength-degradation theories developed to explain strength degradation at normal impact. If more damage does not occur, then existing analyses can be used as a conservative basis for design. It was also felt that such a study may increase our understanding of the damage mechanisms themselves and, therefore, of similar angular effects in erosion phenomena.

Strength-degradation tests were run on crown-glass discs using 150-μm SiC particles at a velocity of about 94 m/s. Various angles of exposure were used in the study with at least 10 specimens per angle. Strength results from ring-on-ring tests indicate an increase of strength as the impact angle becomes more oblique. However, the strength increase is less than that predicted from current theories, assuming that only the normal component of the velocities is effective in providing the driving force for crack formation. Plastic stresses arising from the shear component of velocity appear to contribute to crack formation and, thus, to strength degradation. However, the degradation appears to be small relative to that occurring from the normal component, so the elastic-plastic theory of strength degradation proposed earlier can be applied to obtain a conservative estimate of strength.

The above observations suggest that a shear component of velocity contributes to strength degradation. These observations are consistent with earlier observations on the erosive wear of ceramic materials, which indicate a contribution to erosion is a result of oblique impact of erosive particles. Shear stresses that occur during oblique impact apparently enhance the intensity of the plastic zone that results in crack formation and, therefore, increase the size of the cracks that are formed at impact.

Our data base for the erosion of brittle materials was expanded by obtaining erosion data on silicon (room temperature, 500°C, 1000°C), fused silica (room temperature, 500°C), soda-lime silicate glass (500°C and 600°C), and sapphire (room temperature, 500°C, and 1000°C). These data were combined with erosion data on aluminum oxide and hot-pressed silicon nitride obtained in earlier studies to show the dominant effect of fracture toughness (K_{IC}) and hardness (H) on the erosion rate. The largest resistance to erosion was found in materials for which the ratio of the toughness to the hardness, K_{IC}/H, was high. Therefore, K_{IC}/H

appears to be an important parameter for evaluating the erosion resistance of ceramic materials. In the year to come, these data will be used to summarize the effect of material properties, such as K_{IC} and H, on the resistance of materials to erosive wear. Comparisons between data obtained from these studies and theoretical expressions for the erosion rate will be made to determine the applicability of the erosion theories to brittle materials.

3.2.5. Microstructure of Ceramics

B. J. Hockey and N. J. Tighe

The objective of this subtask is to investigate the relation between structural and mechanical properties of ceramic materials. This subtask develops and applies techniques of high-resolution transmission and scanning electron microscopy to study deformation-and-fracture and wear processes in hard materials.

Earlier transmission-electron-microscopy studies on impact damage were extended this year by the use of scanning electron microscopy. This technique was used to evaluate the role of microstructure in determining the extent and type of impact damage that occurs during erosion. Temperature and particle velocity were used as parameters in studies on glass, silicon, sapphire, 30-μm-grain-size alumina, 3-μm-grain-size alumina, and hot-pressed silicon nitride. As indicated by the size of lateral cracks formed during impact, brittle behavior was enhanced as the fracture toughness (K_{IC}) decreased. For example, Si_3N_4, which has a fracture toughness of about 6 $MPa \cdot m^{1/2}$, showed very little chipping or crack formation associated with the damage at the contact area. In contrast, glass and silicon, which have relatively low values of toughness (about 0.8 and 0.7 $MPa \cdot m^{1/2}$, respectively), exhibited well-developed crack structures, with both lateral and median vents extending far beyond the immediate impact site. The type and extent of damage appeared to correlate with erosion rates measured on these materials (discussed below), confirming the importance of high fracture toughness to good erosion resistance.

Perhaps the most interesting observation made in these microstructural studies was on glass impacted at room temperature with 150-μm SiC particles at a velocity of about 94 m/s. Under these conditions, the temperature elevation was so high that pools of molten glass formed at the impact site. At oblique angles of impact, molten glass attached itself to the impacting particles and glass fibers were pulled from the surface of the glass. Simple theoretical estimates indicate glass temperatures in excess of 900°C. A more detailed model, which was developed to explain thermal effects during erosion, confirmed these high-temperature estimates.

The effect of ambient temperature on erosion damage was investigated by comparing surface damage occurring at room temperature with that occurring at elevated temperatures (500°C, 600°C, and 680°C for glass; 500°C for silicon; 500°C and 1000°C for Al_2O_3 and Si_3N_4). Despite the higher ductility of these materials at elevated temperatures, the damage during impact was very similar to that observed at room temperature. However, qualitative differences between room-temperature and elevated-temperature erosion were observed. In glass, lateral cracks did not extend as far at 500°C and 600°C as they did at room temperature. Furthermore, plastic deformation at the contact site was enhanced at high temperatures. These differences in appearance of the contact site account for the observed decrease in the erosion rate of glass at elevated temperatures. For the crystalline materials studied (Al_2O_3, Si_3N_4, Si), differences in appearance of the contact site occurred, but were not as obvious as those observed for the glass, which probably accounts for the fact that the erosion rate at elevated temperatures was virtually identical to that obtained at room temperature.

3.2.6. Engineering Evaluation of Composites

M. B. Kasen and R. E. Schramm

This effort began in 1973 with a comprehensive literature review of the existing state of knowledge on the effect of cryogenic temperatures on the mechanical and thermal properties of composite materials. An increasing use of composite materials in high-technology cryogenic areas had created the need for a reliable data base on low-modulus (glass-reinforced) and high-modulus (graphite-, boron-, kevlar-reinforced) polymer-matrix composite laminates. These reviews, published in Cryogenics, June and September 1975, provided the background for establishing test programs. Data available in 1975 indicated that all of these composite types were acceptable structural materials for cryogenic use. But the temperature dependence of the mechanical properties and the values for the properties showed a large scatter. It was apparent that this variability reflected inadequate test methodology and relatively poorly characterized materials.

The NBS testing programs were initially funded by ARPA as part of a program to acquire data relevant to the construction of superconducting machinery. A continuation of these studies was funded by the U.S. Air Force Aero Propulsion Laboratory (AFAPL), Wright-Patterson AFB, Ohio. The object of the latter program was to provide composite property data relevant to construction of lightweight, airborne superconducting power packages based on either generator or magnetohydrodynamic designs.

These studies required development of improved testing techniques capable of producing valid tensile, compressive, and shear data from all types of composite materials from 295 to 4 K. Information derived during this phase was communicated to Committee D-30 of ASTM, which is primarily responsible for establishing standard methods of composite testing. M. B. Kasen of the Fracture and Deformation Division is a member of this committee. Participation was timely, since such standards were almost nonexistent.

Development of test methods proceeded concomitantly with the acquisition of systematic data on the cryogenic temperature effects. The NBS objective was to characterize the major mechanical properties of state-of-the-art boron-, glass-, graphite- and kevlar-reinforced epoxy products from 295 to 4 K. Twin outputs of the program were the establishment of the first systematic data base reaching to liquid-helium temperature and an assessment of the need to develop special epoxy-resin formulations for cryogenic use.

Key properties are those required for prediction of crossply laminate performance using macromechanical composite theory developed in the aerospace industry. Required data are longitudinal and transverse uniaxial strengths, moduli, and Poisson's ratios, and in-plane shear strength and modulus. These data have been acquired for epoxy-matrix laminates reinforced with 0.14-mm (5.6-mil) boron, S-glass, kevlar 49, and types AS, HM-S, and GY-70 graphite fibers. A 0.14-mm (5.6-mil) boron-reinforced aluminum was also characterized. The data have thus far failed to define performance regions; therefore the development of special composite formulations is necessary for cryogenic use. But the possibility that such a development might be justified under cyclic loading conditions remains to be investigated.

Another major direction in the program reflected the need to use large quantities of low-cost, high-pressure industrial laminates as structural support and electrical insulation in large superconducting magnets for magnetic fusion energy and magnetohydrodynamic power generation in the consumer area. The commercial high-pressure industrial glass-epoxy laminates produced under NEMA (National Electrical Manufacturer's Association) designations G-10 and G-11 are normally selected for this application. But such materials display large property variability at cryogenic temperatures. Therefore, NBS has cooperated with NEMA and the U.S. laminating industry to establish a uniform specification for cryogenic grades of such laminates. These products, designated G-10CR and G-11CR, are now in commercial production. Their mechanical, electrical, and thermal properties have been extensively characterized at NBS-Boulder with the participation of the Massachusetts Institute of Technology, Los Alamos Scientific Laboratory, Westinghouse, and General Electric. The performance of these materials under neutron and gamma radiation at 4 K is under assessment at Oak Ridge National Laboratory.

The composite program during the past year included characterization of the performance of graphite-epoxy laminates at cryogenic temperatures. In addition, we served as a consultant to the USAF on composite-materials selection for the prototype advanced-composite superconducting generators being designed for the Air Force by General Electric and the lightweight magnetohydrodynamic power systems being designed by General Dynamics/Convair in association with the Magnet Corporation of America. Characterization of the mechanical properties of the cryogenic-grade G-10CR and G-11CR materials also continued.

3.3 Elastic-Plastic Fracture Mechanics

Safety and durability are primary considerations in the design and construction of engineering structures. Sophisticated methods to assess structural safety and durability have been developed on the basis of linear-elastic fracture mechanics. These analytical methods are applicable to the high-strength alloys used for aerospace vehicles and to the heavy section steels used for nuclear pressure vessels. Unfortunately, the methods of linear-elastic fracture mechanics do not apply to a wide range of metal structures, including bridges, pressure vessels, ships, offshore structures, and pipelines. In these applications, the materials of construction (steels and aluminum alloys are typical) are highly plastic (nonlinear) before fracture. Consequently, linear-elastic methods do not apply and the assessments of structural safety and durability are based on empirical methods and prior experience. Although current methods usually provide a reasonable record of structural safety, improved efficiency and productivity could be achieved if more rational methods were used to establish material-toughness requirements, allowable stress levels, minimum service temperatures, and weld-quality standards. The objective of this task is to contribute to the scientific basis (i.e., elastic-plastic fracture mechanics) for developing fracture-prevention procedures applicable to materials that exhibit extensive plasticity before fracture.

The Fracture and Deformation Division program in elastic-plastic fracture mechanics consists of five subtasks:

1. Current fracture-control procedures are being reviewed and test standards for improved procedures are being developed.

2. J-integral evaluations are used to characterize the fracture resistance of structural alloys and determine the driving force for fracture under elastic-plastic conditions.

3. The significance of defects, particularly in weldments, is being evaluated on the basis of plastic-strain cycling tests and analytical studies.

4. The elastic-plastic fracture properties of alloys and weldments used for low-temperature applications, such as LNG tankage and superconducting-magnet structures, are being evaluated.

5. Elastic-deformation phenomena are being studied to contribute to our understanding of the fundamental basis of strength.

3.3.1. Fracture Control

H. I. McHenry, R. deWit, D. T. Read, and B. W. Christ

Minimum-toughness requirements are frequently included in material-procurement specifications. Standard test methods are essential to ensure that the material toughness meets specified requirements. The Fracture and Deformation Division is contributing to the standardization of test methods for evaluating the fracture toughness using the J-integral, the J-resistance curve, and the crack-opening-displacement methods. Division activities include membership in the appropriate ASTM committees and participation in round-robin testing programs.

A survey of fracture-control practices used by American industry was conducted for the U.S. Navy. The specific objectives of the resulting report were: (1) to review the elements of fracture control and to prepare a detailed summary of industrial practices relative to each element and (2) to identify fracture-control concepts potentially transferable to the Navy. Twelve classes of structures were reviewed, including ships, offshore structures, bridges, pressure vessels, aircraft, piping, cryogenic tankage, electrical-power-generation equipment, space vehicles, and pipelines.

A tutorial report on fracture mechanics is being prepared in collaboration with Professor G. R. Irwin of the University of Maryland. This report includes both linear-elastic and elastic-plastic fracture mechanics. Fracture and subcritical crack growth owing to fatigue and stress corrosion are discussed. A summary of fracture-mechanics concepts has been completed.

3.3.2. J-Integral Evaluations

D. T. Read, R. L. Tobler, T. A. Whipple, and H. I. McHenry

The J-integral is a characterization of the elastic-plastic field in the vicinity of the crack tip. The value of the J-integral for any contour surrounding the crack tip has been shown experimentally to be a criterion for the onset of crack extension. Experimental methods have been developed to determine the critical value of J, J_{IC}, which is a measure of the plane-strain fracture toughness. The Fracture and Deformation Division is conducting research using the J-integral to characterize the fracture toughness of structural alloys, to measure the driving force for fracture under elastic-plastic loading conditions, and to conduct analytical studies to evaluate the influence of geometric configuration and stress-strain characteristics.

During the past year, we have made substantial improvements in our test facilities, experimental methods, and analytical capabilities. A 1-MN-capacity servohydraulic fatigue-test machine has been procured and installed. It is being used to apply a uniform strain field to tensile panels with flaws that are small compared with the overall panel size. A minicomputer has been procured and computer-interactive J-integral test procedures have been developed. These advanced test procedures are now being used to evaluate the fracture toughness of stainless steel alloys and weldments for cryogenic service. A finite-element-analysis computer code for elastic-plastic fracture-mechanics analysis, developed by the Navy, has been obtained and is operational on an NBS computer. The two-dimensional-analysis code features crack-tip-singularity elements that enable simplified grids for calculating the J-integral and thereby substantially reduce the computer-time requirements for elastic-plastic analysis. The computer analyses are being used to study the influence of strain hardening and geometric configuration on the plastic strain field in tensile panels with through-thickness cracks.

A major new experimental effort has been started to measure directly the J-contour-integral on tensile panels under elastic-plastic loading conditions. Single-edge-notch tensile panels are instrumented with strain gages along the vertical boundaries and displacement gages along the horizontal boundaries. Gage signals are recorded by a computer and the strain-energy density is calculated on the basis of the stress-strain characteristics of the test material. The rotational contribution to J is computed from displacement signals from LVDT transducers mounted along the top and bottom of the specimen. Tests to date have confirmed the feasibility of the method and have provided a positive check on the finite-element-analysis predictions. This represents a start on the goal of relating the J-integral to the applied strain and flaw size for a variety of geometric configurations and structural alloys. Measurements of this type are being conducted for the Navy to establish a J-integral design curve and for the Office of Pipeline Safety Regulation to develop an analytical model for prediction of critical flaw sizes in pipeline girthwelds.

3.3.3. Significance of Defects

R. deWit, J. H. Smith, D. T. Read, M. B. Kasen, J. G. Early, and H. I. McHenry

The Fracture and Deformation Division is conducting programs for the Navy and for the Office of Pipeline Safety Regulation regarding the significance of defects, particularly in welded structures. Weld-quality standards usually stipulate allowable defect sizes on the basis of workmanship considerations, i.e., what level of quality can usually be achieved by a qualified welder using the proper welding materials and procedures under reasonable working conditions? These quality levels may differ significantly from the quality required to ensure structural integrity.

In the Navy program, a J-integral design curve is being developed along the lines proposed in the Draft British Standards Rules for Derivation of Acceptance Levels for Defects in Fusion Welded Joints. The program involves the experimental determination of the relationships of the J-integral fracture toughness, the applied strain, and the defect size. Initial tests, currently in progress, involve tensile panels of ship steel with edge cracks. Future work will progress to center cracks, surface cracks, and cracks in welds. The influence of residual stress on the design curve will be assessed using wide-plate tests currently being fabricated by the Navy. The program is being conducted in collaboration with the Naval Ship Research and Development Center and Professor S. T. Rolfe of the University of Kansas.

The program for the Office of Pipeline Safety Regulation is being conducted to establish weld-quality requirements for the Alaska Natural Gas Transportation System. Initial studies involve analytical modeling of the significance of defects using methods comparable to those used for the trans-Alaska pipeline assessment conducted previously. Future work will involve J-integral studies comparable to the Navy program and verification testing on small-scale and full-scale pipe specimens. In addition to the fracture studies, fatigue tests are being conducted to evaluate the effect of plastic-strain cycling on nonplanar defects, such as porosity and slag. Load-controlled fatigue tests are planned to determine the influence of simulated-service loading on the growth of planar defects, such as lack of fusion and lack of penetration.

3.3.4. Low-Temperature Properties

R. P. Reed, H. I. McHenry, D. T. Read, R. L. Tobler, and R. E. Schramm

The increased use of natural gas, usually shipped and transported in liquefied form (LNG), has led to materials research on economical structural alloys and insulation materials. Such research has been necessary to satisfy regulations based on fracture-control plans for LNG ships and stringent safety requirements for LNG storage sites which are inspired by the potentially dangerous consequences of LNG. Our research, sponsored by the Gas Research Institute and the Maritime Administration, now focuses on development of improved low-temperature LNG ship-hull steel plate and characterization of the mechanical properties of concrete and foam insulations used by the LNG industry. To develop economical steel plate more tolerant to high-heat-input welding techniques, major ship-plate producers and LNG ship builders were assembled and combined with NBS in a joint program. Better steels have been identified and characterized for use by the shipbuilding industry.

A major developing technology is the use of superconducting magnets in energy applications. High magnetic fields are required for fusion-plasma and MHD-plasma confinement and guidance. Superconducting machinery, under prototype development, provides the potential for better performance coupled with lighter weight and reduced space requirements. Power transmission via superconducting underground cables is under intensive development. Energy storage, using large superconducting rings, is being considered. In all applications, the magnet or superconductor, with appropriate structural supports, is expected to operate at liquid-helium temperature (4 K) up to 20 years.

Such emphasis on liquid-helium design and material use has led to large national materials programs, sponsored by DARPA and DoE and managed by our division. These programs have produced a low-temperature materials handbook; mechanical, thermal, electrical, and magnetic characterization of economical structural alloys including austenitic stainless steels, aluminum alloys, and superalloys; an annual Low-Temperature Materials Workshop held each October in Vail, Colorado; and joint research programs between NBS and its subcontractors, which have included Battelle, Westinghouse, General Electric, Martin-Marietta, Teledyne-McKay, Alcoa, Armco, and Belfour-Stulen. Major research emphasis has been to characterize the austenitic stainless steels (AISI 304, 316, and 310 grades) and to develop reliable welding processes and filler metals for welding austenitic stainless steels for use at low temperatures. The development and characterization of low-temperature composite insulator standards is discussed in the previous task.

This year's low-temperature fracture-mechanics highlights include:

1. Additions of 0.2% nitrogen to an iron-chromium-nickel austenitic stainless steel (AISI 304) have achieved yield-strength increases of a factor of five at liquid-helium temperatures. Since nitrogen alloying is inexpensive and the preliminary J-integral measurements indicate sufficient toughness, additional research will proceed to characterize high-nitrogen stainless steels at 4 K.

2. The temperature dependence of the flow strength of austenitic stainless steels has been measured and analytically characterized. Anomalous regions of decreases of strength with decreasing temperature have been identified, and correlation with the martensitic transformation is progressing.

3. A correlation between low-temperature fracture toughness and ferrite concentration in stainless-steel weldments has been obtained; higher ferrite concentrations reduce the low-temperature toughness.

3.3.5. Elastic Deformation Phenomena

H. M. Ledbetter

Elastic constants provide fundamental information about solids to both the solid-state physicist, who wonders what holds solids together, and to the materials engineer, who wonders what tears them apart.

Our effort on solid-state elastic constants comprises three categories: (1) critical reviews of elastic-property data, (2) experiment, and (3) theory.

Our critical reviews focus on materials of both scientific and technological importance: iron, nickel, copper, zinc, iron-nickel alloys (completed); copper-zinc alloys, aluminum (in progress) magnesium, titanium, and others (planned). Besides recommending "best" elastic constants, these reviews consider effects of variables such as temperature, pressure, alloying, magnetic field, and mechanical deformation, and identify suggested areas for further study. From both university laboratories and industrial laboratories, we have received considerable encouragement for more studies of these kinds.

Our experimental studies deal with metals, alloys, composites, and polymers; with single crystals and with polycrystals. Notable recent studies include the paramagnetic spin-glass transition in manganese stainless steels, the omega-phase effects in niobium-titanium alloys, and precise measurement of the complete set of elastic constants of a boron-aluminum composite and their reconciliation with theory. Laser-induced bulk and Rayleigh waves have been used to study composite superconducting wires. Because superconducting wires are used in critical design applications such a magnets, these studies are important, especially in terms of rule-of-mixture predictions and in the compositional variation of the wire's physical properties, especially those that are design parameters.

Our theoretical efforts focus on three principal problems: (1) relationships between elastic constants and other physical properties, particularly the Debye characteristic temperature; (2) relationships between physical properties of single crystals and polycrystals, that is, the tensor-averaging problem; and (3) elastic constants and interatomic potentials. On the latter problem, collaborating with T. Suzuki, we recently calculated the elastic constants of the alkali metals using pseudopotentials and related these constants to the phase-transition behavior of the metals. From these calculations is emerging an exciting new concept for low-temperature solid-state nucleation of the new phase. Basically, the traditional surface-energy-term approach, which fails to predict reaction rates, is replaced by a lattice-deformation-energy term that might.

3.3.6. Test Methods and Standards

B. W. Christ, J. G. Early, C. G. Interrante, G. E. Hicho, and J. H. Smith

The development of test methods and standards often follows closely the failure-analysis tasks carried out for other agencies. In addition, ASTM and ASME often call on NBS expertise for assistance in formulating test methods and standards. Staff members of the Fracture and Deformation Division are contributing to the following work.

Hydrogen Embrittlement: This project carries out research to establish guidelines to be used for developing standard fracture-mechanics test methods for hydrogen embrittlement of steel exposed to aqueous media. Emphasis is on pressure-vessel steels and structural steels of moderate strength. These steels are of commercial significance in the petrochemical industry and the transportation industry. Ties have been established with the Pressure Vessel Research Committee of the Welding Research Council.

ASTM Subcommittee E24.03-Alternative Fracture Test Methods: Chairmanship of this subcommittee involves fostering fracture test methods that differ from ASTM Standard E399, which is a plane-strain fracture-toughness test. Alternative methods apply to high-toughness structural metals and include the Precracked Charpy and Dynamic Tear Test Methods. Applications of the Equivalent Energy Method of data analysis are being examined by this subcommittee.

ASTM Subcommittee E24.05-Fracture Terminology: Chairmanship of this subcommittee involves developing standard terminology for Fracture Toughness Testing. Numerous definitions have been developed and balloted.

ASTM Committee E38-Resource Recovery: Membership on this committee involves contributing to the development of standards. Two standards have been prepared -- "Standard Methods of Test for Municipal Ferrous Scrap," and "Standard Specifications for Municipal Ferrous Scrap." Part of the data base for the former method was developed in a technical paper by J. G. Early et al., "Determination of Combustible Material in Ferrous Scrap Recovered from Refuse," (to appear in the Journal of Resource Recovery and Conservation).

ASTM Task Group E28.04.03-Verification of Alignment: Chairmanship of this task group involves developing a standard method for verifying alignment under tensile loading. This method applies to tensile, stress rupture, creep, uniaxial fatigue, and microstrain testing. A draft method is ready for subcommittee ballot.

U.S. Coast Guard-Equivalence of Codes and Standards: This task was recently undertaken with the sponsorship of the U.S. Coast Guard and Department of Transportation. The objective is to make recommendations to the sponsor concerning the equivalency to U.S. specifications of structural, piping, and pressure vessel materials for ships produced to foreign specifications.

United Nations Specification For Compressed Gas Containers: This task is being performed for the Materials Transportation Bureau of the U.S. Department of Transportation. An international specification for seamless and welded steel containers has been prepared.

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Elastic Constants at Low Temperatures: Recent Measurements on Technological Materials at NBS
H. M. Ledbetter
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K. D. Timmerhaus, R. P. Reed, and A. F. Clark, editors,
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Dynamic Elastic Modulus and Internal Friction in Fibrous Composites
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H. M. Ledbetter and J. C. Moulder
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K. D. Timmerhaus, R. P. Reed and A. F. Clark, editors,
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Materials Studies for Magnetic Fusion Energy Applications at Low Temperatures - II
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Fiberglass-Epoxy in a Conical Superconducting Field Magnet Support
R. E. Schramm and M. B. Kasen
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R. L. Tobler, R. P. Mikesell, and R. P. Reed
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Tensile and Fracture Behavior of a Nitrogen-Strengthened, Chromium-Nickel-Manganese Stainless Steel at Cryogenic Temperatures
R. L. Tobler and R. P. Reed
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Strength Degradation of Glass Impacted with Sharp Particles, II. Tempered Surfaces
S. M. Wiederhorn, D. B. Marshall, and B. R. Lawn
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5. INVITED TALKS

Summary of Fracture Mechanics Concepts
Oak Ridge National Laboratories, Oak Ridge, Tennessee
R. deWit
March 1978

Development of Some Analytical Fracture Mechanics Models for Surface Defects in Plates of Ductile Metals
Third International Symposium on Continuum Models of Discrete Systems
R. deWit
June 1979

Operational Experiences in Nuclear Power Plants, Regulation and Research
Panel for Special Symposium on In-Service Data Reporting and Analysis
American Society of Mechanical Engineers, San Francisco, California
R. C. Dobbyn
December 1978

The Performance of Materials in Advanced Coal Conversion Pilot Plants
Oak Ridge National Laboratory, Oak Ridge, Tennessee
R. C. Dobbyn
May 1979

How Should We Handle the Subjective Component of In-Service Data Reporting and Analysis
Materials and Fabrication Committee, PVP Division
American Society of Mechanical Engineers, San Antonio, Texas
R. C. Dobbyn
August 1979

Selected Topics from Railroad Tank Car and Hydrogen Embrittlement Programs
Eighth Fracture and Deformation Division Seminar, NBS, Gaithersburg, Maryland
J. G. Early
December 1978

Some Effects of Geometry on the High Temperature Fracture Notched Components
Oak Ridge National Laboratory, Oak Ridge, Tennessee
R. J. Fields
October 1978

Investigation of Appropriate Fracture Criteria for Si_3N_4 at High Temperatures
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
R. J. Fields
April 1979

Effective Heat Treatment on the Oxidation of Hot-Pressed Si_3N_4 as Determined by Infrared Reflection Analysis
American Ceramic Society Conference on Composites and Advanced Materials, Cocoa Beach, Florida
S. W. Freiman
January 1979

Fracture Mechanics Applied to Ceramics
ASTM Subcommittee E24.02 Meeting, Atlanta, Georgia
S. W. Freiman
February 1979

Effect of Crack Velocity on Fracture Morphology in Ceramics
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
S. W. Freiman, J. J. Mecholsky, and A. C. Gonzalez
May 1979

Current Status of Predicting Service Lifetimes for Ceramic Implants
Biomaterials, Gordon Conference, Tilton, New Hampshire
S. W. Freiman
July 1979

Effects of Surface on the Mechanical Properties of Ceramics
Sagamore Conference, Sagamore, New York
S. W. Freiman, J. J. Mecholsky, and P. F. Becher
July 1979

Atmospheric Influences on Brittle Crack Propagation
Ceramic Engineering Seminar, University of Illinois, Urbana, Illinois
E. R. Fuller, Jr.
December 1978

Cementing of Geothermal Wells-Property Verification
API Task Group on Cements for Geothermal Wells, Houston, Texas
E. R. Fuller, Jr.
January 1979

The Ductile-Brittle Character of Fracture
American Physical Society 1979 March Meeting, Chicago, Illinois
E. R. Fuller, Jr.
March 1979

Kinetics of Chemically Assisted Brittle Fracture
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
E. R. Fuller, Jr.
May 1979

Mechanical Property Testing of Refractory Concretes at High Pressure and Temperature
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
E. R. Fuller, Jr.
May 1979

Considerations of the Ductile-Brittle Character of Fracture
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
E. R. Fuller, Jr
May 1979

Stress Waves from Particle Impact
Office of Naval Research Workshop on the Erosion of Materials, NBS, Gaithersburg, Maryland
E. R. Fuller, Jr.
June 1979

Computer Assisted Impact Testing
ASTM Symposium on Computer Automation of Materials Testing, ASTM Committees E-24 and E-28, Philadelphia, Pennsylvania
C. G. Interrante
November 1978

A System for Studies of Crack-Growth Rate in Aggressive Environments
ASTM Symposium on Computer Automation of Materials Testing, ASTM Committees E-24 and E-28, Philadelphia, Pennsylvania
C. G. Interrante
November 1978

Railroad Tank Car Problems
Seventh Fracture and Deformation Division Seminar, NBS, Gaithersburg, Maryland
C. G. Interrante
December 1978

Analysis of Railroad Tank-Car Failures
The American Welding Society, Northeast Tennessee Section, Oak Ridge, Tennessee
C. G. Interrante
March 1979

Impact Testing of Metallic Materials with Emphasis on Test Methods, Instrumentation, and Acquisition and Analysis of Data
Building Composites Group Seminar, NBS, Gaithersburg, Maryland
C. G. Interrante
April 1979

Status of DoT Fracture Mechanics Pipeline Welding Research
Pipeline Welding and Inspection Conference, Houston, Texas
M. B. Kasen
February 1979

Significance of Flaws in Girth Welds of Pipelines
Paton Institute of Electrowelding, Kiev, USSR
M. B. Kasen
June 1979

Practice for Property Testing of Geothermal Cements
Standardization Conference of American Petroleum Institute,
San Diego, California
R. F. Krause, Jr.
June 1979

Proposed Practice for Testing Geothermal Cements
API Task Group on Cements for Geothermal Wells, San Diego, California
R. F. Krause, Jr.
June 1979

NBS/DoE Welding Program
NBS/DoE Workshop on Materials at Low Temperatures, Vail, Colorado
H. I. McHenry
October 1978

Ship Steels with Improved Toughness and Weldability
AWS Conference on Welding in Shipbuilding: Productivity and
Economics, San Diego, California
H. I. McHenry
March 1979

Fitness for Purpose Evaluation of Defects in Pipeline Girthwelds
ASME Conference on Structural Integrity, Washington, D.C.
H. I. McHenry
May 1979

Structural Alloys for Superconducting Magnets in Fusion Energy
Systems
Fifth International Conference on Structural Mechanics in Reactor
Technology, Berlin, West Germany
H. I. McHenry
August 1979

Mechanical Properties of Austenitic Stainless Steel Base- and Weld-
Metal
NBS/DoE Workshop on Materials at Low Temperatures, Vail, Colorado
R. P. Reed
October 1978

Structures, Insulators, and Conductors for Large Superconducting
Magnets
First Topical Conference on Fusion Reactor Materials, Miami, Florida
R. P. Reed
January 1979

Low Temperature Effects of Defects in Stainless Steel Welds
Paton Institute of Electrowelding, Kiev, USSR
R. P. Reed
June 1979

The Effect of High Temperature Processes on Predictive Testing
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
N. J. Tighe
May 1979

Analysis of the Refractories from a Coal Gasification Plant (CO_2 Acceptor Process)
American Ceramic Society, Bedford Springs, Pennsylvania
S. M. Wiederhorn
October 1978

Erosion of Ceramics
NACE Conference on Erosion/Corrosion of Coal Conversion System Materials, Berkeley, California
S. M. Wiederhorn
January 1979

High Temperature Fracture of Ceramic Materials
DoE Workshop on Time Dependent Fracture, Germantown, Maryland
S. M. Wiederhorn
February 1979

Effect of Fluid Viscosity on Crack Propagation
American Ceramic Society, 81st Annual Meeting, Cincinnati, Ohio
S. M. Wiederhorn
April 1979

Structural Ceramics
DoE Workshop on Coal Conversion Systems, Knoxville, Tennessee
S. M. Wiederhorn
June 1979

Erosion of Ceramics
Energy Materials Coordinating Committee Conference on Structural Ceramics, sponsored by DoE, Knoxville, Tennessee
S. M. Wiederhorn

6. RECENT SEMINARS

D. J. Barber
Deformation of Dolomite
July 2, 1979

P. Beaumont
Micromechanisms of Fracture in Fibrous Composites During Monotonic Loading
June 18, 1979

J. A. Begley
Fracture Mechanics and Corrosion
February 4, 1979

S. J. Burns
Thermodynamics of Fracture
May 29, 1979

A. L. Broz
Projects in the Nondestructive Testing Field
July 23, 1979

G. C. Chell
The Significance of Warm Prestress in Understanding and Interpreting Failure Criteria
January 4, 1979

T.-J. Chuang
A Plane-Strain Elasticity Model for the Diffusive Growth of an Intergranular Creep Crack
August 7, 1979

R. L. Crane
The Nondestructive Evaluation/Fracture Mechanics Interface
April 5, 1979

R. L. Crane
Consultation on Nondestructive Evaluation Procedures for Welds in Gas Transmission Pipelines
May 14, 1979

R. deWit
The R-Curve in Fracture Mechanics
October 31, 1978

R. deWit
The R-Curve in Fracture Mechanics II
January 23, 1979

R. deWit
A Summary of Fracture Mechanics Concepts
April 3, 1979

J. G. Early
Report on Selected Topics from the Railroad Tank Car and Hydrogen Embrittlement Programs
December 12, 1978

C. Fortunko
Projects in the Nondestructive Testing Field
July 27, 1979

S. W. Freiman
Fractographic Analysis of Ceramics
October 17, 1978

S. W. Freiman
Fracture Mechanics for Structural Ceramics
October 27, 1978

H. Frost
The Application of Physical Acoustics to Nondestructive Evaluation
March 15, 1979

E. R. Fuller, Jr.
Atomistic Influences on Brittle Crack Propagation
December 1, 1978

E. R. Fuller, Jr.
Theory of Chemically Assisted Fracture: A Progress Report
February 6, 1979

A. H. Heuer
Precipitation in Star Sapphire
June 12, 1979

C. G. Interrante
Railroad Tank Car Problems
December 5, 1978

F. F. Lange
Transformation Toughening of Ceramics
June 1, 1979

B. R. Lawn
Elastic/Plastic Indentation Fracture in Brittle Solids
April 17, 1979

C. J. McMahon, Jr.
Embrittlement of Steels by Solute Segregation
May 8, 1979

R. S. Polvani
Using Beryllium for Gyroscopes
January 9, 1979

N. J. Tighe
Ceramics for Turbine Engines
March 6, 1979

T. Suzuki
Phonon Dispersion and Martensitic Transformations
February 21, 1979

T. Suzuki
Elastic Constants and Structural Phase Transitions
July 2, 1979

S. M. Wiederhorn and B. J. Hockey
Effect of Temperature on the Erosion of Ceramics
October 3, 1978

S. M. Wiederhorn
Mechanisms of Erosive Wear in Ceramic Materials
April 4, 1979

R. S. Williams
Nondestructive Evaluation of Fracture Mechanics
May 25, 1979

7. CONSULTING AND ADVISORY SERVICES

Committee on Recommendations for U.S. Army Basic Scientific Research (National Research Council)
S. M. Wiederhorn

Department of Energy Review Panel: Alternate Waste Forms for Immobilization of High Level Radioactive Wastes
S. M. Wiederhorn

Geothermal Well Cementing Advisory Panel
E. R. Fuller

Interagency Coordination Group for the Application of Ceramics to Heat Engines
S. M. Wiederhorn

Metal Properties Council Technical Advisory Committee
R. P. Reed

National Materials Advisory Board Committee on Ceramics for Heat Engines
S. M. Wiederhorn

National Science Foundation Advisory Committee for Metallurgy and Materials Science
R. P. Reed

Ship Materials Fabrication and Inspection Advisory Group of the Ship Research Committee (National Academy of Sciences)
H. I. McHenry

Steel Industry Study Advisory Committee, U.S. Department of Commerce
J. G. Early, J. H. Smith

Welding Research Council Long-range Planning Cooperative Technology Program
H. I. McHenry

8. PROFESSIONAL-SOCIETY AND COMMITTEE PARTICIPATION

American Association for the Advancement of Science
S. W. Freiman, B. J. Hockey, H. M. Ledbetter, J. H. Smith

American Ceramic Society
Members: J. M. Bukowski, R. J. Fields, S. W. Freiman (Secretary of Glass Division), E. R. Fuller, Jr. (Secretary-Treasurer of the Baltimore-Washington Section), B. J. Hockey, C. L. McDaniel, N. J. Tighe
Committee Participation:
Executive Committee: N. J. Tighe
Forum Committee: N. J. Tighe
Sosman Lecture Committee: N. J. Tighe

American Chemical Society
Members: R. F. Krause, Jr., C. L. McDaniel, S. M. Wiederhorn
Committee Participation:
Editorial Committee Subchairman: S. M. Wiederhorn

American Institute for Mining, Metallurgical, and Petroleum Engineers (AIME)
Members: B. W. Christ, R. deWit (key reader), J. G. Early, S. Polvani, J. H. Smith

American Iron and Steel Institute
Task Force on Evaluation of Fracture Criteria for Ship Steels and Weldments: H. I. McHenry

American National Standards Institute (ANSI)
Materials and Stresses Committee of the Pressure Piping Code, B31: H. I. McHenry

American Petroleum Institute
Task Group on Cements for Geothermal Wells: E. R. Fuller, Jr.

American Physical Society
R. C. Dobbyn, E. R. Fuller, Jr., R. deWit, E. R. Fuller, B. J. Hockey

American Society for Metals (ASM)
Members: B. W. Christ, R. deWit, J. G. Early, R. J. Fields, G. E. Hicho, C. G. Interrante, H. I. McHenry, T. R. Shives, N. J. Tighe
Committee Participation:
Long Range Planning Committee: C. G. Interrante (Chairman)
Metals Information Publications Committee: J. H. Smith

American Society for Testing and Materials (ASTM)

Members: R. deWit, R. C. Dobbyn, B. W. Christ, J. G. Early, R. J. Fields, S. W. Freiman, G. E. Hicho, C. G. Interrante, M. B. Kasen, T. R. Shives, J. H. Smith, R. L. Tobler, S. M. Wiederhorn

Committee Participation:

COT Committee on Terminology of Committee on Standards: C. G. Interrante

Committee C-21 Ceramic Whitewares: S. M. Wiederhorn

Committee D30 Composite Materials: M. B. Kasen

Subcommittee D30.05 High-Modulus Fibers and Their Composites: M. B. Kasen

Subcommittee E9.03 Fatigue of Composites: M. B. Kasen

Subcommittee E10.02-D Computer Methods for Analysis of Charpy Data: C. G. Interrante

Committee E24 Fracture Testing: B. W. Christ (Member of Executive Committee), E. R. Fuller, Jr., G. E. Hicho, C. G. Interrante (Member of Executive Committee), J. H. Smith, R. L. Tobler, S. M. Wiederhorn

Task Group E24.01.09 Elastic Fracture: R. L. Tobler

Subcommittee E24.03 Alternative Test Methods: B. W. Christ (Chairman)

Task Group E24.03.03 Precracked Charpy Testing Methods: C. G. Interrante

Subcommittee E24.05 on Terminology: C. G. Interrante (Chairman), R. deWit (Secretary), J. H. Smith

Subcommittee E24.07: S. W. Freiman (Chairman)

Task Group E28.04.03 Verification of Alignment Under Tensile Load: B. W. Christ (Chairman)

Committee E38 Resource Recovery: J. G. Early (Secretary)

Subcommittee E38.02 Ferrous Metals Resource Recovery: J. G. Early (Secretary)

Joint ASTM-ASME-MPC Committee on Effect of Temperature on the Properties of Metals: B. W. Christ (Guest Member representing NBS), R. P. Reed

American Society of Mechanical Engineers (ASME)

Members: R. deWit, R. C. Dobbyn, J. H. Smith, N. J. Tighe

Committee Participation:

Ceramics Committee: N. J. Tighe

Gas Turbine Division: N. J. Tighe

Joint Applied Mechanics Division and Materials Division Committee on Constitutive Equations: R. deWit

Subcommittee 109, Materials and Fabrication, Pressure Vessel and Piping Division: R. C. Dobbyn (Chairman)

American Welding Society
Members: C. G. Interrante, H. I. McHenry, J. H. Smith
Committee Participation:
Conference Program Advisory Board, Evaluation of Welded Structures Based on Fitness for Service: H. I. McHenry (Chairman)
Technical Activities Committee: H. I. McHenry (Member-at-Large)

Ceramic Educational Council
J. M. Bukowski

Compressed Gas Association
Cylinder Specification Subcommittee: B. W. Christ

Department of Energy
Subcommittee on Erosion/Corrosion of Turbine Materials: B. J. Hockey

Department of Transportation
Technical Pipeline Safety Standards Committee: B. W. Christ

Electron Microscopy Society of America
B. J. Hockey, N. J. Tighe

Interagency Coordination Group for the Application of Ceramics to Heat Engines
S. M. Wiederhorn

International Commission on Glass
Subcommittee VI A: S. M. Wiederhorn (Chairman)

International Cryogenic Materials Conference Board
R. P. Reed (Chairman)

International Institute of Welding
Commission XV - Fundamentals of Design and Fabrication for Welding: J. H. Smith

International Powder Metallurgy Society (Planseeberichte für Pulvermetallurgie, Austria)
J. G. Early

International Society for Stereology
R. deWit

International Standards Organization (ISO)
ISO/TC 164 on Mechanical Testing: C. G. Interrante
ISO/TC 164/SC4 on Toughness Testing: C. G. Interrante
ISO/TC 164/WG1 on Terms, Symbols, Definitions: C. G. Interrante

Keramos
J. M. Bukowski

Maryland Institute of Metals
R. deWit

Mechanical Failures Prevention Group
T. R. Shives (Editor), W. A. Willard (Editor)

Metals Properties Council (MPC)
Committee on Materials for the Gasification and Liquefaction of Coal: J. H. Smith
Technical Advisory Committee: R. P. Reed

National Academy of Sciences (NAS)
Project Advisory Committee on Investigation of Steels for Improved Weldability in Ship Construction: H. I. McHenry (Chairman)
Ship Materials, Fabrication and Inspection Advisory Group of the Ship Research Committee: H. I. McHenry

National Institute of Ceramic Engineers
J. M. Bukowski

National Materials Advisory Board (NMAB)
Committee on Reliability of Ceramics for Heat Engine Applications:
S. M. Wiederhorn

National Research Council
Committee on Recommendations for U.S. Army Basic Scientific Research: S. M. Wiederhorn

New York Academy of Sciences
R. deWit

Office of Energy-Related Inventions
Reviewer of Invention Disclosures: J. G. Early

Science and Technology, Office of the Assistant Secretary
Ad Hoc Committee for Technical Evaluation of a Proposal to Revive the Steelmaking Industry in Youngstown, Ohio: J. G. Early, J. H. Smith

Sigma Xi
J. G. Early, S. W. Freiman, B. J. Hockey, R. S. Polvani, J. H. Smith

Society for Natural Philosophy
R. deWit

Standards Committee for Women
N. J. Tighe

U.S. Civil Service Examiners for Metallurgist, Interagency Board
J. G. Early (Chairman)

University of Washington Program on the Nature and Properties of
Ceramic Materials Advisory Committee: S. M. Wiederhorn

Washington Academy of Sciences
R. deWit

Washington Society for Electron Microscopy
B. J. Hockey, N. J. Tighe

Welding Research Council (WRC)
Long Range Planning Committee: H. I. McHenry
Pressure Vessel Research Committee (PVRC): C. G. Interrante, G. E. Hicho
PVRC Hydrogen Embrittlement Subcommittee: C. G. Interrante, G. E. Hicho
Subcommittee on Line Pipe Steels: M. B. Kasen, H. I. McHenry
Task Group on Field Welding: M. B. Kasen, H. I. McHenry
Weldability (Metallurgical) Committee: H. I. McHenry

9. SPONSORED CONFERENCES

NBS-DoE Workshop on Materials at Low Temperatures
Vail, Colorado
October 1978

Basic Science Division Meeting of the American Ceramic Society
National Bureau of Standards, Gaithersburg, Maryland.
November 1978

Science of Ceramic Machining and Surface Finishing, II
National Bureau of Standards, Gaithersburg, Maryland.
November 1978

Ninth Meeting of Interagency Coordination Group for Application of Ceramics to Heat Engines
National Bureau of Standards, Gaithersburg, Maryland
November 1978

ONR Workshop on Erosion of Materials
National Bureau of Standards, Gaithersburg, Maryland
June 1979

International Cryogenic Materials Conference (ICMC)
University of Wisconsin, Madison, Wisconsin
August 1979