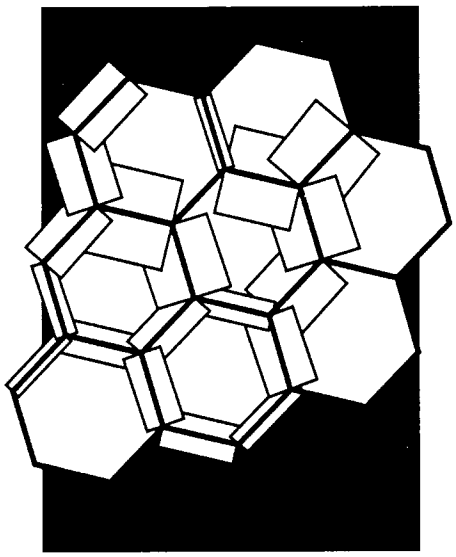
HYDROGEN EFFECTS IN MATERIALS



HYDROGEN EFFECTS IN MATERIALS

Proceedings of the Fifth International Conference
on the Effect of Hydrogen on the Behavior of Materials
sponsored by the Structural Materials Division (SMD)
Mechanical Metallurgy and Corrosion & Environmental Effects Committees
of The Minerals, Metals & Materials Society
held at Jackson Lake Lodge, Moran, Wyoming
September 11-14, 1994

Edited by

Anthony W. Thompson
Lawrence Berkeley Laboratory
Berkeley, California

and

Neville R. Moody
Sandia National Laboratories
Livermore, California

A Publication of
TMS
Minerals • Metals • Materials

A Publication of The Minerals, Metals & Materials Society
420 Commonwealth Drive
Warrendale, Pennsylvania 15086
(412) 776-9000

Printed in the United States of America
Library of Congress Catalog Number 96-75439
ISBN Number 0-87339-334-1

TMS
Minerals • Metals • Materials

If you are interested in purchasing a copy of this book, or if you would like to receive the latest TMS publications catalog, please telephone 1-800-759-4867.

CONTENTS

PERMEATION

MECHANICAL PROPERTIES

CRACK GROWTH SUSCEPTIBILITY

FRACTURE MECHANISMS

STRESS CORROSION CRACKING

HYDROGEN IN TITANIUM ALLOYS

HYDROGEN IN STAINLESS STEELS AND SUPERALLOYS

ENGINEERING APPLICATIONS

FOREWORD

In the five years since our previous conference addressed hydrogen effects on material properties, there has been a significant amount of work that made another conference appropriate to assess progress. We chose to return to Jackson Lake Lodge, Wyoming, for the fourth time. The response was overwhelming with over 150 abstracts submitted. After a difficult selection process, the conference consisted of 118 presentations from 16 countries, divided into seven oral and three poster sessions. These sessions addressed hydrogen effects in metals and alloys, from permeation and effects on properties to crack propagation and fracture. Keynote and invited speakers provided overviews of core topics and pressing issues. These were followed by contributed papers discussing these topics in depth as well as new results. Discussions after each presentation highlighted the controversial issues and defined our understanding of hydrogen effects. In that sense, this fifth international conference on hydrogen in materials met our goals and was successful in its intentions.

The proceedings begins with an invited perspective of progress made in studying hydrogen effects over the last twenty years by I. M. Bernstein. The balance of the proceedings is then divided into ten areas that reflect the directions and issues which have been evident in hydrogen research for the past five years. The first two sections deal with the fundamental aspects of hydrogen permeation and interaction with defects in metals and alloys. These are followed by three sections addressing hydrogen effects on crack growth susceptibility, stress corrosion cracking, and fracture. This is followed by a section providing an overview of hydrogen effects on mechanical properties of metals and alloys, two sections on hydrogen effects in titanium, stainless steels and superalloys, and two sections on engineering alloys and applications. The emphasis on titanium alloys, stainless steels, and superalloys reflects the strong focus in recent years on hydrogen-resistant alloys required for aerospace applications in hydrogen environments. Comparison with previous conferences shows we have made progress in understanding hydrogen effects in these alloys as well as in all aspects of hydrogen effects on material behavior. We hope the papers in these proceedings stimulate discussion of hydrogen interactions and mechanisms that control behavior of materials, and also help to stimulate, focus, and direct future research.

The papers in this volume have been reproduced directly from camera-ready manuscripts submitted by the authors for post-conference publication. Although it was possible to correct many grammatical and typographical errors, the number of corrections had to be minimized in the interest of economical publication. We hope that the readers view any errors in this light. Discussion during the conference was captured by written forms given to questioners, and then to speakers. Those which were completed and returned to us are included here.

The success of this conference was due to the efforts of many people to whom we are grateful. We especially wish to thank R. H. Jones, who joined us on the program committee, and H. G. Nelson and R. O. Ritchie, who helped us obtain funding; their help was invaluable. Our appreciation is also given to R. H. Jones, D. Eliezer, N. Stoloff, H. G. Nelson, W. W. Gerberich, J. F. Knott, and R. P. Gangloff who served as session chairmen

and promoted lively discussions between all participants. Partial support funding was provided by grants from the National Science Foundation and from the Ames Research Center of the National Aeronautics and Space Administration, and without that support, the conference finances would have had to be much different.

We thank a number of our colleagues at Sandia National Laboratories, the Lawrence Berkeley Laboratory, and University of California at Berkeley who generously devoted their time and efforts. To Jim Angelo, Ben Odegard, and Steve Robinson from Sandia National Laboratories, we express our gratitude for their coordination and assistance with all program functions. We also extend our thanks to Tony Thompson's graduate students, David Allen, Xavier Pierron, and Kezhong Li, for their help at the conference with forms for questions posed by the audience and for answers given by the speakers, which enabled us to include the discussions for many papers in these proceedings.

To our wives, JoAnne Moody and Mary Thompson, goes a special thanks, for they helped with registration, ensured that many activities for participants and their families ran smoothly, and provided support and encouragement to us through all phases of preparation for the conference. We also extend our gratitude to Carmella Orham who did a myriad of secretarial and typing tasks in support of the conference. Finally, we gratefully acknowledge the provision of support, through availability of both people and resources, given generously by Sandia National Laboratories, the Lawrence Berkeley Laboratory, and University of California at Berkeley, that made this conference a success.

Anthony W. Thompson
Lawrence Berkeley Laboratory
Berkeley, CA

Neville R. Moody
Sandia National Laboratories
Livermore, CA

AUTHORS