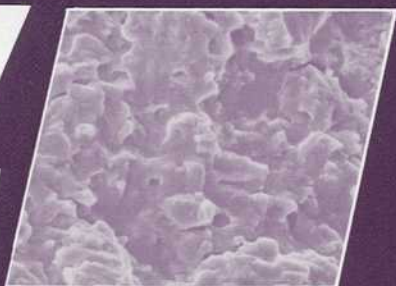

LOW CYCLE FATIGUE



Solomon/Halford/Kaisand/Leis

EDITORS

ASTM **STP 942**

LOW CYCLE FATIGUE

A symposium
sponsored by
ASTM Committee E-9
on Fatigue
Bolton Landing (on Lake George), New York
30 September – 4 October 1985

ASTM SPECIAL TECHNICAL PUBLICATION 942
H. D. Solomon, General Electric Company,
G. R. Halford, NASA-Lewis Research Center,
L. R. Kaisand, General Electric Company, and
B. N. Leis, Battelle Columbus Laboratories,
editors

ASTM Publication Code Number (PCN)
04-942000-30



1916 Race Street, Philadelphia, Pa. 19103

Library of Congress Cataloging-in-Publication Data

Low cycle fatigue: a symposium / sponsored by ASTM Committee E-9 on Fatigue, Bolton Landing (on Lake George), New York, 30 September-4 October 1985; H. D. Solomon . . . [et al.], editors.

(Special technical publication; STP 942)

Includes bibliographies and index.

"ASTM publication code number (PCN) 04-942000-30."

ISBN 0-8031-0944-X

I. Metals—Fatigue—Congresses. I. Solomon, H. D. (Harvey D.)

II. American Society for Testing and Materials. Committee E-9 on Fatigue. III. Series: ASTM special technical publication; 942.

TA460.L678 1987

87-23714

620.1'63—dc19

CIP

Copyright © by AMERICAN SOCIETY FOR TESTING AND MATERIALS 1988

Library of Congress Catalog Card Number: 87-23714

NOTE

The Society is not responsible, as a body,
for the statements and opinions
advanced in this publication.

Foreword

The symposium on Low Cycle Fatigue: Directions for the Future was held in Bolton Landing (on Lake George), New York, 30 September to 4 October 1985. It was sponsored by ASTM Committee E-9 on Fatigue, with support from the Hudson-Mohawk Chapter of AIME and the Eastern New York Chapter of ASM. The symposium was organized by Harvey D. Solomon (chairman), Brian Leis, Gary Halford, and Leonard Kaisand.

The organizing committee thank the international advisory committee for their support and suggestions:

Argentina:	Dr. J. C. Crespi	The Netherlands:	Dr. H. P. Van Leeuwen
Australia:	Dr. J. M. Finney		Dr. J. Schijve
Belgium:	Dr. J. M. Drapier	People's Republic	
Canada:	Prof. T. Bui-Quoc	of China:	Prof. M. Yan
	Prof. A. Plumtree		Prof. X-L Yu
Federal Republic		Spain:	Dr. R. R. Jordana
of Germany:	Prof. W. Bunk	Sweden:	Dr. R. Lagneborg
	Prof. Dr. D. Munz	Switzerland:	Dr. M. Nazmy
	Prof. Dr. P. Neumann	United Kingdom:	Dr. C. J. Beevers
	Dr. H. Nowack		Dr. E. G. Ellison
	Dr.-Ing. W. Schutz		Dr. R. H. Jeal
France:	Dr. J. L. Chaboche		Prof. J. F. Knott
	Dr. C. Amzallag		Dr. I. L. Mogford
	Prof. J. Lemaitre		Prof. K. J. Miller
Israel:	Dr. A. Berkovits		Dr. B. Tomkins
Japan:	Dr. Y. Asada		Dr. P. Watson
	Prof. K. Iida		Prof. G. A. Webster
	Prof. R. Ohtani		
	Prof. T. Tanaka		
	Prof. T. Yokobori		

The organizing committee also thanks the session chairmen for their assistance: D. F. Mowbray, B. Leis, G. R. Halford, L. F. Coffin, R. C. Bill, K. Wright, R. V. Miner, S. D. Antolovich, J. B. Conway, S. S. Manson, F. Lawrence, H. D. Solomon, R. P. Skelton, J. Wareing, R. Williams, and L. Kaisand.

Related ASTM Publications

Fatigue in Mechanically Fastened Composite and Metallic Joints, STP 927 (1986), 04-927000-30

Fatigue at Low Temperatures, STP 857 (1985), 04-857000-30

Multiaxial Fatigue, STP 853 (1985), 04-853000-30

Rolling Contact Fatigue Testing of Bearing Steels, STP 771 (1982), 04-771000-02

Low-Cycle Fatigue and Life Prediction, STP 770 (1982), 04-770000-30

Methods and Models for Predicting Fatigue Crack Growth under Random Loading, STP 748 (1981), 04-748000-30

Fatigue Crack Growth Measurement and Data Analysis, STP 738 (1981), 04-738000-30

Hold-Time Effects in High-Temperature Low-Cycling Fatigue, STP 489 (1971), 04-489000-30

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

ASTM Editorial Staff

**Allan S. Kleinberg
Janet R. Schroeder
Kathleen A. Greene
Bill Benzing**

Contents

Introduction	1
FUTURE DIRECTIONS	
Some Perspectives on Future Directions in Low Cycle Fatigue—L. F. COFFIN	5
Future Directions for Low Cycle Fatigue—S. S. MANSON	15
CYCLIC DEFORMATION	
Effect of Elevated Temperatures on the Low Cycle Fatigue of 2.25Cr-1Mo Steel—Part I: Constant Amplitude Straining—J. POLÁK, J. HELEŠIC, AND M. KLESNIL	43
Effects of Testing Method on Cyclic Hardening Behavior in Face-Centered-Cubic Alloys—A. C. PICKARD AND J. F. KNOTT	58
Fracture of Pearlite under Conditions of High Deformation Fatigue—M. SCHWARTZ AND J. C. CRESPI	77
Low Cycle Fatigue of Some Aluminum Alloys—Y. S. CHUNG AND A. ABEL	94
Cyclic Stress-Strain-Time Response of a 9Cr-1Mo-V-Nb Pressure Vessel Steel at High Temperature—R. W. SWINDEMAN	107
Viscoplasticity Based on Overstress Applied to Creep-Fatigue Interaction—E. KREMPL, H. LU, M. SATOH, AND D. YAO	123
LOW CYCLE FATIGUE DAMAGE	
A Nonlinear History-Dependent Damage Model for Low Cycle Fatigue—B. N. LEIS	143
Very Low Cycle Fatigue Life Influenced by Tensile or Compressive Prestrain—K. IIDA	160

Effects of Compression and Compressive Overloads on the Fatigue Behavior of a 2024-T351 Aluminum Alloy and a SAE 1045 Steel—D. L. DUQUESNAY, M. A. POMPETZKI, T. H. TOPPER, AND M. T. YU	173
---	-----

Deformation and Fatigue Damage in 1070 Steel under Thermal Loading—M. L. KARASEK, H. SEHITOGLU, AND D. C. SLAVIK	184
Discussion	204

CRACK PROPAGATION

Application of Small Specimen Crack Growth Data to Engineering Components at High Temperature: A Review—R. P. SKELTON	209
Discussion	235

Life of Crack Initiation, Propagation, and Final Fracture under High-Temperature Creep, Fatigue, and Creep-Fatigue Multiplication Conditions—A. T. YOKOBORI, T. YOKOBORI, AND T. KURIYAMA	236
--	-----

Growth of Small Cracks and an Evaluation of Low Cycle Fatigue Life—K. HATANAKA AND T. FUJIMITSU	257
--	-----

Prediction of Crack Growth under Creep-Fatigue Loading Conditions—K. M. NIKBIN AND G. A. WEBSTER	281
Discussion	291

Fatigue Crack Propagation of Nickel-Base Superalloys at 650°C—J. GAYDA, T. P. GABB, AND R. V. MINER	293
Discussion	309

HIGH-TEMPERATURE LOW CYCLE FATIGUE

A Model for Predicting Low Cycle Fatigue Life under Creep-Fatigue Interaction—K.-T. RIE, R.-M. SCHMIDT, B. ILSCHNER, AND S. W. NAM	313
Discussion	328

An Update of the Total-Strain Version of Strainrange Partitioning—J. F. SALTSMAN AND G. R. HALFORD	329
Discussion	340

Low-Frequency, High-Temperature Low Cycle Fatigue of 60Sn-40Pb Solder—H. D. SOLOMON	342
Discussion	370

Creep-Fatigue Behavior of Ni-Co-Cr-Al-Y Coated PWA 1480 Superalloy Single Crystals—R. V. MINER, J. GAYDA, AND M. G. HEB SUR	371
Discussion	384
High-Temperature Low Cycle Fatigue Behavior and Lifetime Prediction of a Nickel-Base ODS Alloy—M. Y. NAZMY	385
Discussion	397
Comparison of Creep-Fatigue Life Prediction by Life Fraction Rule and Strainrange Partitioning Methods—M. YAMAUCHI, T. IGARI, K. SETOGUCHI, AND H. YAMANOUCHI	399
Creep and Creep-Fatigue Intergranular Damage in Austenitic Stainless Steels: Discussion of the Creep-Dominated Regime—C. LEVAILLANT, J. GRATIER, M. MOTTOT, AND A. PINEAU	414
Discussion	436
Influence of Temperature and Environment on the Fatigue Mechanisms of Single-Crystal and Polycrystal 316L— J. H. DRIVER, C. GORLIER, C. BELRAMI, P. VIOLAN, AND C. AMZALLAG	438
Discussion	454
A Model for Life Predictions of Nickel-Base Superalloys in High-Temperature Low Cycle Fatigue—G. R. ROMANOSKI, S. D. ANTOLOVICH, AND R. M. PELLOUX	456
Discussion	468
Elevated Temperature Fatigue-Creep Behavior of Nickel-Base Superalloy IN 625—T. BUI-QUOC, R. GOMUC, A. BIRON, H. L. NGUYEN, AND J. MASOUNAVE	470
Discussion	485
Application of the Overstress Concept for Creep-Fatigue Evaluation—M. MORISHITA, K. TAGUCHI, T. ASAYAMA, A. ISHIKAWA, AND Y. ASADA	487
Discussion	498
An Integrated Approach to Creep-Fatigue Life Prediction— P. AGATONOVIC AND R. HEIDENREICH	500
Mapping of Low Cycle Fatigue Mechanisms at Elevated Temperatures for an Austenitic Stainless Steel—K. KANAZAWA, K. YAMAGUCHI, AND S. NISHIJIMA	519
Discussion	530

A Maximum Stress Modified Life Equation on the Basis of a Fatigue-Creep Interaction Map—G. L. CHEN, Q. F. HE, L. GAO, AND S. H. ZHANG	531
Effect of Nitrogen on Creep-Fatigue Interaction in Austenitic Stainless Steels at 600°C—J.-O. NILSSON	543
Oxidation-Fatigue Interactions in a Single-Crystal Superalloy— P. K. WRIGHT	558
Elevated-Temperature Low Cycle and Thermomechanical Fatigue Properties of AISI H13 Hot-Work Tool Steel—G. ENGBERG AND L. LARSSON	576
Fatigue of Solder Joints in Surface Mount Devices—M. C. SHINE AND L. R. FOX	588
A Micromechanics Model of the Initiation of Grain-Boundary Crack in High-Temperature Fatigue—M. TANAKA AND H. IIZUKA	611
 THERMAL AND THERMOMECHANICAL LOW CYCLE FATIGUE	
Bithermal Fatigue: A Link Between Isothermal and Thermomechanical Fatigue—G. R. HALFORD, M. A. MCGAW, R. C. BILL, AND P. D. FANTI	625
Discussion	637
Thermal-Mechanical Cyclic Stress-Strain Responses of Cast B-1900+Hf—N. MARCHAND, G. L'ESPÉRANCE, AND R. M. PELLOUX	638
Thermomechanical Fatigue Behavior of a Superalloy— J. L. MALPERTU AND L. RÉMY	657
Discussion	670
Thermal Fatigue Testing of Coated Monocrystalline Superalloys— J. W. HOLMES, F. A. MCCLINTOCK, K. S. O'HARA, AND M. E. CONNERS	672
Thermal-Mechanical Fatigue of Cast René 80—T. S. COOK, K. S. KIM, AND R. L. MCKNIGHT	692
Discussion	708

MICROSTRUCTURAL EFFECTS

- Influence of Material Microstructure on Low Cycle Fatigue Failure, with Particular Reference to Austenitic Steel—**
J. WAREING 711
- Effect of Temperature, Microstructure, and Stress State on the Low Cycle Fatigue Behavior of Waspaloy—**D. R. STAHL,
M. MIRDAMADI, S. Y. ZAMRIK, AND S. D. ANTOLOVICH 728
- Microstructural Aspects of Crack Initiation and Propagation in Extremely Low Cycle Fatigue—**T. KUNIO, M. SHIMIZU,
N. OHTANI, AND T. ABE 751
- Low Cycle Fatigue of Al-Mg-Si Alloys—**K. DETERT AND R. SCHEFFEL 765
- Low Cycle Fatigue of Strain Aging Ferrous Alloys—**S. M. PICKARD,
F. GUIU, AND A. P. BLACKIE 776
- Influence of Nitrogen Solutes and Precipitates on Low Cycle Fatigue of 316L Stainless Steels—**S. DEGALLAIX, G. DEGALLAIX, AND
J. FOCT 798
- A New Approach to Low Cycle Fatigue Behavior of a Duplex Stainless Steel Based on the Deformation Mechanisms of the Individual Phases—**T. MAGNIN, J. M. LARDON, AND
L. COUDREUSE 812
- Effect of HIP on Elevated-Temperature Low Cycle Fatigue Properties of an Equiaxed Cast Superalloy—**D. L. ANTON AND
L. H. FAVROW 824
- Effect of Microstructures on Low Cycle Fatigue Behavior in a TC6 (Ti-6Al-2.5Mo-2Cr-0.5Fe-0.3Si) Titanium Alloy—**
S. Q. ZHANG, C. H. TAO, AND M. G. YAN 838
- Quantification of Slip Lines in Fatigue—**W. G. FRICKE, JR. 853

MULTIAXIAL AND VARIABLE AMPLITUDE LOADING

- Engineering Significance of Recent Multiaxial Research—**G. E. LEESE 861
Discussion 873
- Damage Development During Multiaxial Fatigue of Unnotched and Notched Specimens—**J. W. FASH, N. J. HURD, C. T. HUA, AND
D. F. SOCIE 874

Observations of Cracking Behavior in Tension and Torsion Low Cycle Fatigue—J. A. BANNANTINE AND D. F. SOCIE	899
Effect of Elevated Temperatures on the Low Cycle Fatigue of 2.25Cr-1Mo Steel—Part II: Variable Amplitude Straining—J. POLÁK, A. VAŠEK, AND M. KLESNIL	922
Discussion	937
Effect of Superimposed Stresses at High Frequency on Low Cycle Fatigue—J.-Y. GUEDOU AND J.-M. RONGVAUX	938
Influence of High Frequency Vibrations on the Low Cycle Fatigue Behavior of a Superalloy at Elevated Temperature—J. OUYANG, Z. WANG, D. SONG, AND M. YAN	961
Fatigue Life and Short Crack Propagation of Turbine Rotor Steels under Variable Strain Loading—T. MORI, H. TOYODA, AND S. OHTA	972

NOTCHES

Some Contributions to the Further Development of Low Cycle Fatigue Life Analysis Concepts for Notched Components under Variable Amplitude Loading—H. NOWACK, W. OTT, J. FOTH, H. PEEKEN, AND T. SEEGER	987
The Improved Neuber's Rule and Low Cycle Fatigue Life Estimation—Y.-S. WU	1007
Relations Between the Strain Energy Density Distribution and Elastic-Plastic Stress-Strain Fields Near Cracks and Notches and Fatigue Life Calculation—G. GLINKA	1022
Correlation Between Strain Singularity at Crack Tip under Overall Plastic Deformation and the Exponent of the Coffin-Manson Law—Y. MURAKAMI	1048
Notch Effect on Low Cycle Fatigue in Creep-Fatigue at High Temperatures: Experiment and Finite Element Method Analysis—M. OHNAMI, Y. ASADA, M. SAKANE, M. KITAGAWA, AND T. SAKON	1066
Evaluation of Low Cycle Creep-Fatigue Degradation for Notched Components—S. N. SINGHAL AND R. A. TAIT	1096

LIFE PREDICTION

Evaluation of Life Prediction Methods in High Temperature Fatigue—L. RÉMY, F. REZAI-ARIA, R. DANZER, AND W. HOFFELNER	1115
Strain Energy Partitioning Approach and Its Application to Low Cycle Fatigue Life Prediction for Some Heat-Resistant Alloys—Z. DUAN, J. HE, Y. NING, AND Z. DONG	1133
Fatigue Life Estimations for Cast Steels Using Low Cycle Fatigue Behavior—S. G. LEE AND R. I. STEPHENS	1144
High-Temperature Low Cycle Fatigue Crack Propagation and Life Laws of Smooth Specimens Derived from the Crack Propagation Laws—R. OHTANI, T. KITAMURA, A. NITTA, AND K. KUWABARA	1163
Reconsideration of Macroscopic Low Cycle Fatigue Laws Through Observation of Microscopic Fatigue Process on a Medium Carbon Steel—S. HARADA, Y. MURAKAMI, Y. FUKUSHIMA, AND T. ENDO	1181
Grain Boundary Oxidation and an Analysis of the Effects of Oxidation on Fatigue Crack Nucleation Life—Y. OSHIDA AND H. W. LIU	1199
Computer-Based Prediction of Cyclic Deformation and Fatigue Behavior—A. CONLE, T. R. OXLAND, AND T. H. TOPPER	1218
Low Cycle Fatigue Characterization of a HP-IP Steam Turbine Rotor—V. BICEGO, C. FOSSATI, AND S. RAGAZZONI	1237
Author Index	1261
Subject Index	1263

ISBN 0-8031-0944-X