

# EROSION: Prevention and Useful Applications

W. F. Adler, *editor*

 **STP 664**

AMERICAN SOCIETY FOR  
TESTING AND MATERIALS

# EROSION: PREVENTION AND USEFUL APPLICATIONS

A symposium  
sponsored by ASTM  
Committee G-2 on  
Erosion and Wear  
AMERICAN SOCIETY FOR  
TESTING AND MATERIALS  
Vail, Colo., 24-26 Oct. 1977

ASTM SPECIAL TECHNICAL PUBLICATION 664  
W. F. Adler, Effects Technology Inc.  
editor

List Price \$55.00  
04-664000-29



AMERICAN SOCIETY FOR TESTING AND MATERIALS  
1916 Race Street, Philadelphia, Pa. 19103

**Copyright© by AMERICAN SOCIETY FOR TESTING AND MATERIALS 1979**  
**Library of Congress Catalog Card Number: 78-068438**

**NOTE**

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

**Printed in Baltimore, Md.**  
**February 1979**

## Foreword

The papers contained in this Special Technical Publication are an outgrowth of the papers presented at the American Society for Testing and Materials Symposium on Erosion: Prevention and Useful Applications sponsored by Committee G-2 on Erosion and Wear. The symposium was held in Vail, Colo., 24-26 Oct. 1977. Dr. W. F. Adler, Effects Technology, Inc., Santa Barbara, Calif., Dr. D. A. Summers, University of Missouri, Rolla, Mo., and Dr. Fun-Den Wang, Colorado School of Mines, Golden, Colo., were members of the organizing committee. This was the fifth symposium on erosion to be sponsored by ASTM. Previous symposia were held in 1961, 1966, 1969, and 1973.

## Related ASTM Publications

Erosion, Wear, and Interfaces with Corrosion, STP 567 (1974), \$35.00,  
04-567000-29

Unified Numbering System for Metals and Alloys, DS 56A (1977), \$49.00,  
05-056001-01

## A Note of Appreciation to Reviewers

This publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of ASTM publications is a direct function of their respected opinions. On behalf of ASTM we acknowledge with appreciation their contribution.

*ASTM Committee on Publications*

## Editorial Staff

Jane B. Wheeler, *Managing Editor*  
Helen M. Hoersch, *Associate Editor*  
Ellen J. McGlinchey, *Senior Assistant Editor*  
Helen Mahy, *Assistant Editor*

# Contents

<b>Introduction</b>	1
SOLID PARTICLE IMPINGEMENT	
<b>Electron Microscopy Study of Erosion Damage in Copper—L. K. IVES AND A. W. RUFF</b>	5
Discussions	33
<b>Fundamental Mechanisms of the Erosive Wear of Ductile Metals by Solid Particles—I. FINNIE, A. LEVY, AND D. H. MCFADDEN</b>	36
Discussions	57
<b>Mechanisms of the Erosion of Metals by Solid Particles— I. M. HUTCHINGS</b>	59
Discussion	75
<b>Multiparticle Erosion of Pyrex Glass—G. A. SARGENT, P. K. MEHROTRA, AND H. CONRAD</b>	77
<b>Solid-Particle Erosion of High-Technology Ceramics (<math>\text{Si}_3\text{N}_4</math>, Glass-Bonded <math>\text{Al}_2\text{O}_3</math>, and <math>\text{MgF}_2</math>)—M. E. GULDEN</b>	101
Discussions	121
<b>Test Facility for Material Erosion at High Temperature— W. TABAKOFF AND T. WAKEMAN</b>	123
Discussions	134
<b>Mechanisms of Erosion of a Ductile Material by Solid Particles— J. MAJI AND G. L. SHELDON</b>	136
Discussions	147
<b>Relative Erosion Resistance of Several Materials—J. S. HANSEN</b>	148
<b>Erosion-Corrosion of Coatings and Superalloys in High-Velocity Hot Gases—R. H. BARKALOW, J. A. GOEBEL, AND F. S. PETTIT</b>	163
Discussions	190
<b>Calculated Tolerance of a Large Electric Utility Gas Turbine to Erosion Damage by Coal Gas Ash Particles—M. MENGUTURK AND E. F. SVERDRUP</b>	193



## LIQUID DROP IMPINGEMENT

- Analysis of Brittle Target Fracture from a Subsonic Water Drop Impact**—M. ROSENBLATT, Y. M. ITO, AND G. E. EGGUM 227  
Discussions 250
- Response of Infrared Transmitting Materials to High-Velocity Impact by Water Drops**—J. V. HACKWORTH, L. H. KOCHER, AND I. C. SNELL 255
- Multiple Water Drop Impact Damage in Layered Infrared Transparent Materials**—T. L. PETERSON 279  
Discussion 296
- High-Speed Liquid Jet and Drop Impact on Brittle Targets**—J. E. FIELD, D. A. GORHAM, AND D. G. RICKERBY 298  
Discussion 318
- Damage Mechanisms in Polymers and Composites Under High-Velocity Liquid Impact**—D. A. GORHAM, M. J. MATTHEWSON, AND J. E. FIELD 320  
Discussions 340

## HYPERVELOCITY EROSION

- Erosion Damage in Carbon-Carbon Composites at Hypersonic Impact Velocities**—W. F. ADLER AND A. G. EVANS 345  
Discussions 372
- Influence of Materials Construction Variables on the Rain Erosion Performance of Carbon-Carbon Composites**—G. F. SCHMITT, JR. 376

## CAVITATION EROSION

- Influence of Crystal Structure on the Failure Mode of Metals by Cavitation Erosion**—C. M. PREECE, S. VAIDYA, AND S. DAKSHINAMOORTHY 409  
Discussions 431
- Influence of Test Parameters in Vibratory Cavitation Erosion Tests**—MASANOBU MATSUMURA 434  
Discussions 456

## LIQUID JET TECHNOLOGY

- Effect of an Air-Injected Shroud on the Breakup Length of a High-Velocity Waterjet**—D. L. EDDINGFIELD AND M. ALBRECHT 461  
Discussions 471

<b>Adaptation of Jet Accumulation Techniques for Enhanced Rock Cutting</b> —M. MAZURKIEWICZ, C. R. BARKER, AND D. A. SUMMERS	473
<b>Dual-Orifice Waterjet Predictions and Experiments</b> —B. P. SELBERG AND C. R. BARKER	493
Discussions	510
<b>A Study of Erosion by High-Pressure Cavitating and Noncavitating Waterjets</b> —M. M. VIJAY AND W. H. BRIERLEY	512
<b>Cavitating Jet Apparatus for Cavitation Erosion Testing</b> —A. LICHTAROWICZ	530
Discussion	549

#### LIQUID JET APPLICATIONS

<b>Mechanism of Fracture of Hard Rock Using a Drag Bit Assisted by Waterjets</b> —MICHAEL HOOD	553
<b>CAVIJET Coal-Cutting Parameters</b> —A. F. CONN AND S. L. RUDY	562
Discussion	581
<b>Marine Applications of High-Pressure Waterjets</b> —J. A. HILARIS AND T. J. LABUS	582
<b>Use of High-Pressure Waterjets in Utility Industry Applications</b> —F. A. HUSZARIK, J. M. REICHMAN, AND J. B. CHEUNG	597

#### SUMMARY

<b>Summary</b>	619
<b>Index</b>	629