UCRL--50016-84-2

DEC5 003831

Mechanical Engineering Department

Technical Abstracts

Manuscript date: July 1, 1984

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Preface

The Mechanical Engineering Department publishes abstracts twice a year to inform readers of the broad range of technical activities in the Department, and to promote an exchange of ideas. Details of the work covered by an abstract may be obtained by contacting the author(s).

General information about the current role and activities of each of the Department's seven divisions precedes the technical abstracts. Further information about a division's work may be obtained from the division leader, whose name is given at the end of each divisional summary.

All of the abstract entries are identified by a report number—a UCRL or UCID—and most of the abstracts are taken from a published document—a Laboratory report, journal article, or meeting paper. However, some of the abstracts printed here are the sole extent of the published work and, therefore, do not represent the contents of any other, larger work. Some of the abstracts have received additional editing to meet the specific requirements of the present document.

The abstracts are arranged alphabetically by first-listed author. For consecutive abstracts having the same first-listed author, the abstracts are arranged by report number—UCRLs before UCIDs.

An Author Index, Report Index, and Key Word Index are provided. For indexing purposes, each abstract entry is identified by a letter/number indexing term: the letter matches the surname of the abstract's first-listed author, and the number is the sequential order of the abstract within the letter grouping.

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Divisional Roles and Activities

Nuclear Test Engineering Division

The Nuclear Test Engineering Division (NTEd) provides mechanical engineering and technical expertise for a wide range of activities in three programs of the Lawrence Livermore National Laboratory (LLNL): Nuclear Test, Nuclear Systems Safety, and Energy.

Nuclear Test Program

Our nuclear testing responsibilities involve design, structural evaluation, fabrication, and proof testing of diagnostic and device canisters that position radiation detectors and protect nuclear explosives in an underground environment. We synthesize, procure, and certify the arming and firing systems, and we develop downhole and containment systems to meet the requirements for zero-detectable radioactivity release. Our advanced development projects include studies of new engineering concepts, analytical and design methods, and diagnostic techniques. In carrying out this work, we strive to improve data quality and field operations, maximize safety, and optimize cost-effectiveness and resource utilization. Included in this programmatic support is spill-effects testing under the Liquefied Gaseous Fuels Program.

Nuclear Systems Safety Program

The safety of nuclear power plants and associated facilities is the major concern of the Nuclear Regulatory Commission (NRC). We are responsible for providing technical data relating to reactor safety on which the NRC can base licensing decisions and develop assessment tools to protect public health and safety. Facilities in the nuclear fuel cycle—processing and fabrication, reactor containment systems, interim waste storage, and spent fuel reprocessing—are considered from the viewpoint of safety and structural integrity.

Our multidisciplinary work is grouped into four categories: seismic and structural safety, reactor engineering, systems/operations, and licensing reviews. The NRC relies on LLNL as the primary facility for research on the seismic safety of nuclear power plants. Our multiyear Seismic Safety Margins Research Program, for example, defines the adequacy of seismic design for the safety of nuclear power plants in the U.S. Reactor

engineering work involves accident analysis and studies of thermal-hydraulic and fluid-structure interaction phenomena. Systems/operations projects are concerned with risk assessment and control room design reviews. We also provide technical assistance to the NRC licensing staff on reactors that are operating or under construction.

In addition, our engineering mechanics expertise is applied to specific projects in other areas, including effort for the Magnetic Fusion Program, the Plant Engineering Department, and H, W, and Y Programs.

Energy Program

We provide mechanical engineering support to several of the Laboratory's smaller energy projects and to a number of efforts for the Earth Sciences Department. Current work is under way in oil shale retorting, radionuclide migration, spent reactor fuel storage, and geophysics research. We are responsible for designing, building, and operating both laboratory experiments and off-site field engineering tests.

(For further information, contact R.J. Wasley, Ext. 2-9966.)

Nuclear Explosives Engineering Division

The Nuclear Explosives Engineering Division's (NEED) major mission is to support the Laboratory's Nuclear Design Program through the engineering and fielding of nuclear devices for testing at the Nevada Test Site. The Division also supports the Nonnuclear Ordnance Program, and B and H Division Experimental Research. In addition, NEED performs studies and develops hardware for Y Program, Z Division, and D Division.

NEED's project teams are dedicated to specific engineering areas, including conceptual nuclear design for advanced fission and fusion systems, hydrodiagnostic development, and maintenance and upgrade of many test facilities at Site 300. The Methods Development Group develops computational tools for engineering analysis in the fields of solid mechanics, fluid mechanics,

and heat transfer. In turn, the Division's Applied Mechanics Group supports Laboratory programs with calculational expertise in the same fields. The High Pressure and Auxiliary Systems Group supports the Laboratory programs with expertise in high pressure technology by designing, building, and testing high pressure systems handling up to 100,000 psi.

(For further information, contact R.W. Werne, Ext. 2-8301.)

Weapons Engineering Division

The Weapons Engineering Division (WED) is responsible for engineering activities supporting nuclear weapons development, production, and maintenance of an important portion of the national stockpile. The Division also provides engineering feasibility studies and modeling of advanced weapons concepts, maintains active support of weapon safety studies, and investigates new technologies for weapon control.

The activities involve new weapon development, computer modeling and analysis, environmental testing, initiation systems development, weapons technology development and close liaison with the Department of Energy (DOE) and the Department of Defense.

Production work involves communicating product definition and design intent to DOE contractors responsible for component fabrication and assembly. In addition, active monitoring of the stockpile requires a careful effort in disassembly surveillance of stockpile weapons to ensure that design requirements have indeed been met and to monitor physical changes that may eventually limit the useful life of a weapon.

The Special Materials Office in WED purchases goods and services from DOE contractors, military commands, and other governmental agencies for all LLNL programs. The Office is also responsible for coordinating Laboratory guidance on process development activities by DOE contractors, purchasing special isotopes used in a variety of programs and providing DOE with a forecast and management plan on nuclear material usage.

(For further information, contact R.E. Clough, Ext. 2-8296.)

Energy Systems Engineering Division

The Energy Systems Engineering Division (ESED) is engaged in a variety of work to provide mechanical engineering support to the Y Program in two major categories: laser isotope separation (LIS) and inertial confinement fusion (ICF). In the LIS effort, coherent laser light is used to selectively photoionize atoms of a given isotope in a material containing several isotopes. The ionized atoms can then be separated and enriched using extractor/collectors. The ICF effort is directed at understanding the basic physics problems associated with imploding small fusion targets with high power lasers, and at developing a fusion process to provide an unlimited source of power for use during the next century. Each major category has both military and civilian applications.

(For further information, contact J.E. Keller, Jr., Ext. 2-7582, or J.R. Hauber, Ext. 2-6027.)

Engineering Sciences Division

The Engineering Sciences Division (ESD) provides complete technical services to LLNL programs for materials characterization, engineering measurements, nondestructive evaluation, and mechanical systems design and evaluation. The Division has more than 20 separate laboratories and facilities that are organized into sections responsible for specific technological areas.

The Materials Test and Evaluation Section provides mechanical testing, such as ASTM standard tests and special tests tailored to individual customer requirements. To characterize and improve engineering designs, the section carries out developments in the fields of acoustic emission, fracture mechanics, high-rate material response, experimental stress analysis, and composite materials.

The Engineering Measurements Section is engaged in work ranging from the design of a single transducer to the fielding of complete measurements systems. Service for the calibration and installation of transducers and accelerometers is also available.

The Nondestructive Evaluation Section provides inspection and diagnostic testing services for LLNL programs. X-ray and gamma source radiography, radiation gauging, ultrasonics, eddy

current, dye penetrant, magnetic particle, and radiographic techniques are available.

The Engineering Design Section performs design, analysis, and mechanical fabrication in support of the Chemistry and Materials Science Department and many ESD projects. The section is particularly experienced in automated machine design, composites processing and fabrication, tritium handling, and mass spectrometry.

The Life Sciences Section provides mechanical engineering support for Biomed and Environmental Research, Hazards Control, and Toxic Waste Management. Examples of developments to meet the varied requirements of these groups include a cell sorter in Biomed, personnel dosimetry equipment in Hazards Control, and storage and/or burial containers for Toxic Waste Management.

The LLNL Plutonium Facility is managed by the Chemistry and Materials Science Department with operational support provided in part by ESD. The Plutonium Engineering Section in ESD provides engineering design, fabrication, and testing services for the Facility and its users.

The Engineering Information Section serves the Laboratory's Mechanical, Electronics, and Plant Engineering Departments through the Engineering Record Center, which archives, reproduces, and distributes engineering designs. The section also maintains two libraries containing technical references, government and industry specifications, and vendor data. A Specification Engineering and Standards Group assists in defining requirements for acquiring equipment and stores stock items from outside manufacturers.

(For further information, contact J.P. Mahler, Ext. 2-8360.)

Magnetic Fusion Engineering Division

The Magnetic Fusion Engineering Division (MFED) supports the LLNL physics programs in four principal areas:

- Magnetic fusion energy (MFE) confinement experiments.
- MFE development and technology.
- Particle-beam development.
- High energy physics.

The four areas share a common technological base, although their individual goals differ greatly. Each area requires support from essentially all mechanical engineering disciplines and

from specialists in normal and superconducting magnetics, cryogenic systems, vacuum systems, high-voltage components, and nucleonics.

Our role in the MFE confinement experiments is to provide systems engineering and to design and fabricate mechanical hardware. The research in magnetic mirror confinement of nuclear fusion reactions is expected to lead to utilizing deuterium, an isotope of hydrogen present in sea water, as a nearly inexhaustible energy source. The major confinement experiments are the Tandem Mirror Experiment Upgrade (TMX-U) and the Mirror Fusion Test Facility (MFTF-B).

In MFE development and technology, our mission is to develop the technical base and engineering skills necessary to meet future needs of magnetic confinement systems. Our active programs are the development of a multifilamentary Nb₃Sn superconductor, high-vacuum technology, and fusion reactor studies. Basic research and development are emphasized to lay the groundwork for future fusion experiments.

The particle-beam development program, funded by the Defense Advanced Research Projects Agency, involves building high-current, high-voltage, electron accelerators. Such accelerators are of interest for basic physics research and in the weapons community. The present program calls for developing two accelerators, the Experimental Test Accelerator and the Advanced Test Accelerator, a 10-kA, 50-MeV machine.

Our role in high-energy physics is to provide tools with which to pursue fundamental understanding of energy and matter. Technical support is provided for experiments performed at the 100-MeV electron linear accelerator, three 400-keV dc high-current accelerators, a 3-MeV electrostatic accelerator, a 6-MeV tandem electrostatic accelerator, and a 76-cm cyclotron.

The MFED consists of 10 project groups plus a division office.

(For further information, contact A.K. Chargin, Ext. 2-6696.)

Materials Fabrication Division

The Materials Fabrication Division (MFD), a multidisciplinary organization in the Mechanical Engineering Department, provides services that are not available from commercial sources. The number and diversity of LLNL research efforts

make this division one of the Laboratory's largest. We have about 450 highly skilled persons and more than 3,700 pieces of equipment in our inventory.

With these facilities and the special capabilities of our staff, we provide services in the fields of optics, welding, vacuum process, glass, plastics, sheet metal, metal finishing, metrology, forming, inspection, and assembly, as well as conventional and numerically controlled machining of metals, high explosives, and ceramics.

In-house fabrication services are available for all LLNL programs when requirements call for:

- Fabrication capabilities not readily available elsewhere.
- Rapid turnaround time.
- Handling of materials that are toxic, radioactive, or classified.

In addition, the Division's facilities are used to develop improved manufacturing techniques and to advance machine tool research. Our operating philosophy is to satisfy the mechanical fabrication needs of the programs, consistent with priorities set by those programs.

Notable projects underway by the Division are as follows:

- *Precision Fixturing Project:* We constructed a precision roundness gauge and developed an extension of the classical shell theory in order to establish manufacturing methods for reducing the elastic deformation of workpieces due to fixturing. The new theory has provided a versatile and accurate tool for the calculation of the transmitted distortion in ring/shell/plate complex structures. The roundness gauge has provided direct measurement of distortion to verify the theory and assess the performance of candidate structures. Agreement has been obtained between theory and experiment to a level of 2% of the distortion. Experimental measurements of distortion have been made with a resolution exceeding 1 μ m.

- *Precision Contouring of Brittle Materials:* We developed a technique for forming precision contours in brittle materials using an inexpensive diamond "crushing" tool. Material removal has been demonstrated in Zerodur and flint glass with minimal tool wear. This capability has the potential to reduce the pre-polishing machine time used to produce optics, and to make possi-

ble the production of a whole class of workpieces that have been very difficult or impossible to manufacture using traditional methods.

- LLNL has entered into an agreement with the Defense Advanced Research Projects Agency to study the feasibility of designing and building a special machine tool called the Large Optics Diamond Turning Machine (LODTM). LODTM is a \$10.5 M project and was brought on-line in mid-1983. It will be used to machine reflective optics for the Air Force High Power Laser Program (ALPHA). This project is an example of how state-of-the-art electrical engineering hardware can be applied to machine tools to create previously unobtainable manufacturing capabilities. LODTM will machine 5-foot-diameter optics to within 1- μ m. tolerances (1 part in 60,000,000).

Substrates for the ALPHA program will be molybdenum coated with copper by processes developed at LLNL. We use magnetron ion plating (a high energy physical vapor deposition process) to deposit very adherent copper on molybdenum. This copper is then overcoated with approximately 8 mils of electroplated copper. Quantitative adhesion tests have shown that use of this process to coat molybdenum provides adhesion unattainable by any other process.

- A major class of activity in MFD's Vacuum Processes Laboratory is the fabrication of nuclear targets and calibration foils for nuclear test diagnostics. We are often challenged by the seemingly unlimited variety of material and configuration requirements that change with every event. For the Romano event, 270 foils were produced. They were fabricated in six different combinations of four materials (aluminum, magnesium, copper, and zinc) deposited in various thicknesses onto unbacked Parylene* substrates. Programmatic specifications required that all coatings be pinhole-free and light-tight within 10% of the nominal thickness and within 5% in thickness uniformity. All of the metallic coatings were deposited by electron beam gun evaporation.

(For further information, contact D. K. Fisher, Ext. 2-7643.)

*Parylene is a registered trademark of the Union Carbide Corporation.

Abstracts

A1

UCRL-90098

S. L. Albertson

Hindsight in Developing an 'In-House' Digital Data Acquisition System for Mechanical Testing, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the IMOG Subgroup, St. Petersburg, FL, January 10-12, 1984.

Key words: Data acquisition systems, testing

A DEC LSI-11/23 minicomputer was the basis for a data collection system designed at LLNL. Hardware selection and software development is now complete and the system (DVM-node) is in use. However, the system design is not perfect. Improvements and shortcomings are discussed, along with demonstrations of what the DVM-node can do and is doing in our testing area.

A2

UCRL-90271

H. P. Alessio

On the Relationship of Digraph-Matrix Analysis to Petri Net Theory and Fault Trees, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the *Journal of Reliability Engineering*.

Key words: Digraph matrix analysis, reliability, petri nets

Digraph Matrix Analysis (DMA) is a tool for mathematically representing large complex systems in order to evaluate their structure and reliability. In this paper, we prove that there is an isomorphism between DMA and Petri net theory. In addition, we explore the relationship of DMA to fault trees and discuss DMA's reachability and minimum cut-set solutions.

B1

UCRL-90518

G. M. Bianchini, D. D. Kingman, and J. B. Holt

Synthesis of Ultra-Fine Aluminum Nitride in a R.F. Nitrogen Plasma, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for

the *Workshop on Thermal Plasma Synthesis of Materials*, Los Alamos National Laboratory, Los Alamos, NM, March 20-24, 1984.

Key words: Particle size, aluminum nitride, plasmas

Ultra-fine aluminum nitride (AlN) particles, with an average size of 150 Å, were synthesized by passing a pure aluminum powder through a radio-frequency nitrogen plasma. Aluminum powder (average size 30 µm) was introduced into the plasma tail flame. Particle morphology and size were influenced by several experimental factors, such as feed rate, place of introduction into the plasma, quenching characteristics, and size of the aluminum powder. One 100% conversion was achieved with a nitriding agent such as NH₃. The particle size of the AlN can also be controlled within certain limits.

B2

UCRL-90219

N. J. Brown and P. P. Hed

Spherical Lapping Velocities, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Topical Meeting of Optical Fabrication and Testing, Optical Society of America, Monterey, CA, April 18-20, 1984.

Key words: Velocity, spheres, polishing

This paper describes the velocity distributions between mating surfaces rotating in arbitrary orientations. The paper also describes two cases of use.

B3

UCRL-90220

N. J. Brown and L. M. Cook*

The Role of Abrasion in the Optical Polishing of Metals and Glass, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Topical Meeting on Science of Polishing, Optical Society of America, Monterey Conference Center, Monterey, CA, April 16-17, 1984.

Key words: Abrasives, diamond turning, optics

* Schott Optical Glass Company.

The attempt to bridge from metal to glass presents many problems. We review an abrasive technique for polishing diamond-turned optics. We also review a mathematical analysis of the groove problem.

B4

UCRL-90833

J. B. Bryan, D. L. Carter, R. W. Clouser, and S. L. Thompson

Single Point Diamond Crushing of Glass, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Precision Machining Workshop, Society of Manufacturing Engineers, Berkeley, CA, June 5, 1984.

Key words: Glass, diamond turning

Single point diamond crushing of glass was originally developed by Dr. R. E. Reason of Taylor and Hobson in England 34 years ago as a means of shaping glass aspheres prior to polishing. It has recently been tried at LLNL. A surface finish of 50 μ in. peak-to-valley with occasional deeper pits has been achieved on Zerodur and BK-7 glass. A depth of cut of 0.008 in. or more can be taken at a surface speed of 900 ft/min. Tool wear is on the order of 10 μ in. after removal of 1 in.³ of Zerodur. The tool's cost is \$5.45 each.

B5

UCRL-90848

R. B. Burdick

Modal Testing and Analysis of Nova Laser Structures, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the 3rd International Modal Analysis Conference, Orlando, FL, January 1985.

Key words: Nova

The Nova laser fusion project is an ongoing project at LLNL. The project seeks to develop a feasible method of achieving controlled fusion reaction, initiated by multiple laser beams tar-

geted on a tiny fuel pellet. The Nova system is comprised of three large steel structures and a large spherical aluminum chamber, all integrated to facilitate the amplification, turning, and targeting of the laser beams. In conjunction with design engineers, the Nova system was first modeled and analyzed by sophisticated finite element techniques. A modal test was then conducted on each of the structures for model verification and correction. This paper discusses the test results for the largest of the steel structures and the aluminum targeting chamber.

B6

M-148

M. W. Butler

Postshot Drilling Handbook, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: Sampling, drilling, radiochemistry

This handbook provides an outline of the general equipment and procedures used in recovering radiochemical samples from underground nuclear tests. The primary purpose of the handbook is to provide an overall picture of postshot drilling for those who have little or no knowledge of the subject.

This handbook is a revision of the *Postshot Drilling Handbook* first published in October 1966 as UCID-15034. The original text was written as a joint effort by Walter H. Johnson, Jim Cramer, Bobby Thompson, and Wally Sitko. Revisions to the handbook have been made by M. W. Butler, staff member of the Drilling Engineering Group at the Nevada Test Site. In keeping with plans stated in the initial work, this revision is being made to keep pace with changes in drilling equipment and techniques.

Among the significant changes in drilling technology are improvements in drilling bits, containment equipment, and drilling fluids. In addition, postshot drilling as practiced by LLNL at the Nevada Test Site has been altered to where there is now almost sole use of the angle rig. In this method the Dyna Drill is predominately used from start to completion of the postshot drilling sequence, significantly decreasing drilling time for radiological sampling.

C1

UCID-20083

K. W. Campbell

An Empirical Assessment of Near-Source Strong Ground Motion for a 6.6 m_b (7.5 M_s) Earthquake in the Eastern United States, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3839.

Key words: Earthquakes, ground motion, seismic risk, nuclear power plants

To help assess the impact of the current U.S. Geological Survey position on the seismic safety of nuclear power plants in the Eastern United States (EUS), several techniques for estimating near-source strong ground motion for a Charleston-size earthquake were evaluated. The techniques for estimating the near-source strong ground motion for a 6.6 m_b (7.5 M_s) in the EUS are based on site-specific analyses, semi-theoretical scaling techniques, and intensity-based estimates. The first technique involves the statistical analysis of ground motion records from earthquakes and recording stations having the same general characteristics (earthquakes with magnitudes of 7.5 M_s or larger, epicentral distances of 25 km or less, and sites of either soil or rock). Discussed are recommendations for source and characterization scaling of the bias resulting primarily from an inadequate sample of near-source recordings from earthquakes of large magnitude.

The second technique evaluated requires that semi-theoretical estimates of peak ground motion parameters for a 6.6 m_b (7.5 M_s) earthquake be obtained from scaling relations. Each relation uses a theoretical expression between peak acceleration magnitude and distance, together with available strong motion data (majority coming from California) to develop a scaling relation appropriate for the EUS. None of the existing ground motion models for the EUS include the potential effects of source or site characteristics. Discussed are adjustments to account for fault mechanisms, site topography, site geology, and the size and embedment of buildings.

The final approach used relations between strong ground motion parameters and Modified Mercalli intensity in conjunction with two methods to estimate peak parameters for a 6.6 m_b

(7.5 M_s) earthquake. As with other techniques, adjustment of peak acceleration estimates are discussed. Each method differently approaches the problem of estimating near-source strong ground motions. The results and limitations of each technique are discussed and recommendations for future work are presented.

C2

UCRL-53491

T. Y. Chuang, S. C. Lu, B. J. Benda, and J. J. Johnson

Impact of Changes in Damping and Spectrum Peak Broadening on the Seismic Response of Piping Systems, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3526.

Key words: Damping, piping systems, seismic effects

The Technical Committee on Piping Systems of the Pressure Vessel Research Committee has proposed two modifications to regulatory guides that affect seismic analysis of piping systems. One modification would change damping values for piping systems specified in Regulatory Guide 1.61. The other modification would provide an alternative to the peak broadening procedure of Regulatory Guide 1.122.

In this study, we quantified the reduction in piping responses of three piping systems in the Zion nuclear power plant resulting from these two modifications, separately and in combination. We conclude that:

- The proposed damping values reduce piping response substantially.
- The proposed alternative to peak broadening reduces piping response only marginally.

C3

UCRL-53526

D. W. Coats

Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazards Models for Department of Energy Sites, Lawrence Livermore National Laboratory, Livermore, CA (1983).

Key words: DOE critical facilities, safety, winds, models

Development of seismic and wind hazard models is part of a three-phase effort aimed at establishing uniform building design criteria for seismic and wind hazards at Department of Energy (DOE) sites throughout the United States. In Phase 1, we gathered information on the sites and their critical facilities, including nuclear reactors, fuel-reprocessing plants, high-level waste storage and treatment facilities, and special nuclear material facilities. In Phase 2, we initiated development of seismic and wind hazard models. These hazard models express the annual probability that the site will experience an earthquake or wind speed greater than some specified magnitude. This report summarizes the final wind/tornado hazard models recommended for each site and the methodology used to develop these models. Final seismic hazard models have been published separately by TERA Corporation. A complete summary of the seismic hazard methodology and seismic hazard curves will be included in a separate Laboratory report. In the final phase, the DOE will use the hazards models and recommended uniform design criteria to evaluate critical facilities.

D1

UCRL-89553

E. N. C. Dalder, W. D. Ludemann, and
R. P. Kershaw

Optimization of Thermomechanical Processing of High-Strength, High-Conductivity Copper Alloys for Magnetic Fusion Energy Applications, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the TMS-AIME and ASM Symposium on Synergism of Microstructure, Mechanisms, and Mechanics in Fracture, Los Angeles, CA, February 26-March 2, 1984.

Key words: Copper alloys, magnetic fusion energy, thermal conductivity

The material for such items as the conductor for normal magnets, high-heat flux components, and microwave heating devices to inject energy into the plasma, requires the high electrical and thermal conductivities of copper but with room-temperature yield strengths up to an order of magnitude greater than that of annealed high-conductivity copper.

We subjected two copper alloys, Amzirc (Cu, 0.15% Zr, 0.08% Ag) and M2C (Cu, 0.4% Cr,

0.08% Mg, 0.15% Zr), to a combination of controlled hot-forging, warm-rolling, and cold-rolling treatments and evaluated them for room-temperature tensile properties, electrical conductivity, and retention of these properties after thermal exposures in the 400 to 500°C range. We rationalized the results on the basis of changes in precipitate morphology and grain size as a result of thermomechanical processing and thermoexposure.

D2

UCRL-89657

E. N. C. Dalder, M. C. Juhas, D. C. Freeman,
and R. P. Kershaw

Interrelations Between 4 K Fracture Toughness and Microstructure of Stainless Steel Welds and Base Metals, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the TMS-AIME and ASM Symposium on Synergism of Microstructure, Mechanisms, and Mechanics in Fracture, Los Angeles, CA, February 26-March 2, 1984.

Key words: Stainless steels, welds, microstructure

No information exists on the strength-toughness relationships in stainless steels and welds at 4 K. These materials are used in advanced energy-conversion experiments, at high stresses and low temperatures, and are metastable at service temperatures under plastic strain. Local stress concentrators, both geometric and microstructural, result in small regions of these materials being metastable during service.

We performed elastic-plastic fracture toughness tests at 4 K, followed by extensive optical and electron microscopy examination of fracture surfaces and underlying microstructures. We compare results with existing models of microstructure-fracture interaction, and make suggestions for further work.

D3

UCRL-89658

E. N. C. Dalder, M. C. Juhas, and
R. P. Kershaw

Effects of Microstructure on Cryogenic Performance of Type 316L Weld Metal, Lawrence Livermore

National Laboratory, Livermore, CA (1984). Prepared for the 65th Annual American Welding Society Convention, Dallas, TX, April 9-13, 1984.

Key words: Microstructure, austenitic stainless steels, welds

Type 316L austenitic stainless-steel-welding consumables, deposited by the shielded metal arc (SMA), flux-cored metal arc (FCMA), or gas metal arc (GMA) welding process, have emerged as the preferred joining method for fabrication of N_2 -strengthened austenitic stainless steels in thicknesses up to 139 mm. These specially developed stainless steel structures are used as the force containment members in the superconducting magnet systems that are an integral part of magnetic fusion energy power conversion systems. However, commercial specifications for Type 316L austenitic (and most other) stainless steel welding consumables have wide permissible ranges of composition in critical elements such as Cr, Ni, Mn, Mo, Si, C, and N_2 , which can result in wide variations in ferrite number (FN) in weldments made under practical shop and field conditions.

During the optimization of various Type 316L welding consumables used with the SMA, FCMA, and GMA fusion welding processes to produce useful welds for -452°F service, an extensive data base on the tensile, elastic-plastic fracture toughness and optical microscopy of these weldments was assembled and used to develop specific welding consumables and procedures.

To develop a sufficient understanding of what microstructural factors control the tensile strengths, ductilities, and fracture toughnesses of Type 316L weld metal intended for use at -452°F , an extensive evaluation of the microstructural features of these welds, as revealed by optical and electron microscopy (SEM), was undertaken.

Explanations are presented on the manner in which fissures and continuous ferrite networks affect cryogenic strength, ductility, and fracture toughness. The development of empirically based predictive methods are used to relate these undesirable microstructural features of stainless steel weld metal to the static and low-cycle fatigue performance of the welds in typical end-product applications. Recommendations are presented on how to improve the performance of welding consumables for cryogenic structures, with particular emphasis on: (1) development of

"all-position," shielded, metal arc welding consumables, and (2) development and qualification of a welding consumable for a fully automated, high weld-metal-deposition rate welding process.

D4

UCRL-89989

**E. N. C. Dalder, R. M. Scanlan, and
M. C. Juhas**

Development of Fusion Welding Consumables and Procedures for Joining Austenitic Stainless Steel Superconducting Magnet Cases for Liquid Helium Service. Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the American Society for Metals (ASM) Meeting, International Conference on New Development in Stainless Steel Technology, Detroit, MI, September 16-20, 1984.

Key words: Austenitic stainless steels, MFTF, superconducting magnets, fusion welding

The Mirror Fusion Test Facility (MFTF-B) is a reactor-sized, deuterium-burning, break-even experiment facility under construction at LLNL; it is the centerpiece of the tandem-mirror Magnetic Fusion Energy Program. Plasma confinement is accomplished with high magnetic fields: up to 225,000 times that of the earth's magnetic field, that are developed with 42 large superconducting magnets. To successfully confine and support the magnets under the high resulting loads, a special austenitic stainless steel, Type 304 LN (Fe-19% Cr-9.5% Ni-2% Mn-0.2% C-0.15% N_2) was developed for use in thicknesses to 5.5 in. (138 mm). Concurrent with the base metal development, special filler metals, based on Type 316 L austenitic stainless steel (Fe-17% Cr-13% Ni-2.5% Mo-2.0% Mn-0.03% C-0.05% N_2), were developed for use with the shielded-metal-arc (SMA), short-circuiting gas-metal-arc (SC-GMA), and flux-cored-metal-arc (FCMA) processes. The two special constraints that made these weld metal developments necessary were:

- Ferrite levels in stainless-steel weld metals must be minimized to maintain 4.2 K (-452°F) fracture toughness.
- A minimum level of ferrite must be present in mostly austenitic stainless-steel weld metals to prevent solidification-related cracking in highly restrained joints up to thicknesses of 5.0 in. (127 mm).

Satisfying these two conflicting requirements was accomplished by a combination of composition control in the welding consumable and process variable control during the actual shop and field welding. In the course of development of the various welding consumables and qualification of a particular welding-consumable/welding-process pair for special welding-position applications, extensive 4.2 K (-452°F) mechanical property, chemical composition, and microstructural data bases were developed. The major part of the paper examines possible interactions between these data bases in an attempt to develop explanations for the 4.2 K (-452°F) mechanical property trends and the possible roles of weld metal primary solidification mode, solidification-related cracking, and ferrite level and distribution on cryogenic mechanical properties.

D5

UCRL-90466

J. W. Dini and H. R. Johnson*

Plating on Some Difficult-to-Plate Metals and Alloys, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Symposium on Difficult to Plate Materials, Deutsche Gesellschaft für Galvanotechnik, Ulm, West Germany, May 3-4, 1984.

Key words: Electroplating, metal films

Electrodeposition of coatings on metals such as beryllium, beryllium-copper, Kovar, lead, magnesium, thorium, titanium, tungsten, uranium, zirconium, and their alloys can be difficult. This is due in most cases to a natural oxide surface film that readily reforms after being removed. The procedures we recommend for plating on these metals rely on either replacing the oxide film with a displacement coating or etching to allow mechanical keying between the substrate and plated deposit. The effectiveness of the procedures is demonstrated by interface bond strengths found in ring-shear and conical-head tensile tests.

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D6

UCRL-90360

J. N. Doggett

Critical Issues for the Fusion Power Demonstrator, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the American Nuclear Society 1984 Annual Meeting, New Orleans, LA, June 3-8, 1984.

Key words: FPD, thermonuclear reactors, MARS, criticality studies

The Engineering Test Reactor (ETR) is a fusion device that incorporates all of the systems of a power producing reactor and whose purpose is to demonstrate the technical and scientific feasibility of a commercial reactor system.

At the present time there are two major approaches to commercial fusion systems. Both programs are looking at what the requirements of an ETR should be. In one of these programs, the Tandem Mirror program, the ETR is called the Fusion Power Demonstrator (FPD), and its design is being conducted by a group of national laboratories and industrial firms under the direction of LLNL.

The FPD design study is in the process of looking at several versions of an ETR, each of which will incorporate an ignited central cell. The design options will vary from a bare ignition device through engineering break-even (zero line power during steady state) to modest power production capability (~200 MW). The baseline configuration of the device is based on the design generated by the Mirror Advanced Reactor Study (MARS) completed in 1983.

Included in this paper is a description of the configurations developed in the study, the performance requirements, and technology assumptions. Particular emphasis is placed on design issues critical to the system from either the technological challenge or the cost impact of various subsystems such as magnets, heating systems, and maintenance.

The highest cost subsystem in a tandem mirror system is the magnet set, which always makes it a critical issue. The overall machine operating parameters are largely determined by the magnet

geometry and maximum field. The baseline parameters are related to the peak field in the choke coil (presently set at 24 T), while the specific geometry is determined by the neutron shielding requirements between the end cell "C-coils" and the reacting plasma.

The ion pumping system is used to remove unwanted ions from the portion of the machine where the confining potential barriers are established. There are several methods for obtaining the desired effect; charge exchange beam pumping is the best understood method, but it also is the most costly and difficult to apply. Enhanced radial drift pumping is the method that offers the most in potential cost saving and ease of application, but it has yet to be demonstrated experimentally.

The next generation of fusion experiments will be highly activated by neutron irradiation and will be expected to operate at an availability higher than that of present devices. For these reasons, maintenance system performance will be a critical issue in the ability of these machines to accomplish their missions.

D7

UCRL-89597

J. C. Doyle, Jr., and J. D. Lee

Monte Carlo Calculations of 14-MeV Neutron Multiplication in Thick Beryllium Assemblies and Comparison With Experimental Results, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for *Nuclear Science and Engineering*.

Key words: Monte Carlo methods, beryllium, neutron transport, TART (computer program)

Integral experiments performed at the Institute for Reactor Development at Jülich, West Germany, have raised doubts about the adequacy of current nuclear data and calculational methods in predicting neutron multiplication and leakage from beryllium assemblies bombarded with 14-MeV neutrons. Experimental values of inferred neutron multiplication were reported to be less than calculated values by ~25%. We have performed calculations of the experiments using the TART Monte Carlo code. The ratio of measured leakage multiplication to our calculated leakage multiplication is 0.85 for 8-cm-thick be-

ryllium and 0.99 for 12-cm-thick beryllium. However, much uncertainty exists in the procedure leading to the stated experiment values of "apparent multiplication." We also performed calculations for a series of experiments done at LLNL in 1955 and 1956. A 14-MeV neutron source was placed in the center of a cylindrical beryllium assembly 8 in. in radius and 24 in. in height. The beryllium assembly was encased in an aluminum can surrounded by a manganese bath. The ratio of experimental to calculated neutron leakage multiplication is 0.88. Much uncertainty exists in both series of experiments.

F1

UCRL-90286

W. W. Feng

Inflation of a Plane Circular Viscoelastic Membrane, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the XVIth International Congress of Theoretical and Applied Mechanics, Lyngby, Denmark, August 19-25, 1984.

Key words: Viscoelasticity, membranes, deformation

The large deformation creep and relaxation of a plane circular neo-Hookean viscoelastic membrane is studied. By introducing three new physical variables, the governing equilibrium equations are reduced to three ordinary differential integral equations. With the derivation of a recurrence formula for evaluating the hereditary integrals, these equations are further reduced to three first-order ordinary differential equations for each time step. Some numerical results are presented and some experiments are performed. The experimental data are used to demonstrate the viscoelastic effects and to determine the mechanical properties of the membrane under biaxial stress. The extension of the formulation to a general theory of large deformation of axisymmetric membranes is mentioned.

F2

UCRL-90657

W. W. Feng

On the Viscoelastic and Aging Characteristics of Polymers, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the VIII

Inter-American Conference on Materials Technology, San Juan, Puerto Rico, June 25-29, 1984.

Key words: Deformation, viscoelasticity, polymers, hardening

This paper concerns the time dependent mechanical properties for incompressible polymer-like materials subjected to finite deformations. There are two parts: the viscoelastic effects and the aging characteristics. A method for determining these mechanical properties is presented in detail.

For the viscoelastic effect, a constitutive equation is introduced. The constitutive equation consists of a long-term elastic constant and a relaxation function. The relaxation function is expressed in terms of a series of exponential functions, each term with a constant coefficient and a relaxation time constant in the exponent. Therefore, the determination of viscoelastic properties of polymers is reduced to the evaluation of these constants. In this paper, the linear regression and the method of least squares is employed. It leads to a system of algebraic equations that are solved simultaneously by the Gauss-Jordan elimination method.

For the aging effect, the basic constitutive equation is assumed to have the same form used in the viscoelastic case, except that the long-term elastic constant is a function of the aging time and the relaxation function is a function of the aging time as well as the creep time. By introducing two new functions of the aging time only, one can relate the material properties of the virgin specimen to the aged specimen. With the proper choice of these functions, the relaxation curves of an aged specimen can be obtained by vertical and horizontal shifts of the relaxation curve of the virgin specimen on a log-log plot. These shifts are interpreted as a physical measure of the aging affect.

The purpose of this work was to characterize the DXT system owned by the Nondestructive Evaluation Section and to determine the minimum detectable change in thickness seen by this system for five common materials. Errors in data set due to positioning variations, system drifts, and collimator design were observed.

Positioning inconsistencies from 0.01 mm to 0.13 mm were noticed for downward stage movement. Other axial movement accuracies were within the smallest step size limit, linearly equal to 0.01 mm. Cumulative error in transmission data was less than 0.1%. Emission and small signal data varied from 7.6 to 13.8% by changing the collimator composition from D-38, uranium-238 to lead. The detectable change in thickness values obtained by this work was comparable to that obtained by a similar system years earlier.

Overall system performance is very sound. But to minimize errors, the system should be allowed to run for up to 60 min before scanning begins, and move upward while scanning. Before data is taken the user should determine the best collimator to use: D-38 for transmission data, lead for emission data. The relative aperture size must also be considered.

G1

UCRL-90033

S. K. Ghose*

Tritium Related Safety Considerations for Mirror Upgrades, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the 10th IEEE Symp. on Fusion Engineering, Philadelphia, PA, December 5-9, 1983.

Key words: Tritium contamination, radiation safety

One of the primary objectives of the MFTF-B upgrades is to demonstrate the technology of tritium breeding in a reactor-like configuration. This requires use and processing of tritium, involving an inventory of several hundred grams at the plant. This paper reviews the results of a preliminary assessment of the radiation hazard associated with the handling of tritium. The radiation dose consequences due to tritium release from normal operation and due to postulated accidents on plant personnel and the public were assessed. Maximum credible (probability $<10^{-3}$,

F3

UCID-19994

S. Fletcher

Characterization of a Precision Radiation Gauge, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: Gauges

but $>10^{-7}/\text{yr}$) accidental releases were estimated to be 10 g in the reactor building and 100 g in the tritium-processing building. Higher probability ($>10^{-3}/\text{yr}$) accidents or component failures would result in much smaller releases. In the reactor building, the most severe accident would result from the rupture of a plasma exhaust duct from the end cell or the tritium feed pipe to the neutral beam injector, accompanied by a fire. In the tritium processing building, the most severe accident would be the rupture of the Isotope Separation System (ISS) distillation columns and vacuum jackets accompanied by a fire. The radiation dose at the site boundary (i.e., to the public) due to normal operation is estimated to be at least an order of magnitude below the Department of Energy (DOE) suggested value (10 mR/yr). The integrated radiation dose at the site boundary due to an accidental release is also estimated to be well below the DOE suggested value (5 rem). The dose commitment to the worker under any situation can be maintained well below the DOE suggested values by adopting appropriate operating procedures.

* Bechtel Group, Inc., San Francisco, CA.

G2

UCRL-90086

A. Goldberg, D. R. Lesuer, J. C. Stone and J. Pratt*

Observations on Tearing of Carbon-Black-Loaded Elastomers, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the VIII Inter-American Conference on Materials Technology, San Juan, Puerto Rico, June 25-29, 1984.

Key words: Elastomers, fracturing, fatigue (materials)

As part of a program directed towards the understanding of loading response, damage, and failure of tank track-pad elastomers, we are evaluating the morphology of fracture surfaces of a number of laboratory-tested samples and field-tested pads. In the laboratory we are testing a number of elastomers, including natural rubber (NR) and styrene butadiene rubber (SBR), loaded with carbon black ranging from 0 to 40 wt%.

This effort includes tensile testing, testing for tearing resistance, and evaluating damage from low-cycle fatigue. In this paper, we report mainly on the effect of temperature, strain rate, and carbon-black loading on the tearing and fracture behavior and morphology of SBR.

Tests were performed on both notched (razor-blade cut) and smooth rectangular sheet samples, covering a range of strain rates from 10^{-4} to $1.5 \times 10^2/\text{s}$, with temperatures from -195 to 180°C . Morphologies of fractured samples were evaluated using light and scanning electron microscopy. In addition, we photographically recorded the stretching and tearing behavior that occurred at the root of the cut during the actual deformation process.

Propagation of the cut occurs by the sequential tearing and collapsing of individual bundles of long chain molecules that can result in a highly textured, rock-like, rumped region (nodules) along the fractured surface. This texture is formed during slow cut growth. By contrast, rapid cut growth usually results in a relatively smooth texture with river patterns and ledges typical of glassy fractures.

An increase in temperature or a decrease in strain rate extends the slow cut-growth region, with a corresponding refinement of the individual nodules and a simultaneous increase in coarseness along the rapid cut-growth region. When these structures are present, the cut propagation path is normal to the tensile axis; this is typical for the lower carbon loadings.

A distinctly different slow cut-growth morphology usually is observed for intermediate and high carbon loadings. Here, the slow cut-growth path deviates from the normal to the tensile axis and can approach values close to 90° (parallel to the tensile axis). This deviation increases with an increase in temperature, a decrease in strain rate, or an increase in carbon-black loading. The deviated tearing develops a chevron or hillock-like morphology typical of knotty tearing; it is associated with frequent changes in the tear paths along oriented regions of weakness. When the fracture becomes catastrophic, it then proceeds to failure normal to the tensile axis similar to the behavior exhibited with low carbon-black loadings. Based on these morphological observations, we explain the effects of carbon-black loading, temperature, and strain rate on tearing energy in terms of competing influences between tear-path deviation, hysteresis, relative stiffness, and resistance to cut growth.

We describe similarities in fracture morphologies between field-tested track pads and laboratory-tested samples. Typical fracture morphologies observed at sub-zero temperatures, both above and below the glass transition temperature, are also discussed. Many of the features reported in the fracture of ceramic glasses were observed in our studies, especially for the low-temperature elastomer fractures, such as Wallner lines, cavitation scarps, transition (burst) hackle, and river patterns.

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H1

UCRL-90194

P. P. Hed

Novolac As Stain Protective Film During Optical Glass Fabrication, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Topical Meeting on Optical Fabrication and Testing, Optical Society of America, Monterey, CA, April 18-20, 1984.

Key words: Optical glass, resin coatings

Certain mixtures of novolac resin in organic solvents can be used as stain protective lacquers for polished glass elements. Their preparation and application are described.

H2

UCRL-89949

R. W. Hoard

The Application of He-II Technology to the Production of Ultrahigh-Field Superconducting Magnets, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the 10th IEEE Symp. on Fusion Engineering, Philadelphia, PA, December 5-9, 1983.

Key words: Superconducting magnets, magnet coils, heat transfer

Data and operating experience acquired during the last 3 years on the heat-transfer properties of pressurized superfluid He-II indicates that the fluid can be successfully used as a coil coolant

for high-field superconducting magnets. Indeed, the fluid seems to offer triple benefits over that of ordinary normal LHe: (1) coil conductors can be driven to wetted perimeter heat fluxes exceeding 1 W/cm^2 ; (2) the reduced low temperature operation at 1.8 K enhances the critical current densities (J_c) of both Nb_3Sn and ternary additions to the compound by 140 to 200%; (3) the upper critical field (H_{c2}) also increases, allowing viable solenoid magnet designs approaching 20-T fields. This paper reviews the significant properties of He-II relevant to magnet design, describes current superconducting coils and systems that utilize the fluid, and discusses the possible application of the present data base to production of future ultrahigh-field superconducting coils yielding 20-T fields.

H3

UCID-19853

R. W. Hoard, D. N. Cornish, R. M. Scanlan, J. P. Zbasnik, R. L. Leber, R. B. Hickman, and J. D. Lee

Ultra-High-Field Superconducting Magnets, Lawrence Livermore National Laboratory, Livermore, CA (1983).

Key words: Superconducting magnets, MARS, magnet coils

Recent advanced mirror fusion reactor studies indicate a trend towards using very-high-field barrier solenoid coils. Indeed, the Mirror Advanced Reactor Study and the Fusion Power Demonstrator Study call for solenoid magnet peak fields of 24- and 20-T, respectively. During these studies, most of the investigators and magnet designers felt that only a portion of these fields could be obtained by using superconducting magnets, with the remainder being supplied by inner, copper resistive coils. Such coils in a high-radiation environment pose many problems. It is therefore desirable to generate as much of the field as possible with superconductors, thus minimizing or eliminating the resistive coil problems by making the coils smaller. The data base on the material properties of superconducting materials, compiled up to and including 1981, shows that our present superconducting magnet technology also has problems at high fields. The main factors limiting conceptual superconducting coil designs to

peak field values of approximately 15 T are: (1) low critical-current densities in Nb₃Sn, at fields >15 T; (2) the increased stabilizer resistivity due to higher magneto-resistance requires more stabilizer, thus lowering the overall current density; and (3) additional stabilizer in the coil pack lowers the overall current density still further, resulting in a need for more turns and larger magnets.

H4

UCRL-89991

M. A. Hoffman* and D. S. Rowe†

Interfacing the Tandem Mirror Fusion Reactor to a Synthetic Hydrogen Thermochemical Plant, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for Nuclear Technology/Fusion.

Key words: Tandem mirror reactors, synthetic fuels, hydrogen fuels, thermochemistry

Use of the energy from a fusion reactor to produce synfuels such as hydrogen is a challenging goal because of the special thermal requirements imposed on the blanket design. This paper considers the interfacing of the tandem mirror reactor to the General Atomic thermochemical process (TCP) for hydrogen production by considering two types of interfacing approaches. The first approach uses electrical energy to Joule heat a high temperature part of the TCP and can have an overall plant efficiency of about 30 to 36%. The second approach uses high temperature thermal energy to heat the high temperature part of the TCP and has an overall plant efficiency of 43%. The tradeoff between these two approaches involves consideration of overall plant efficiency versus the feasibility of developing a cost-effective, high temperature blanket and heat transport system for long lifetime and high reliability.

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† Rowe & Associates, Bellevue, WA.

H5

UCID-19989

D. L. Howard

The LABAN Emplacement Pipe Load-Release Test and Stemming/Canister Alignment Study, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: LABAN (event), canisters

An emplacement pipe load-release test and a study of downhole alignment during stemming were performed on the LABAN event. The purpose of these experiments was to determine canister and line of sight (LOS) distortion induced by downhole stemming and load-release procedures. The load-release test was aborted at approximately 40% completion due to excessive canister distortions. This report summarizes test results in terms of emplacement pipe loads versus vertical canister motions, canister and LOS lateral displacements, and the changes in LOS alignment that resulted from the downhole stemming and load-release processes.

H6

UCRL-90745

H. Humpal

Performance Testing of Wire Electric Discharge Machines (EDMs), Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the SME Clinic on Conventional and Wire Electrical Discharge Machining, Hartford, CT, May 22-24, 1984.

Key words: Electrical discharge machining

This paper describes acceptance test requirements and techniques that were defined and specified by LLNL to assure that LLNL would ultimately receive a precision wire electric discharge machine (EDM) to meet their requirements. Unique methods of evaluating the performance of wire EDMs are described. The results

show that these EDMs can produce parts to precise overall form tolerances.

Described are test methods that provide a means of separating the performance variables of EDM machines and an overview of how these tests can help predict the production of precision parts. Basic parametric tests are: straightness, squareness, positioning accuracy, repeatability and backlash, 360°C disk, and 360° magnetic ball bar (unique). The part-cut performance tests described are: square, disk, and narrow slot. Part-cut histories are given to show attainable results.

L1

UCID-20086

H. E. Lambert

Circuit Breaker Operation and Potential Failure Modes During an Earthquake: A Preliminary Investigation, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: Earthquakes, nuclear power plants, safety

Numerous circuit breakers important to nuclear plant safety must open and/or close during a strong-motion earthquake.

This study addresses the effect of such an earthquake on circuit breaker operation. It focuses on the loss-of-offsite-power transient caused by an earthquake at the Zion Nuclear Power Plant. This report also describes the operator action necessary to prevent core melt if circuit-breaker failures occur simultaneously on three 4.16 kV buses. Potential seismically induced circuit-breaker failure modes were uncovered. Due to the complexity of the problem, this study is not intended to be definitive but serves as a focusing tool for further work.

L2

UCRL-90091

D. R. Lesuer, A. Goldberg, D. S. Hiromoto, and J. Pratt*

Evaluation of Low Cycle Fatigue Damage and Tearing in NR and SBR Based Elastomers, Lawrence Livermore National Laboratory, Livermore, CA

(1983). Prepared for the VIII Inter-American Conference on Materials Technology, San Juan, Puerto Rico, June 25-29, 1984.

Key words: Elastomers, fatigue (materials)

As part of a program to understand loading response, damage, and failure of tank track pads, we are studying low cycle fatigue damage development and cut growth in elastomers. The materials studied include natural rubber (NR) and styrene butadiene rubber (SBR), both containing a range of carbon black (0-40 wt% HAF N300). Testing for low cycle fatigue damage was done as a function of temperature using a test unique to elastomers. A sample is conditioned by cyclically loading in tension at an arbitrary temperature and frequency for a given number of cycles. The residual strength in the conditioned sample is then evaluated by tensile loading to failure. The ultimate strength determined here serves as a measure of material degradation due to fatigue loading.

Results show that for the elastomers studied, damage accumulation is extremely sensitive to temperature and fatigue stress level—decreasing residual strength was observed with increasing temperature and stress level. Increasing carbon-black content increased the residual strength. The fracture surfaces produced were examined with the optical light microscope and the scanning electron microscope. Regions subject to fatigue damage can be readily identified and at low magnification show radial markings originating from a material heterogeneity. The elastomers studied differ widely in material characteristics that can influence the development of low cycle fatigue damage. Results to date suggest that, for these materials, hysteresis and strain crystallization play a key role in determining fatigue damage resistance.

The material cut-growth resistance was measured by a fracture mechanics parameter called the tearing energy (strain-energy release rate) obtained from cut strips of rubber that are tensile loaded to failure. Testing was done as a function of strain rate and temperature. For the materials with 20 wt% carbon black and less, the tearing energy decreases with increasing temperature. This reflects the decrease in hysteresis in the material with an increased temperature. Strain crystallization also has a significant influence on the tearing energy for NR. For materials with greater

than 20 wt% carbon black, hysteresis and strain crystallization are still significant factors in determining the tearing energy. In addition, the propagating cut can deviate from its initial orientation (perpendicular to the applied stress) to an orientation approaching the direction of the applied stress. This tear-path deviation is more pronounced at higher temperatures and can be a significant factor in producing high tearing energy at high temperature.

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L3

UCRL-89959

T. Lo, T. A. Nelson, R. Y. Chen,* and C. Grimes*

Containment Integrity of SEP Plants Under Combined Loads, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the Specialty Conference on Structural Engineering in Operating Nuclear Facilities, ASCE, NC State University, Raleigh, NC, September 10-12, 1984.

Key words: Nuclear power plants, containment vessels, criticality studies.

The U.S. Nuclear Regulatory Commission (NRC) is nearing completion of Phase II of the Systematic Evaluation Program (SEP) in which eleven of the oldest operating nuclear power plants have been evaluated against current licensing criteria for selected issues. As a part of this review, LLNL provided seismic and structural analysis expertise in coordination with the NRC staff and a Senior Seismic Review Team consisting of recognized seismic design experts. Because the containment structure is the last barrier against the release of radioactivity, an independent assessment was undertaken to identify the design weaknesses and to estimate the margins of safety for these older containments under combined seismic and loss-of-coolant conditions. The results also shed light on the margins of safety in other Category 1 structures at these older plants.

The containment designs analyzed consisted of three light-bulb shaped drywells used in boiling water reactor systems, and three steel-lined con-

crete containments and a spherical steel containment used in pressurized water reactor (PWR) systems. The results indicate that four of the seven designs are adequate even under current design standards. For the remaining three designs, which were all PWR containments, the possible problem areas identified were: buckling of the steel liner; buckling of the spherical steel containment; through-wall cracking of concrete; and over-stress in the concrete shell near its base. These issues are being pursued in greater detail under the SEP.

*U.S. Nuclear Regulatory Commission, Washington, D.C.

L4

UCID-19722

S. C. Lu and C. K. Chou

Reliability Analysis of Stiff Versus Flexible Piping—Status Report, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-7318.

Key words: Piping systems

Conservative design procedures adopted for nuclear piping systems usually result in stiff piping designs that use excessive support devices such as rigid supports and snubbers. Use of these piping support devices has created safety concerns. This report describes the interim result for a piping research project conducted at LLNL for the U.S. Nuclear Regulatory Commission. The overall objective of this research project is to develop modified design requirements and criteria that will improve piping reliability and minimize the use of pipe supports, snubbers, and pipe whip restraints. The current study was conducted to establish the necessary groundwork for this effort based on the piping reliability analysis.

A confirmatory piping reliability assessment for stiff versus flexible piping systems indicated that removing rigid supports tends, in general, to reduce thermal stress but to increase seismic stress in the pipe. As a result, piping design can be made more reliable by some reduction of

rigid supports. We also observed that piping design using snubbers among support devices may not exhibit the intended reliability because snubbers often fail to perform the desired function. It was demonstrated that certain piping systems with snubbers removed actually exhibit higher reliability than do those of the original design.

The Steering and Technical Committees on Piping Systems established by the Pressure Vessel Research Committee (PVRC) have investigated changes to be implemented in Regulatory Guides 1.61 and 1.122 aimed at more flexible piping design. An independent impact assessment conducted by this project concluded that: (1) PVRC proposed changes substantially reduce calculated piping responses; (2) proposed changes allow piping redesigns with significant reduction in number of supports and snubbers without violating ASME code requirements; and (3) the more flexible piping redesigns are capable of exhibiting reliability levels equal to or higher than the original stiffer designs.

M1**UCRL-89757****G. L. Mara**

Welding and Brazing Metallurgy of Tungsten and Molybdenum Alloys, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for the AIIME Annual Meeting, Los Angeles, CA, February 26-March 3, 1984.

Key words: Welding, brazing, bonding, tungsten alloys (Re), molybdenum alloys (Re)

I examined the welding behavior and brazing characteristics of tungsten and molybdenum alloyed with rhenium. These materials were evaluated as wrought and chemically vapor-deposited products. The joining processes studied included electron beam welding, solid state bonding, and vacuum furnace and induction brazing. The major factor influencing the weldability of W-25 wt% Re was found to be weld segregation and the formation of the federite phase (metastable A-15 phase). Weld preheat and the selection of welding parameters are also shown to be significant. Solid-state bonding of W-25 wt% Re and the use of noble metal interlayers as a diffusion aid are presented. The brazing metallurgy of W-25 wt% Re using Mo-Re and Pt alloys is examined. The brazing and solid-state bonding

processes are shown to be successful methods for achieving high temperature joints that avoid the metallurgical difficulties posed by fusion welding.

M2**UCID-20011****R. C. Murray**

GEMINI—An Efficient Computer Program for Three Dimensional Linear Static and Seismic Analysis, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: GEMINI (computer program), three dimensional computations, seismic analysis

GEMINI is a computer program for the calculation of static and dynamic response of linear elastic structures by the finite element method. Requests for extended capability, advances in element technology, and major algorithmic improvements in solution methodology have led to the development of GEMINI. GEMINI is written in standard FORTRAN with a modular format to allow new elements to be inserted as well as to allow equation solvers, eigenvalue routines, and modal analysis techniques to be implemented and evaluated. GEMINI is compatible with the CDC 7600 and the Cray-1 computers.

P1**UCRL-53525****J. W. Pasternak**

Bond Graph Time Simulations Using Extracted Modal Parameters from the Nova Spaceframe, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: Nova, models

Bond graphs are a convenient way of representing the energy exchange, storage, and dissipation mechanisms for interacting energetic systems. One major advantage for using bond graphs to model physical systems is that the governing state equations are always in first order form and can usually be integrated fairly easily with today's modern digital computers.

This report demonstrates a procedure for simulating the dynamics of a large inherently distributed structure using bond graph modeling techniques and incorporating a limited number of normal modes previously measured from an experimental modal analysis.

P2

UCRL-90666

J. H. Pitts

Performance of the Cascade Inertial-Confinement-Fusion Conceptual Reactor, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the 13th Symposium on Fusion Technology Congress, Centre of Villa Ponti, Varese, Italy, September 24-28, 1984.

Key words: Inertial confinement fusion reactors

The Cascade conceptual reactor is a safe and efficient concept for converting inertial-confinement-fusion energy into electricity. Centrifugal action in a 4.5-m-radius rotating football-shaped chamber permits a 1-m thick loosely packed granular blanket to be held against the walls. Sand-grain-sized granules in the blanket, made of lithium oxide (or other solid-lithium ceramics), flow into the small ends of the chamber and absorb energy from pulsed fusion reactions as they cascade along the walls of the chamber to the larger radius central section. These granules protect the walls from radiation-damaging neutrons and breed tritium in the process. The granules are then removed from the chamber and transported to heat-exchangers, where 3000 MW_t are removed before the granules are recycled back into the chamber. We describe the design characteristics and performance of the reactor, heat exchangers, and the balance of plant. Also, we examine two options for the chamber construction, and we compare the smaller sized fluidized-bed heat-exchanger option to the larger vacuum heat-exchanger option and show how each is coupled to the balance of plant.

P3

UCRL-90742

J. H. Pitts and O. R. Walton

Granular Flow Along the Interior Surface of Rotating Cones, Lawrence Livermore National Labora-

tory, Livermore, CA (1984). Prepared for the 8th International CHISA Meeting, Prague, Czechoslovakia, September 3-7, 1984.

Key words: Rotation, cones, granular materials

Relationships are developed between the effective cone half-angle, α_{eff} , and the actual cone half-angle, α , for subcritical flow of granular material along the inside surface of a rotating cone. Rotational speed must be high enough to keep the granular material against the wall. If α_{eff} is between the wall friction angle, ϕ_w , and the angle of repose, ϕ_r , the flow rate depends on the exit aperture area and rotational speed, and may be controlled at the exit.

Laboratory experiments show that exit control is possible over the entire range of effective cone half-angles from $\phi_w < \alpha_{eff} < \phi_r$, and even beyond these limits. The most uniform thickness of granular material is obtained when the cone half-angle is close to ϕ_r .

Application of these results shows the feasibility of a solid-granule blanket for the Cascade inertial-confinement fusion reaction chamber concept to convert fusion energy into electricity.

R1

UCID-19933

T. A. Reitter

A Heat Conduction Analog Model of Urban Fire Spread, Lawrence Livermore National Laboratory, Livermore, CA (1983).

Key words: Analog simulation

This report describes a model of urban fire spread. The model attempts to simulate the gross features of urban fire spread by adjusting parameters in a two-dimensional transient heat conduction code. The requirements imposed on the model are that the spread probabilities agree with those taken from empirical data or more sophisticated models and that the results for the simple test problems be physically plausible. The effects of a constant wind velocity have also been simulated, but the results suffer from the lack of data for adjustment of parameters. The results of this preliminary investigation are encouraging. However, justification for further development requires a direct comparison of costs and results using a more sophisticated model.

R2**UCID-20024**

J. Romo, J. W. Weed, G. Griggs, T. Brown, and P. Tassano

Foil Fabrication for the Romano Event, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: ROMANO (event), metal foils, parylenes

The Vacuum Processes Laboratory (VPL) is part of the Materials Fabrication Division (MFD) of LLNL's Mechanical Engineering Department. VPL conducted various vacuum-related support activities for the ROMANO nuclear physics experiment. This report focuses on the foil-fabrication activities carried out between July and November 1983 for the ROMANO event. Other vacuum related activities for the event, such as outgassing tests of materials, are covered in separate documentation.

VPL was asked to provide 270 coated Parylene foils. However, due to the developmental nature of some of the procedures, approximately 400 coated foils were processed. In addition, VPL interacted with MFD's Plastics Shop to help supply Parylene substrates to other organizations (e.g., Lawrence Berkeley Laboratory and commercial vendors), which had also been asked to provide coated foils for ROMANO. The purposes of this report are

- To document the processes developed and the techniques used to provide the foils.

- To suggest future directions.

The report is divided into four sections:

- Nuclear target foil fabrication.
- Parylene substrate preparation and production.

- Calibration foil fabrication.

- Foil and substrate inspections.

R3**UCRL-90138**

H. L. Rutan

Ultrasonic Machining (Impact Grinding), Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Topical Meeting on Op-

tical Fabrication and Testing, Optical Society of America, Monterey, CA, April 18-20, 1984.

Key words: Ultrasonic machining, optics, grinding

This presentation describes ultrasonic machining (impact grinding) of hard brittle materials in general, and its use in optics at LLNL.

S1**UCRL-53538**

M. W. Schwartz

Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3826.

Key words: Shipping containers, fracturing, safety

This report summarizes the results of research conducted to provide recommendations for criteria that will prevent brittle fracture of shipping containers made of thick-wall ferritic steel forgings under hypothetical accident conditions resulting in high levels of dynamic loading. These recommendations are based upon an assessment of their impact upon industry in the area of costs and safety considerations as manifested by the limit-state probabilities associated with various criteria. A fracture initiation criterion based upon yield stress levels and allowable flaw sizes specified in Section XI of the ASME code is recommended.

W1**UCID-20085**

H. J. Weaver and R. B. Burdick

Modal Parameter Estimation via Shaker vs Speaker Excitation, Lawrence Livermore National Laboratory, Livermore, CA (1984).

Key words: Shakers, laser materials

When dynamically testing delicate laser components (e.g., an elliptical glass laser disk) it is often impossible to provide a direct contact excitation source such as an impact hammer or

shaker. This is because of the delicate and/or brittle nature of the material from which the components are constructed. The alternate approach that is often used in a test of this type is to excite the component with an acoustic speaker. In this paper, we describe a small series of tests in which we compare the modal parameters obtained by using a speaker as an excitation source with those obtained on the same object when the excitation was provided by a shaker.

W2

UCRL-90552

J. W. Weed

Nuclear Target Foil Fabrication for the Romano Event, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Integrated Contractors Meeting on Coatings, Sandia National Laboratory, Albuquerque, NM, June 26-28, 1984.

Key words: ROMANO (event), metal foils, parylenes

Diagnostic nuclear target foils were fabricated by LLNL's Vacuum Processes Lab for the ROMANO event. Thin films of zinc and magnesium, in thicknesses ranging between 125 and 750 nm, were deposited using electron beam evaporation methods onto Parylene* substrates. Several thicknesses of Parylene were used, varying from 200 to 500 nm. Interfacial nucleating layers of copper or aluminum were deposited between the Parylene and the zinc or magnesium to increase adhesion. I describe the processes developed and techniques used to produce the coated foils and Parylene substrates, as well as characteristics of the fabricated foils and data reflecting their quality.

* Parylene is a registered trademark of Union Carbide Corporation.

W3

UCRL-89829

R. D. Weglein, R. F. Wilson, and
B. W. Maxfield

A Precision Acoustic Microscope for Surface Characterization, Lawrence Livermore National Laboratory, Livermore, CA (1983). Prepared for Butterworth Scientific, Ltd.

Key words: Microscopes, acoustic sensors

We describe the development of a digitally controlled acoustic microscope facility that spans the decade frequency range from 10 MHz to greater than 100 MHz. In this initial implementation, a 12.7 mm focal length system with instantaneous frequency range of 16-45 MHz was evaluated. Lateral scanning and axial translation provided imaging and acoustic material signature (AMS) information, respectively, via color TV monitor display or hard copy output. We report initial quantitative results of nondestructive-evaluation multimode AMS characterization of a Cu-layer on fused quartz layered structure, as well as other AMS and imaging results.

W4

UCRL-90163

J. D. Williams, B. C. Johnson, D. Milam,
R. C. Murray, and M. A. Summers

Mechanical Design of 74-cm Aperture KDP Crystal Arrays for the Nova Laser, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Quantum Electronics and Applications Conference, IEEE and Optical Society of American, Anaheim, CA, June 19-22, 1984.

Key words: Nova, crystal optics, harmonic analysis

Large aperture potassium dihydrogen phosphate (KDP) crystal arrays have been developed for the generation of second (0.526 μm) and third (0.351 μm) harmonic light on the Nova laser. Details of the mechanical design and optical quality of these arrays are reported.

W5**UCRL-90164****J. D. Williams, B. C. Johnson, and
M. A. Summers**

Performance of 74-cm Aperture Third Harmonic Crystal Arrays, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Quantum Electronics and Applications Conference, IEEE and Optical Society of America, Anaheim, CA, June 19-22, 1984.

Key words: Nova, array processing, harmonic analysis, crystal optics

A large aperture crystal array capable of efficient second- and third-harmonic generation has been developed for the Nova laser. Measurements of the conversion efficiency and optical quality of the first Nova array are reported.

Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3483.

Key words: Piping systems

This is a five-part report that presents the results of studies on the current regulatory position on postulated pipe rupture location criteria and recommends future licensing regulations. Part 1 highlights the current regulatory positions on criteria for postulated pipe rupture locations. Part 2 reviews data on nuclear piping failures related to the failure locations in the piping systems. Part 3 presents a probabilistic assessment of three nuclear piping lines under fatigue loadings. Part 4 recommends modifying the criteria and scopes future work. Part 5 (Appendix A) provides the validation results for the stress corrosion cracking model. The failure case chosen for comparison with the analytical result is a recirculation-line safe-end cracking incident in a boiling water reactor.

W6**UCRL-90218****G. R. Wirtenson, I. M. Thomas, N. J. Brown,
and J. G. Wilder**

Chemical Treatment of Silicate Glasses for Producing Anti-Reflection Surfaces, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the Topical Meeting on Optical Fabrication and Testing, Optical Society of America, Monterey, CA, April 18-20, 1984.

Key words: Fresnel lenses, antireflection coatings

This paper provides a brief description of chemical treatments used to reduce fresnel reflectance of BK7 and SiO₂ for high fluence laser applications in the spectral range 0.25-1.0 μ m.

W8**UCRL-90284****E. M. Wu**

Fracture of Composites, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the 1983-84 Distinguished Lecturer for the NASA-Virginia Technical Composites Program, Virginia Polytechnic Institute and State University, Blacksburg, VA, February 29-March 1, 1984.

Key words: Composite materials, fiber composites, fractures, stress analysis

The salient concepts of conventional fracture mechanics are reviewed to provide background for the formulation of failure criteria of fiber reinforced composites associated with cracks and notches. The intrinsic microstructural redundancy produces multiple failure modes and varied sequential crack propagation trajectories, with respect to both the stress magnitude and spatial locations. Frequently, the cracked configuration preceding catastrophic fracture bears little resemblance to the original crack that initiated the damage. We discuss a fracture modeling

W7**UCRL-53490****H. H. Woo**

A Study of the Regulatory Position on Postulated Pipe Rupture Location Criteria, Lawrence Livermore National Laboratory, Livermore, CA (1984).

approach that combines stress analysis selectively with anisotropic failure criterion. This fracture modeling predicts the threshold conditions for crack extension and propagation trajectories. When combined with suitable statistical strength theory extension, this model approach also qualitatively reconciles predicted and observed crack branching and the configuration of sequential failure of laminates. Since this modeling approach uses lamina properties as basic materials constants, it provides the generality to analytically calculate the damaged state of specific lamination geometries and loading conditions. It may be applied to determine the structural strength degradation of composite laminates weakened by crack and cutouts.

W9

UCRL-90285

E. M. Wu

Failure Criteria for Composites, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for the 1983-84 Distinguished Lecturer for the NASA-Virginia Technical Composites Program, Virginia Polytechnic Institute and State University, Blacksburg, VA, February 29-March 1, 1984.

Key words: Composite materials, stress analysis

Advanced application of composites requires the calculation of the integrity of given structural configurations and load conditions. Failure criterion is an engineering precept that delineates this state of structural integrity. The formulation of failure criterion is discussed from the perspectives of operational utilities and failure mechanism modeling. For operational utilities, the emphasis is to formulate a failure criterion to represent a known data base. Mechanics formalisms are needed to facilitate the interface of failure criterion with other branches of engineering analysis, such as stress analysis and finite element analysis. For failure mechanism modeling, the emphasis is to formulate the failure criterion to quantify the conditions of microfailure mechanisms emanating from the fiber, the matrix, and the interface. We review formulations of failure criteria in both categories and point out their relative merits. We also resolve apparent controversies associated with the interpretation of a specimen-specific data base and the paradox

from format-specific data presentations. Recent advances in the extension of deterministic failure criteria to probabilistic formulation offers some unification of the different perspectives and suggests areas for additional investigation and applications in engineering design.

W10

UCRL-90298

E. M. Wu

Resolution of Size Effect in the Strength of Composites—Statistical Modeling and Applications, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for seminar given by author at Standard Oil of Ohio Research Center, Cleveland, OH, February 10, 1984.

Key words: Fiber composites, models, stress analysis

In homogeneous brittle materials, the failure mechanisms can be characterized by a weakest link model. This model reconciles with the observed size effect that small samples are stronger than larger samples. Thus, a well characterized statistical model enables prediction of the strength of full sized structures from a laboratory-size-samples data base. In heterogeneous fiber reinforced composites, fiber and matrix interact as microstructures, and the weakest link failure of fiber is modified by load sharing in the presence of the matrix binder. We describe the statistical modeling of such failure mechanisms, together with the supporting experimental data and its application to reliability-critical structural design.

W11

UCRL-90472

E. M. Wu

Strength Reliability Assurance of Composites Through Proof-Test, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for presentation at Washington University, St. Louis, MO, on March 5, 1984, and at the University of Utah on March 9, 1984.

Key words: Models, fiber composites, stress analysis

Proof testing is frequently performed on structures where a known level of strength reliability is required. By loading each sample to a level exceeding the service level, the proof test eliminates the rare weak samples, thereby assuring the strength or life of the surviving samples. In the application of proof test to composites, we need to account for the sequential and spatial effects of local fiber failures and global structural redundancy. We present motivating experimental observations, statistical modeling, and strength and life data resulting from a specialized proof test procedure, which is based upon understanding the model and supporting acoustic emission evidences.

W12

UCRL-90512

E. M. Wu

Characterization of Composite Strength by Fiber Testing, Lawrence Livermore National Laboratory, Livermore, CA (1984). Prepared for presen-

tation at the University of Washington, Seattle, WA, March 30, 1984.

Key words: Fiber composites, stress analysis

In the critical structural application of composites, it is necessary that characterization of the statistical strength of the composite be used in a suitable reliability analysis. For a composite loaded along the direction of reinforcing fibers, the role of matrix is to provide microstructural load sharing redundancy around early fiber breaks. Compared to the fiber properties, the composite strength is increased by 1.5 times and the scatter is decreased by one-fifth. Conversely, fiber characterization can be used to provide high statistical resolution of the composite performance. We present a statistical load-sharing model with supporting experimental data. Details on the single filament fiber testing and interpretation are also presented.

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