

**STRENGTH
OF
METALS & ALLOYS**

Volume 1

STRENGTH OF METALS AND ALLOYS

(ICSMA 8)

**Proceedings of the 8th International Conference
on the Strength of Metals and Alloys
Tampere, Finland, 22–26 August 1988**

Edited by

**P. O. KETTUNEN, T. K. LEPISTÖ,
M. E. LEHTONEN**

Volume 1



PERGAMON PRESS

**OXFORD · NEW YORK · BEIJING · FRANKFURT
SÃO PAULO · SYDNEY · TOKYO · TORONTO**

U.K.	Pergamon Press plc, Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
PEOPLE'S REPUBLIC OF CHINA	Pergamon Press, Room 4037, Qianmen Hotel, Beijing, People's Republic of China
FEDERAL REPUBLIC OF GERMANY	Pergamon Press GmbH, Hammerweg 6, D-6242 Kronberg, Federal Republic of Germany
BRAZIL	Pergamon Editora Ltda, Rua Eça de Queiros, 346, CEP 04011, Paraiso, São Paulo, Brazil
AUSTRALIA	Pergamon Press Australia Pty Ltd., P.O. Box 544, Potts Point, N.S.W. 2011, Australia
JAPAN	Pergamon Press, 5th Floor, Matsuoka Central Building, 1-7-1 Nishishinjuku, Shinjuku-ku, Tokyo 160, Japan
CANADA	Pergamon Press Canada Ltd., Suite No. 271, 253 College Street, Toronto, Ontario, Canada M5T 1R5

Copyright © 1989 Pergamon Press plc

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic tape, mechanical, photocopying, recording or otherwise, without permission in writing from the publishers.

First Edition 1989

Library of Congress Cataloguing in Publication Data

International Conference on the Strength of Metals and Alloys
(8th : 1988 : Tampere, Finland)

Strength of metals and alloys (ICSMA 8) : proceedings of the
8th International Conference on the Strength of Metals and
Alloys, Tampere, Finland, 22-26 August 1988 / edited by P. O.
Kettunen, T. K. Leppistö, M. E. Lehtonen.

p. cm. — (International series on the strength and fracture of
materials and structures)

1. Metals—Congresses. 2. Alloys—Congresses. 3. Physical
metallurgy—Congresses. I. Kettunen, P. O. (Pentti O.),
1932-. II. Leppistö, T. K. III. Lehtonen, M. E. IV. Title.
V. Series.

TA460.I532 1988 620.1'6—dc19 88-17862

British Library Cataloguing in Publication Data

International Conference on the Strength of Metals and Alloys
(8th : 1988 : Tampere, Finland)

Strength of metals and alloys.

I. Metals and alloys. Strength
I. title II. Kettunen, P. O. III. Lepisto, T. K. IV. Lehtonen,
M. E. V. Series
620.1'63

ISBN 0-08-034804-1

In order to make this volume available as economically and as rapidly as possible the authors' typescripts have been reproduced in their original forms. This method unfortunately has its typographical limitations but it is hoped that they in no way distract the reader.

INTERNATIONAL SERIES ON THE STRENGTH AND FRACTURE OF MATERIALS AND STRUCTURES

General Editor: D. M. R. TAPLIN, D.Sc., D.Phil., F.I.M.

Other titles in the series

CARLSSON &	
OHLSON	Mechanical Behaviour of Materials (ICM 4) (2 volumes)
EASTERLING	Mechanisms of Deformation and Fracture
FRANCOIS	Advances in Fracture Research (ICF 5) (6 volumes)
GIFKINS	Strength of Metals and Alloys (ICSMA 6) (3 volumes)
HAASEN <i>et al.</i>	Strength of Metals and Alloys (ICSMA 5) (3 volumes)
McQUEEN <i>et al.</i>	Strength of Metals and Alloys (ICSMA 7) (3 volumes)
MILLER & SMITH	Mechanical Behaviour of Materials (ICM 3)
OSGOOD	Fatigue Design, 2nd edition
PIGGOTT	Load Bearing Fibre Composites
SMITH	Fracture Mechanics: Current Status, Future Prospects
TAIT & GARRETT	Fracture and Fracture Mechanics: Case Studies
VALLURI	Advances in Fracture Research (ICF 6) (6 volumes)
YAN <i>et al.</i>	Mechanical Behaviour of Materials (ICM 5)

Related Pergamon Journals (free sample copy gladly sent on request)

Acta Mechanica Solida Sinica
Acta Metallurgica
Canadian Metallurgical Quarterly
Computers and Structures
Corrosion Science
Engineering Fracture Mechanics
Fatigue and Fracture of Engineering Materials and Structures
International Journal of Impact Engineering
International Journal of Plasticity
International Journal of Solids and Structures
Journal of the Mechanics and Physics of Solids
Materials Research Bulletin
Physics of Metals and Metallography
Scripta Metallurgica
Welding in the World

International Committee ICSMA Conference

M. F. Ashby (Great Britain)	R. Lagneborg (Sweden)
Z. S. Basinski (Canada)	K. Lücke (FRG)
B. Baudelet (France)	H. McQueen (Canada)
J. Friedel (France)	W. D. Nix (USA)
P. Haasen, chairman (FRG)	I. J. Polmear (Australia)
P. B. Hirsch (Great Britain)	H. Suzuki (Japan)

ICSMA 8 Scientific Committee

P. Kettunen, chairman (Finland)	V. Lindroos (Finland)
N. Hansen (Denmark)	E. Nes (Norway)
R. Lagneborg (Sweden)	T. Lepistö, secretary (Finland)

ICSMA 8 Organizing Committee

P. Kettunen, chairman	T. Tiainen
K. Hakalehto	P. Voutilainen
V. Lindroos	O. Siltari
M. Mannerkoski	T. Lepistö, secretary

Sponsoring Organizations

**Outokumpu Oy
Rauma-Repola Oy
Finnair
Postipankki
Suomen Yhdyspankki
Tampereen Kaupunki
Suomen Kulttuurirahasto
Suomen Teräksen- ja Metallituottajien Yhdistys
Nordisk Kulturfond**

Contents of Volume 1

Invited lectures

Dislocations and mechanisms revealed by computer simulation D.J. Bacon	3
Low amplitude fatigue of copper crystals from 4.2K to 350K Z.S. Basinski and S.J. Basinski	13
The influence of texture on strain hardening U.F. Kocks, M.G. Stout, and A.D. Rollett	25
The dynamic organization of dislocation structures L.P. Kubin and J. Lépinoux	35
The strength of metal matrix composites under mechanical and thermal loadings H. Lilholt	61
Microstructural concepts for strengthening of metals, ceramics and polymers H. Mecking, N. Claussen, and H.J. Petermann	81
Deformation mechanism of cubic metals at high temperature H. Oikawa and H. Yoshinaga	97
Metastable alloy phases prepared by solid state reactions and ball milling R.B. Schwarz	113
X-ray diffraction line broadening and crystal plasticity M. Wilkens	125

1. Dislocations

A geometrical method to characterize the order in microtwins from in situ observations	133
A. Coujou, A. Beneteau, G. Alcouffe, and Ph. Lours	
Kinematics of the motion of dislocations interacting with small precipitates	139
U. Messerschmidt and F. Appel	
HVEM-in-situ observation of dislocation processes in the system <u>Cu-Co</u>	145
E. Nembach, K. Suzuki, M. Ichihara, and S. Takeuchi	
Dislocation-like defects in an amorphous Lennard-Jones solid	151
L.T. Shi	
Dislocation behaviour in dual phase steels	155
A.W. Sleeswyk and S. Mandziej	
Deformation of crystals controlled by the Peierls mechanism	161
S. Takeuchi and T. Suzuki	
Twinning in a Cu-Al crystals: An instability of plastic flow	167
F. Tranchant, J. Vergnol, and J. Grilhé	
Temperature and strain-rate dependence of the flow stress of bcc transition metal crystals in cyclic deformation	173
M. Werner and A. Seeger	
Computer simulation of the interaction between a screw dislocation and point defects in α -iron lattice	179
K. Makii, T. Tsutsumi, Y. Aono, and E. Kuramoto	

2. Dislocation Arrangements

Thermally activated dislocation motion in fcc solid solutions	187
R.J. Arsenault and S. Li	
Microbands in deformed aluminium	193
B. Bay and N. Hansen	
Monotonic and cyclic deformation-induced dislocation substructures in bcc metals	199
K.J. Bowman, V.K. Sethi, I. Rusakova, and R. Gibala	
In situ deformation of γ' nickel base single crystals. The movement of screw dislocations in {001} planes from -100°C to 880°C	205
N. Clément, D. Caillard, P. Lours, and A. Coujou	
Glide in prismatic planes in beryllium. An in situ study	211
A. Courret and D. Caillard	
Corrugated glide surfaces and the origin of earthquakes	217
P.J. Jackson	

Strengthening through leds D. Kuhlmann-Wilsdorf	221
On the strength anomaly in B-brass H. Saka and Y.M. Zhu	227
TEM-in-situ deformation of Cu-Zn single crystals F. Schmidt-Hohagen and H. Neuhäuser	233
Prismatic slip in hcp metals G. Schoeck and W. Püschl	239
In situ HVEM observations of dislocation transmission by $\Sigma = 9$ grain boundaries in silicon A. Jacques, X. Bailllin, and A. George	245
Formation of prismatic loops induced by in situ straining of the γ ¹ phase of a nickel base superalloy Ph. Lours, B. de Mauduit, A. Bénéteau, N. Clément, and D. Caillard	251

3. Plastic Deformation

Plastic prestrain effects on the buckling characteristics of steel A. Abel	259
Hardening stages of [112] oriented copper single crystals at intermediate and high temperatures P. Anongba, J. Bonneville, and J.L. Martin	265
Plastic behavior of high-purity molybdenum single crystals in tension and compression Y. Aono, E. Kuramoto, D. Brunner, and J. Diehl	271
Characterization of dislocation cells in deformed fcc metals I. Barker, B. Ralph, and N. Hansen	277
A yield function for orthotropic sheets under plane stress conditions F. Barlat, J. Lian, and B. Baudelot	283
Superplastic behavior of mechanically alloyed aluminum IN90211 T.R. Bieler and A.K. Mukherjee	289
Superplastic deformation characteristics in an age strengthening Cu-1.9Be-0.3Ni Alloy P.Q. Chen, T. Jin, and M. Zhao	295
The superplastic-like characteristics of a silicon carbide whisker reinforced aluminum composite A.H. Chokshi, T.G. Nieh, J. Wadsworth, and A.K. Mukherjee	301
Plastic instability and fractography in the heat treatable Al alloy 6261 R. Colás and A. Grinberg	307

Studies of hardening mechanisms of symmetrically oriented single crystals of FCC solid solutions	313
L. Diehl, F. Springer, and Ch. Schwink	
Microstructures of heavily deformed continuously cast 70/30 brass and copper	319
C.Y. Chung, B.J. Duggan, M.S. Bingley, and W.B. Hutchinson	
Hardening anisotropy evolution of fcc polycrystals in channel die testing	325
P. Franciosi and M.G. Stout	
Plastic deformation and fracture of zinc-aluminum alloys under static and impact loading	331
H.A. Ghoneim and M.M. Farag	
Serrated yielding in Al-Zn alloys	337
M. Jovanović, M. Grujičić, and Dj. Drobnjak	
Modelling stage IV work hardening of metals	343
P. Haasen	
Dynamic studies of slip line formation on single crystals of fcc solid solutions	349
A. Hampel, M. Schülke, and H. Neuhäuser	
Load relaxation behavior of polycrystalline OFHC copper	355
S.-P. Hännula, C. Paszkiet, and C.-Y. Li	
Anisotropic strain hardening in polycrystalline copper: a phenomenological model	361
F. Hess and A.W. Sleeswyk	
Shear bands formation in copper single crystals during plane-strain compression	367
Z. Jasieński and A. Piątkowski	
Flow stress anisotropy in commercially pure aluminium	373
D. Juul Jensen and N. Hansen	
Anomalous plasticity of high-purity LiF single crystals in the temperature range 0.55 to 4.2 K	379
H.-J. Kaufmann, S.V. Lubenets, V.D. Natsik, V.V. Pustovalov, L.S. Fomenko, and S.E. Shumilin	
Parameters of dislocation structures and factors determining flow stress at stages III and IV	385
N.A. Koneva, D.V. Lychagin, L.A. Teplyakova, and E.V. Kozlov	
Work-hardening of high purity single crystals of iron and iron-carbon alloys	391
J. Kumagai, S. Takaki, S. Suzuki, and H. Kimura	
The magnitude of the internal stress in a superplastic Pb-62% Sn alloy	397
Y. Ma, Z. Horita, and T.G. Langdon	

Macroscopic strain localization: Role of microstructural instabilities P. Martin, B. Baudelot, G. L'Espérance, A. Korbel, and J.H. Schmitt	403
Numerical simulation of the Portevin-Le Chatelier effect P.G. McCormick	409
The effects of surface films on mechanical behavior of B2 ordered intermetallic alloys R.D. Noebe, J.T. Kim, J.W. McVay, and R. Gibala	415
The relation between flow stress and dislocation structure in gallium antimonide M. Omri, J.-P. Michel, and A. George	421
Slip transfer across the grain boundary in Fe-3wt%Si bicrystals P. Sittner, P.P. Pal-Val, and V. Paidar	427
Strain hardening at large strains A.D. Rollett, U.F. Kocks, J.D. Embury, M.G. Stout, and R.D. Doherty	433
Microstructural influences on the plastic deformation of high chromium ferritic alloys M.P. Shaw, J.M. Robinson, I.M. Wolff, and A. Ball	439
Effect of grain size on the flow stress in terms of the dislocation density measured by resistivity J. Takamura and T. Narutani	445
Plasticity and microstructure of copper in stage IV - cold work hardening M. Zehetbauer, V. Seumer, and W. Witzel	451
Strain rate sensitivity of stress in Ni ₃ (Al,Ta) single crystals J. Stoiber, J. Bonneville, and J.L. Martin	457
Thermodynamics of open systems, self-organization, and crystal plasticity A. Seeger	463
The influence of plastic fronts on the limit load capacity of transversely bended beams in the light of experimental investigations L. Chodor and Z. Kowal	469
Texture and flow stress of cold-drawn aluminium alloys N. Hansen ja D. Juul Jensen	475
On the rule of mixtures for flow stresses of sandwich sheet metals D.N. Lee and Y.K. Kim	481
Plastic deformation of inhomogeneous materials with ellipsoidal inclusions N. Nagayama, T. Abe, and S. Nagaki	489
Deformation and precipitation influencing serrated flow E. Pink	495

**Microstructure and mechanical properties of industrial aluminium
alloys after rolling**

T. Tran Quoc and F. Louchet

501

Contents of Volume 2

4. Strengthening Mechanisms

The influence of pre-irradiation lattice defects on the flow stress of electron-irradiated α -iron Y. Aono, D. Brunner, and J. Diehl	509
Microscopic investigation of shearing and by-passing of coherent ordered δ' precipitates in Al-Li alloys Y. Bréchet and F. Louchet	515
Strengthening in Mo-33Re deformed to large strains J.A. Brusso, D.E. Mikkola, and R.N. Wright	521
Tensile and fatigue strength improvement of titanium PM alloys through microstructural refinement D. Eylon and F.H. Froes	527
High temperature deformation of dispersion hardened Al-Mg alloys S. Kikuchi, M. Uesugi, and M. Koiwa	535
Effect of hydrogen on the mechanical properties of iron-based alloys T. Kimura, H. Matsui, and H. Kimura	541
Grain boundary and γ' -hardening in the superalloy NIMONIC PE16 W. Mangen and E. Nembach	547
Precipitation hardening: an educational film E. Nembach, V. Ruth, K. Suzuki, M. Ichihara, and S. Takeuchi	553
Mechanical properties of aluminium after irradiation by 600 MeV protons F. Paschoud, R. Gotthardt, J.-L. Martin, D. Gavillet, W.V. Green, and M. Victoria	555
Precipitation of Al 1 % Ag single crystals F. Rabe and P. Haasen	561

The influence of microstructure on the strength and electrical conductivity of Cu-Ni-Be alloy A. Rotem, D. Shechtman, and A. Rosen	567
Solution hardening in Au-Ag and Cu-Ni alloy crystals H. Suzuki	573
Micromechanisms of grain-boundary strengthening in austenitic Cr-Ni-Mn heat-resisting steels during creep M. Tanaka, H. Iizuka, and F. Ashihara	579
Reverse temperature dependence of flow stress in precipitation hardened Cu-Ni-Al single crystals H. Tsuda, T. Ito, and Y. Nakayama	585
Effect of prior cold deformation on aging behavior of Al-2.73 wt-% Li alloy D.L. Sun, D.Z. Yang, Y. Hong, and T.C. Lei	591
Quench sensitivity of airframe aluminium alloys H.J. Kolkman, W.G.J. 't Hart, and L. Schra	597
Mechanical properties of graphite-aluminium base composites S.F. Mostafa, A.N. Abdul-Azim, T.A. El-Bassouuni, and A.M. ElSheikh	603
On the critical resolved shear stress of the superalloy NIMONIC 105 E. Nembach, S. Schänzer, W. Schröer, and K. Trinckauf	609
5. Cyclic Deformation and Fatigue	
Effects of high temperature sintering on the fatigue resistance of low alloyed PM-steel S.B. Biner	617
Dislocation arrangements and internal stress of dynamic creep in creep-fatigue interaction test of a Fe-Ni base superalloy G.L. Chen, Q.F. He, J. Li, Y.R. Ren, and W.Y. Yang	623
On the mechanism of fatigue crack growth in single crystals of a nickel-base superalloy O.Y. Chen and A.J. McEvily	629
A new exploration on fatigue diagram X. Chen, J. Ma, and Z. Lin	635
The influence of grain size on fatigue crack propagation in age hardened aluminium-alloys K. Detert, O. Ibáñez, and R. Scheffel	641
Influence of deformation structure on tensile and fatigue fracture in a fully pearlitic steel M. Dollar, A.W. Thompson, and I.M. Bernstein	647

Shear cyclic testing through tensile-compressive fatigue loading	
A.M. Eleiche, S. Abdel-Kader, C. Albertini, and M. Montagnani	653
The low cycle fatigue behaviour of a near alpha titanium alloy	
W.J. Evans	659
High cycle fatigue of polycrystalline Ni₃Al and Ni₃(Al,Mn)	
G.E. Fuchs and N.S. Stoloff	665
Evolutions of dislocation structures in type 316L stainless steel during plastic fatigue at 20, 300 and 600 °C in vacuum	
M. Gerland, B. Ait Saadi, and P. Violan	671
Threshold value at low crack growth rates	
K. Golos	677
Cyclic hardening and crack initiation in intermetallic compounds	
L.M. Hsiung and N.S. Stoloff	683
Improvement of low-cycle fatigue strength by serrated grain boundary	
H. Iizuka, M. Tanaka, and F. Ashihara	689
The effect of creep deformation on high temperature low cycle fatigue transgranular crack propagation in a Ni-based superalloy	
W.M. Laanemäe, K. Bothe, and V. Gerold	695
Fatigue behaviour of Ni-base alloys up to 1273 K	
K.-H. Lang, D. Eifler, and E. Macherauch	701
Influence of a cold working on the behaviour of a AISI 316 L stainless steel in low cycle fatigue	
H.P. Lieurade, A. Ribes, A. Dias, and J.L. Lebrun	707
Cyclic deformation of niobium single crystals	
T.L. Lin, J. Wu, and Z. Chen	713
The effect of temperature on cyclic saturation in copper	
O.B. Pedersen and L.L. Lisiecki	719
Fatigue crack growth for welded joint of 12CrNi3MoV steel in 3.5%NaCl aqueous solution	
R.-T. Liu and L.-J. Ma	725
The effect of surface microcracks on the cumulative damage during cyclic deformation	
T. Magnin and C. Ramade	731
Influence of ion implantation on cyclic behaviour and fatigue damage in mono and polycrystalline copper	
J. Mendez, P. Villechaise, and P. Violan	737
Crack initiation at grain boundaries in f.c.c. materials	
P. Neumann and A. Tönnissen	743
External current response in the corrosion fatigue test	
S. Nunomura, Y. Higo, M. Ono, and Y. Kayano	749

Dislocation structures in Al-1wt% Si polycrystals cyclicly deformed at constant plastic strain K. Pedersen and O. Lohne	755
Surface relief and dislocation structure in fatigued copper single crystal J. Polák and K. Orbtlik	761
Cyclic softening and microstructural changes in 1Cr-1.3Mo-0.3V-bainitic rotor steel K. Rahka, P. Nenonen, Z.-G. Wang, and C. Laird	767
Grain boundary processes in Pb-Sn solders V. Raman	775
Shape and behavior of small fatigue cracks A.W. Thompson	781
Cyclic deformation of [001]-aluminium single crystals M. Videm and N. Ryum	787
Cyclic stress-strain relation and cyclic yield behavior on cyclic deformation C. Wang, J.W. Tang, J.G. Wand, and S.P. Xu	793
The microstructure and fatigue behavior of a low carbon martensite steel J.Y. Wang	799
The effect of microstructures on fatigue crack propagation rate of die steels S.Q. Wang, X.Z. Feng, and S.J. Tian	805
Acoustic emission measurement as damage indicator in the microcrack initiation stage of a cyclically deformed Al-4 pct Cu alloy F. Zhang, P. Fleischmann, and R. Fougeres	811
Fatigue performance of cast arctic offshore steel OS-540 Vaculok J.I. Liimatainen, R.O. Katila, and H.O. Martikainen	817
Cyclic behavior and dislocation arrangements of single crystalline copper in constant and variable amplitude strain cycling V.-T. Kuokkala, T.K. Lepistö, and P. Kettunen	825
Fatigue threshold related to fatigue limit B.-P. Du and N. Li	831
A new design criterion of corrosion fatigue strength E.-H. Han, G.-C. Cui, and X.-J. Wu	837
On fatigue threshold of tempered martensite in low and medium-carbon Low-alloy steels N. Li and B.-P. Du	843
An approach to the study of physical parameters controlling fatigue damage accumulation in polycrystalline copper J. Mendez, M. Ghannouri, and P. Violan	849
The effect of substructure in surface strengthened layer on the fatigue strength of α-brass Y.X. Tan, L.P. Ren, and G. Li	855

6. Plastic Deformation at High Temperatures

Influence of the microstructure on the stress-rupture of the Al-Ni eutectic alloy M.H. Abdel Latif and M.A. Rizk	863
A theoretical consideration of some structural developments during diffusional creep J.B. Bilde-Sørensen and D.A. Smith	869
Subgrain boundary migration during creep of LiF M. Biberger and W. Blum	875
The effect of load changes on the creep behaviour of an AISI-316 stainless steel L.A.C. Bustamante, T.L. da Silveira, and R. Pascual	881
Creep properties of two different Mo base alloys (TZM) H.A. Calderon, G. Kostorz, and G. Ullrich	887
Effect of heat treatments on the anisotropic creep behaviour and deformation modes in a nickel-based single crystal superalloy P. Caron and T. Khan	893
Creep and stress relaxation behaviour of a Ni-based superalloy M. Ignat, M. Dupeux, and H. Rouault-Rogez	899
The steady-state creep behaviour of polycrystalline Zn-0.4wt%Ag over the temperature range 50 °C - 300 °C D.O. Northwood, A.J. Raiskio, and I.O. Smith	905
Modelling intergranular cavity growth by coupled diffusion and power-law creep J. Svoboda and J. Čadek	911
Structure-dependent intergranular creep fracture in iron-tin and iron-tin-molybdenum alloys T. Watanabe, T. Kuwajima, and S. Karashima	917
The relationship between microstructure and mechanical properties of a 9 % Cr, 2 % Mo, Nb, V ferritic steel J.C. van Duyzen and M. Guttmann	923
Plastic deformation behaviour of thin sheet nickel-base materials at temperatures up to 1473 K D. Viereck, G. Merckling, D. Löhe, O. Vöhringer, and E. Macherauch	929
Dynamic strain aging in alpha titanium and alpha zirconium P. Lukás and Z. Trojanová	935
The effect of zigzag grain boundaries on dislocation configurations of GH49 alloy in creep process Y. Zhang, Y. Wang, Z. Li, and C. Zhou	941
Boundary decohesion during high temperature creep deformation T.L. da Silveira, T.C.S. Silva, P.R. Costa, and I. Le May	947