

**PROPERTIES OF MATERIALS
FOR
LIQUEFIED NATURAL GAS
TANKAGE**

STP 579



AMERICAN SOCIETY FOR TESTING AND MATERIALS

PROPERTIES OF MATERIALS FOR LIQUEFIED NATURAL GAS TANKAGE

A symposium
presented at
May Committee Week
AMERICAN SOCIETY FOR
TESTING AND MATERIALS
Boston, Mass., 21-22 May 1974

ASTM SPECIAL TECHNICAL PUBLICATION 579
J. G. Kaufman, symposium chairman

List price \$39.75
04-579000-30



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

© BY AMERICAN SOCIETY FOR TESTING AND MATERIALS 1975
Library of Congress Catalog Card Number: 75-2513

NOTE

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

Printed in Baltimore, Md.
September 1975

Foreword

The symposium on Properties of Materials for Liquefied Natural Gas Tankage was presented at May Committee Week of the American Society for Testing and Materials held in Boston, Mass., 21-22 May 1974. The American Society for Testing and Materials, American Society of Mechanical Engineers, and Metal Properties Council Joint Committee on Effect of Temperature on the Properties of Metals, Low Temperature Panel, sponsored the symposium. J. G. Kaufman, Aluminum Company of America, presided as symposium chairman.

Related ASTM Publications

Fatigue and Fracture Toughness—Cryogenic Behavior, STP 556 (1974),
\$20.25 (04-556000-30)

Fracture Toughness Testing at Cryogenic Temperatures, STP 496 (1971),
\$5.00 (04-496000-30)

Cryogens and Gases: Testing Methods and Standards Development, STP 537
(1973), \$6.25 (04-537000-41)

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*
Charlotte E. Wilson, *Senior Assistant Editor*
Ellen J. McGlinchey, *Assistant Editor*

Contents

Introduction	1
Materials and Liquefied Natural Gas —M. J. WEISS	3
Liquefied Natural Gas	3
Materials	5
Overall Capacity and Costs	8
Significance of Defects in Liquefied Natural Gas Tanks in Ships — P. TENGE, O. SOLLI, AND O. FÖRLI	10
Nomenclature	10
Materials	12
Fatigue Crack Propagation	12
Fracture Toughness and Critical Crack Sizes	16
Defects in 9Ni Steel Welds	19
Defects in 5083 Al Welds	21
NDT, Possibilities and Limitations in Defining Size of Planar Defects	24
Fracture Mechanics Analysis Procedure for Calculating Fatigue Crack Propagation	25
Establishment of Acceptance Criteria	33
Concluding Remarks	41
Crack Growth and Fracture of Thick 5083-0 Plate Under Liquefied Natural Gas Ship Spectrum Loading —R. A. KELSEY, R. H. WYGONIK, AND PER TENGE	44
Material	46
Tensile and Fracture Toughness Properties	46
Tests of Large Plate-Type Specimens	56
Leak Tests	70
Fracture Toughness Tests	74
Conclusions	74
Fatigue Crack Growth Rate of Thick 5083-0 Plate at Room and Low Temperatures —N. L. PERSON AND G. C. WOLFER	80
Materials and Procedures	81
Results and Discussion	85
Summary and Conclusions	92

Fatigue Crack Growth and Fracture Toughness of 5083-0 Aluminum Alloy —G. ARGY, P. C. PARIS, AND F. SHAW	96
Nomenclature	96
Experimental Approach	98
Conclusions	129
Discussion	131
Fracture Toughness and Fatigue Properties of 5083-0 Plate and 5183 Welds for Liquefied Natural Gas Applications —J. G. KAUFMAN AND R. A. KELSEY	138
Material	139
Weld Preparation and Qualification	139
Test Procedures	139
Results	141
Conclusions	151
Strength and Fracture of 5083-0 Aluminum Weldments —R. E. ZINKHAM AND R. F. ASHTON	159
Procedures	161
Discussion of Results	166
Conclusions	173
Toughness Variations Through the Thickness of Thick 5083-0 Aluminum Alloy Plate —R. L. LAKE	176
Material	178
Specimens	178
Procedure	180
Results and Discussion	181
Summary	188
Design Stresses for Aluminum Alloy 5083-0 and 5183 Welds at Cryogenic Temperatures —K. O. BOGARDUS AND R. C. MALCOLM	190
Materials and Test Procedure	191
Test Results	194
Development of Allowable Stress for 5083-0 at Cryogenic Temperatures	194
Allowable Design Stresses for Welded 5083 Plate at Cryogenic Temperatures	201
Studies on Nine Percent Nickel Steel for Liquefied Natural Gas Carriers —T. SAKAI, H. TAKASHIMA, K. TANAKA, H. MATSUMAE, AND H. YAJIMA	205
Materials	206
Fatigue Properties Determined Using Small-Size Specimens	208

Fatigue Properties Determined Using Large-Size Specimens	208
Fatigue Strength of Equator Ring	213
Relation Between Crack Initiation Life and Failure Life	214
Characteristics of Fatigue Crack Propagation in Rolled 9Ni Steel	215
Geometry of Through Crack Produced in Surface-Notched Specimen	217
Relation Between Crack Propagation Rate and Stress Intensity Factor	219
Fractography and Microscopic Crack Growth Rate	220
Brittle Fracture Behavior of Base Metal	222
Fracture Characteristics of Welded Joints	225
Structural Integrity of Spherical LNG Tank	230
Conclusions	236
Fatigue Crack Growth Rate Studies of Partial Thickness Cracks in ASTM Method A 645-74, Five Percent Nickel Steel—	
D. E. MCCABE, D. A. SARNO, AND C. E. FEDDERSEN	238
Material	239
Specimens	241
Instrumentation and Procedure	241
Experimental Methods to Measure Crack Growth	241
Constant Amplitude Program	244
Results of Constant Amplitude Fatigue	246
Variable Amplitude Fatigue Crack Growth	251
Retardation	253
Experimental Results	255
Conclusions	257
Low Temperature Fracture Behavior of Iron-Nickel Alloy Steels—	
R. L. TOBLER, R. P. MIKESSELL, R. L. DURCHOLZ, AND R. P. REED	261
Experimental Procedures and Apparatus	263
Results	270
Discussion	284
Summary	285
Strength and Fracture Toughness of Nickel Containing Steels—	
A. G. HAYNES, K. FIRTH, G. E. HOLLOX, AND J. BUCHAN	288
Materials for Test	290
Test Procedure	293
Results and Discussion	293
Conclusions	321
Newly Developed Welding Material for Liquefied Natural Gas Application—	
T. NISHI, S. SAITO, T. NAKANO, AND Y. HORII	324

Composition Design of MIG Welding Wires	325
Commercial Performance Test	332
Conclusions	345
Cryogenic Toughness Through Microstructure Control in an Iron-Nickel-Titanium Alloy—SUNGHO JIN, B. WHITAKER, J. W. MORRIS, JR., AND V. F. ZACKAY	348
Alloy Selection	349
Process Selection	350
Materials Preparation and Processing	353
Effect of Processing on Mechanical Properties	354
Conclusions	360
Cryogenic Properties of Iron-Manganese and Iron-Manganese- Chromium Alloys—M. J. SCHANFEIN, M. J. YOKOTA, V. F. ZACKAY, E. R. PARKER, AND J. W. MORRIS, JR.	361
Materials and Experimental Procedure	363
Results and Discussion	364
Conclusions	376
Strain-Cycling Fatigue Behavior of Ten Structural Metals Tested in Liquid Helium, Liquid Nitrogen, and Ambient Air— A. J. NACHTIGALL	378
Materials, Apparatus, and Test Procedure	380
Data Analysis and Fatigue Life Predictions	389
Results and Discussion	390
Summary of Results	395
Low Temperature Elastic Properties of Aluminum 5083-0 and Four Ferritic Nickel Steels—W. F. WESTON, E. R. NAIMON, AND H. M. LEDBETTER	397
Experimental	399
Results	403
Discussion	412
Conclusions	417
General Discussion on the Toughness of Nine Percent Nickel Steel— ARNE OMSEN	421
Experimentals	421
Comparison Between Toughness at -162 and -196°C	422
Experience from Current Production of UHB 2N90	422
Conclusions	423