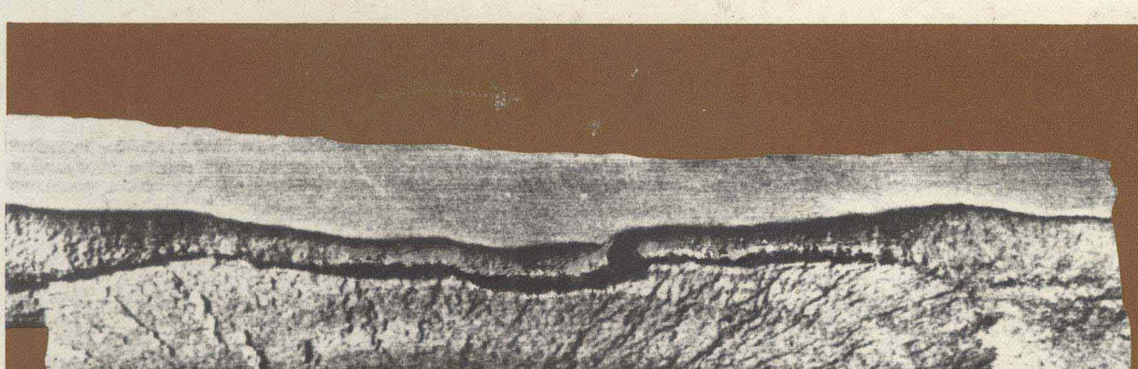
Analyzing Failures

The Problems and the Solutions

Edited by V.S. Goel

Conference Proceedings



American Society for Metals

ANALYZING FAILURES: THE PROBLEMS AND THE SOLUTIONS

Proceedings of the Failure Analysis Program and Related Papers presented at the International Conference and Exposition on Fatigue, Corrosion Cracking, Fracture Mechanics and Failure Analysis

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V. S. Goel

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FOREWORD

This volume contains part of the total number of papers presented at the "International Conference on Fatigue, Corrosion Cracking, Fracture Mechanics and Failure Analysis," held in Salt Lake City, Utah, USA, from 2-6 December 1985. Response to this conference was so good that it resulted in a large number of papers. To satisfy the needs of different interest groups and to keep the proceedings of the conference in a manageable form, it was decided to publish it in four separate volumes:

Analyzing Failures: The Problems and The Solutions
Corrosion Cracking
The Mechanism of Fracture
Fatigue Life: Analysis and Prediction

The above paper collection volumes may be obtained from the American Society for Metals. This conference covered a wide range of topics, some of fundamental interest and some of application interest. To facilitate an early publication, the editing has been kept to a minimum. We hope the the technical merits of the papers outweigh any grammatical or minor stylistic deficiencies.

The advances in the concepts of design are pushing the operational limits of engineering materials and so maximum performance is expected out of the materials. Due to the general economic crunch, almost everyone wants the maximum life out of their equipment. The electric utilities want their plants to run more than the designed plant life (mostly 40 years), aircraft companies want their planes to fly longer, the transportation industry wants that its bridges last indefinitely, and the chemical industry wants their plants to keep on producing products. There is also an increased awareness on the part of the public for safety and reliability of components, because failure of components in large aircraft, nuclear plants or other large structures can lead to large-scale disasters like the Bhopal tragedy in India, the Three Mile Island accident in the USA and the string of airline disasters in 1985.

All of this shows that today materials are expected to show maximum performance, provide long life for maximum economy and at the same time ensure safety and reliability of components and systems. For all this, we need to understand the materials better and apply the principles of fracture mechanics, corrosion and fatigue to the solution of practical problems. This conference was planned to provide a forum for the exchange of ideas and allow a better understanding of the theory and applications of the materials science which can ensure safety in combination with the expected life and performance goals for materials.

The theme of this conference was "Technology Transfer" among the various groups who apply theory to the application of practical problems. There are many specialized meetings in this area which permit workers to come together and discuss problems in their specific application areas. However, there is no single meeting or conference which brings together workers in the various application areas such as Aerospace structures, Army-Navy Applications, Bridges and Architectural Structures, Transportation Industry and Nuclear Industry to learn what is being done in other areas which they may be able to utilize to their advantage. This conference was aimed at bringing together workers from different applications areas to give them a wider perspective. Hence, this conference was of interest to engineers, metallurgists and also to the engineering managers who remain concerned about product failure and liability.

The success of this conference was based on the contributions of the speakers, session chairmen and members of the Technical Review Committee and the Organizing Committee who generously supported this Conference. I would like to thank all the participants on behalf of the American Society for Metals and the co-sponsoring societies for their generous contribution of time and effort towards the success of this Conference.

Dr. V. S. Goel
Chairman, Organizing Committee

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MATERIALS FAILURE PREVENTION AT THE NATIONAL BUREAU OF STANDARDS*

Lyle H. Schwartz, Daniel B. Butrymowicz
National Bureau of Standards
Gaithersburg, Maryland, USA

Abstract

As a Commerce Department agency, the National Bureau of Standards provides the measurement foundation that our industrial economy needs. Crucial to these needs are the safe, efficient, and economical use of materials. The NBS programs that support generic technologies in materials and the mechanisms by which fundamental information is transferred are analyzed. Specific examples are drawn from recent developments in fracture of materials.

THE OCCURENCE OF MECHANICAL FAILURES - has implications for efforts of all concerned with their prevention. Those involved range from basic scientists to government policy makers, as well as engineers, metallurgists, engineering managers and a host of workers in allied areas. The Federal Government has long been concerned with minimizing mechanical failures. This concern has come about for several reasons. The Government purchases and operates a great deal of equipment. Designing, building, and maintaining the most modern and sophisticated machinery that technology is capable of producing requires some assurance that it will perform efficiently and without failure. Furthermore, there are areas of broad public concern, such as safety and quality standardization which justify government concern. Here Congress has granted government agencies the authority to set mandatory standards that are designed to prevent mechanical failures in the private sector. In addition, there are several current national trends that call for enhanced concern with mechanical reliability. These trends relate to the conservation of national resources, and the continuing need for new methods of improving product quality and maintainability in the face of higher labor costs and international competition. There is also the growth of new electronic based technologies, such as computing and telecommunications, requiring new plateaus of operating reliability.

TECHNOLOGY TRANSFER

This conference has as its theme "technology transfer" among the various groups who apply theory to the application of practical problems. The conference organizers have brought together workers from a wide variety of applications areas with the aim of giving them a wider perspective. This contribution to that perspective deals with an overview of materials failure prevention at the National Bureau of Standards, and a brief description of how NBS transfers measurements, standards, data and understanding to U.S. industry, commerce, government, and science. Because these "transfers" are the business of NBS, the Bureau has a wide range of technology transfer activities which are an integral part of all NBS programs. These activities are assigned to and supported by the corresponding technical programs. In addition there are several NBS-wide program areas which are directly responsible for technology transfer.

MATERIALS RESEARCH AT NBS

The technical programs in materials fracture at NBS are centered in the major organizational unit directly charged with materials research, the Institute for Materials Science and Engineering. As the nation's foremost science and engineering measurement laboratory, the National Bureau of Standards has some of the premier research and testing facilities in the United States. Bureau scientists and engineers use these special facilities to pursue measurement-related work needed by U.S. science and industry. The Institute for Materials Science and Engineering is one of the four major technical units comprising NBS. The laboratories and staff of the Institute are providing the nation with a central basis for measurement, data, standards, and reference materials fundamental to the processing, structure, properties, and performance of materials. The program of the Institute supports generic technologies in materials in order to foster their safe, efficient and economical use. Research in the Institute also addresses the science base underlying new advanced materials technologies. Institute research is carried out by a permanent staff of 350 and approximately 150 guest workers and research associates. About 75% of the professional staff hold Ph.D. degrees in the physical sciences.

The Institute for Materials Science and Engineering is organized in five technical divisions focused in the areas of Metallurgy, Ceramics, Polymers, Fracture and Deformation, and Reactor Radiation. The NBS research reactor is a national center for the application of reactor radiation to a variety of problems of national concern in materials science and nondestructive evaluation. The Institute also manages a Bureau-wide, interdisciplinary program in nondestructive evaluation to study the basic interactions between various forms of penetrating energy and materials, to develop standard reference materials, calibration services and other means for achieving traceability to national standards for NDE measurements, and to demonstrate these results in selected generic applications. This program includes not only the well-established NDE methods such as radiography, ultrasonics, eddy currents, magnetic particles, liquid penetrants and leak testing, but also research in the emerging methods of thermal wave imaging, acoustic emission, neutron scattering and laser-based optical inspection. It is clear that new and improved methods of nondestructive evaluation can upgrade the quality of manufactured products and enhance the safety and durability of structures in service.

There are a number of NBS offices which directly support technology transfer, half of them materials related. The Office of Standard Reference Materials develops well-characterized, stable, homogeneous material samples having one or more of the physical and chemical properties certified by NBS. These standard samples are distributed to U.S. manufacturing, business, government, public safety, and research communities. The Institute collaborates with this office in the development of a number of reference materials. The Office of Standard Reference Data assembles, evaluates, and ensures dissemination of scientific and engineering data through collaboration with the user communities.

MATERIALS DATA

Materials data is one of the most important components of the Institute's program. Activities leading to the development of data bases can be found in all of the Institute's divisions. These activities provide critically evaluated numerical data on materials to the community of users, from programs relating to phase diagrams to corrosion. The key role of NBS in reference data is in the validation process. The entire set of data activities rests on the premise that scientists and engineers experienced in a particular measurement technique and familiar with relevant theories can examine a body of data and make value judgments about its accuracy or reliability. The cost of this validation effort is justified by the added value to the ultimate users. Leaving each user to make the value judgments individually or, alternatively, to make do with unreliable data, is clearly an inefficient approach. For the community to realize the maximum benefits of this validation process, the materials data must be accessible via the computer. Modern computer-based modeling enables extension of limited data bases into as-yet unmeasured regimes and more accurate interpolation in those regimes in which measurements have been made.

It should be noted that each of these data programs has industrial society cooperative arrangements (See Table 1), with the cooperating societies providing program guidance and dissemination of the information, and in the area of phase diagrams, providing fund-raising beyond the pilot stage. There are two programs of particular interest. The joint NBS/American Society for Metals program critically evaluates phase diagrams for binary and higher-order alloys, and presents this information in an interactive computer data base. Industry has supported this effort since 1978 with funding of more than four million dollars. Evaluation work is done at NBS and also at research laboratories in universities and industry. This program with ASM will continue on a self-sustaining basis after the initial evaluation program is concluded.

In the second program, an agreement with the American Ceramic Society is expanding an earlier cooperative effort to provide improved, evaluated phase diagrams to the ceramic community. As with the effort on metals systems, NBS is responsible for data evaluation, providing coordination with other phase diagram compilation centers and compiling evaluated phase equilibria data. The Ceramic Society develops funding support and is responsible for data dissemination.

CORROSION DATA - With colleagues from the National Association of Corrosion Engineers (NACE), NBS is about to embark on a major expansion of a corrosion data program, a data effort of particular interest to the conference. This effort will be modeled on NBS's successful earlier programs in phase diagrams, with the National Association of Corrosion Engineers and the National Bureau of Standards joined together to establish a collaborative program to collect, evaluate, and disseminate corrosion data. In this effort, NACE's responsibilities are for overall management of the program and dissemination of the products. Funds for

TABLE 1 - Industrial Society Cooperative Arrangements of the Institute for Materials Science and Engineering, National Bureau of Standards

IMSE DATA CENTERS	SOCIETY COOPERATION GROUPS
Alloy Phase Diagrams	American Society for Metals
Phase Diagrams for Ceramists	American Ceramic Society
Corrosion Data	Association of Corrosion Engineers
Polymer Blends Phase Diagrams	Society of Plastics Engineers
Crystal Data	Committee for Powder Diffraction Standards-International Centre for Diffraction Data, Cambridge Crystallographic Centre for Diffraction Data
Powder Diffraction Data	Joint Committee for Powder Diffraction Standards-International Centre for Diffraction Data
Diffusion in Metals	American Society for Metals-International Copper Research Assocation
Welding Technology	Welding Research Council-American Welding Society-American Welding Institute
Wear and Friction Data	American Society of Mechanical Engineers-American Society of Lubrication Engineers

the pilot stage of the project have come from NACE and NBS, but the full realization of the proposed data program will require the participation of U.S. industry. A major fund raising program is being launched this winter. NACE will seek funds from those in industry and others who will benefit from the successful completion of this program. The program is designed to produce an easy-to-access, user-friendly, computer data base of evaluated corrosion data which can be retrieved in a number of graphical or tabular formats.

INDUSTRIAL RESEARCH ASSOCIATES

In addition to raising funds from industry to launch their portions of the program, a number of the cooperating groups (private companies, trade and professional associations) also support industrial research associate programs at NBS. Their research associates cooperate with NBS scientists in building the computer data bases. Whether in data centers, or in the laboratory, these industry people work side by side with NBS researchers and staff. These industrial research associates represent technology transfer in its most effective form--people-to-people interactions with both parties committed to a common goal.

One of the largest and most successful of these Industrial Research Associate Programs at NBS is one which has among its goals the elimination of defects that could result in materials failures. A steel sensor program was initiated at the National Bureau of Standards in mid-1983 with the American Iron and Steel Institute (AISI). The impetus for this program arose from a workshop sponsored by AISI and NBS in 1982 to review the detailed requirements of high-priority sensors identified by the steel industry (1). The objective of the present program is to develop and evaluate ultrasonic sensors to meet two of these high-priority needs of the steel industry: (a.) detecting pipe and gross porosity in hot steel blooms, or slabs and (b.) profiling the internal temperature of hot or solidifying bodies of steel. Research associates from AISI member steel companies are working closely with NBS personnel in this research with most of the work being carried out in NBS laboratories and collaboratively with universities.

FUNDAMENTAL RESEARCH

There are many specific examples of the fundamental research going on at NBS which will lead to new materials standards in the future. Of particular interest are those examples in the narrow area of fracture, the central theme of the conference. Environmentally-induced cracking appears in a wide range of materials. It occurs as stress corrosion cracking in engineering alloys, as hydrogen embrittlement in high strength steels, as water vapor-induced cracking in glass and ceramics, and as environmental stress cracking in ethylene-based plastics. Institute work in each of these areas is establishing the basic mechanisms and developing test methods to determine the resistance of materials to these forms of failure.

STRESS CORROSION CRACKING - To further illustrate the metals aspect of this phenomenon, research is being carried out in the Corrosion Group of the Metallurgy Division under the leadership of Neville Pugh. These are stress corrosion experiments which are yielding results that show how cleavage can be induced into underlying ductile material by local corrosion at the surface. These experiments are an example of the ability of ductile materials to cleave under dynamic conditions. Specifically, the group has been addressing the problem of transgranular stress corrosion cracking and how to go about improving the resistance of metals to failure. There are many common examples of materials that undergo transgranular stress corrosion cracking, but much of the discussion centers around homogeneous face-centered-cubic alloys. The failure of austenitic stainless steels in chloride media and the ammonia-cracking of admiralty metal represent major practical problems.

Both intergranular and transgranular stress corrosion cracking occur in service, and both are of practical importance although the mechanisms are fundamentally different. In the case of intergranular SCC, it is believed that cracking generally occurs by the film rupture or slip dissolution model where the crack propagates by preferential anodic dissolution at the crack tip. On the other hand, transgranular cracks are thought to