

Lecture Notes in Applied and Computational Mechanics

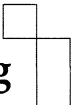
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Anisotropic Behaviour of Damaged Materials

Jacek J. Skrzypek
Artur W. Ganczarski (Eds.)



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Professor Dr. habil. JACEK J. SKRZYPEK
Dr. habil. ARTUR W. GANCZARSKI
Politechnika Krakowska
Cracow University of Technology
Institute of Mechanics and Machine Design
Solid Mechanics Division
Jana Pawla II, 37
PL-31-864 Krakow
POLAND

e-mail: skrzyp@cut1.mech.pk.edu.pl
e-mail: artur@cut1.mech.pk.edu.pl

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Forward

Damage Mechanics, a branch of solid mechanics, has been a subject of intensive studies at Cracow University of Technology just from the very beginning of its formation, shortly after famous paper by L.M. Kachanov, which appeared in 1958. Early works by S.Piechnik and his co-workers, who were stimulated by their Swedish colleagues F.K.G. Odqvist and J. Hult, flourished in the series of international conferences organised over last few decades by Cracow University of Technology (e.g. Summer School on Damage Mechanics Application, Janowice 1977, EUROMECH 251 Damage Mechanics and its Application, 1989). Numerous papers have been published in conference proceedings held world-wide, and submitted to international journals, finally resulting in recent monograph by J. J. Skrzypek and A. Ganczarski *Modeling of Material Damage and Failure of Structures*, Springer Berlin, 1999. It is worthwhile to mention also an active participation of our staff in organisation and frequent activities in this field, to mention IUTAM Symposium Creep in Structures, Cracow, 1990 and numerous CISM courses, Udine, 1987, 1998.

No wonder then, that this time conference organisers went further, attempting to deal with very advanced topics of damage mechanics. Anisotropy has drawn attention of researchers from the very beginning of modern solid mechanics. Let me quote here only the works by outstanding Polish scientist, professor M.T.Huber on anisotropic behaviour of plates published at the beginning of XX century. This line of research has been extended and profoundly developed by a group of Polish colleagues lead by J. Rychlewski. Related originally to elastic behaviour, the anisotropy was also studied with respect to the progressive failure of inelastic materials (as in a series of outstanding works by J. Betten, J.-L. Chaboche, J. Lemaitre, and S. Murakami to mention only few of them). In general, the problem is obviously complex, as such behaviour may result from two different reasons: initial material properties and damage induced anisotropy. The latter is of great interest, as in many materials, even those, which exhibit original material isotropy, an anisotropic damage development may change overall behaviour of a material. Therefore, strict relations with material science are necessary to study effectively these problems. In a long-term projection, one can even think on building structured materials with such an initial anisotropy which will be annihilated by damage induced anisotropy at the working regime. Finally, it is history dependence that makes this behaviour even more complex, and interesting to study.

I am very glad that my colleagues from Cracow University of Technology, co-operating with leading scientist of international community, attempted to contribute to the description of some of the above mentioned problems. Their practical importance seems to justify this effort. I do hope also the proceedings of this conference will stimulate further studies, and will strengthen our international co-operation in a future.

Professor Marcin Chrzanowski
Rector
Cracow University of Technology

Preface

The scope of this book is based on the keynote lectures delivered during the International Symposium on *Anisotropic Behaviour of Damaged Materials ABDM*, held in Kraków-Przegorzały, Poland, September 9–11, 2002.

The Symposium was organized by the Solid Mechanics Division of the Institute of Mechanics and Machine Design – Cracow University of Technology, under auspices of the Dean of the Faculty of Mechanical Engineering, Cracow University of Technology, Prof. S. Michałowski.

The Co-organizers of the ABDM Symposium were:

- Martin-Luther-Universität Halle-Wittenberg,
- Centre of Excellence for Advanced Materials and Structures AMAS at the Institute of Fundamental Technological Research of the Polish Academy of Sciences, Warsaw,
- Committee of Mechanics of the Polish Academy of Sciences, Warsaw.

Ten chapters of this book in their present form essentially exceed lectures delivered at the Symposium. They should rather be read as not only author's recent achievements in the field, but also the state of art and synthesis done by the leaders in the mechanics community. The mixed formula of the Symposium, namely: the invited lectures and presentations of the original papers by the participants was used. 23 original papers, published in the Symposium Proceedings on CD, exhaust the full scope of the ABDM Symposium.

The present book provides a survey of various damage models focusing on the damage response in anisotropic materials as well as damage-induced anisotropy. According to our experience there was a lack of such a book that would deal with the anisotropic damage mechanics with micro-mechanical aspects and thermo-mechanical coupling involved.

The book is divided into three parts. Part I *General description of anisotropically damaged materials* contains Chapters 1–4 on: the mathematical bases of tensor functions application to damage anisotropy (J. Betten, *Rhein.-West. Techn. Hochschule*, Aachen); the multi-scale damage mechanics (J.-L. Chaboche, *ONERA*, Chatillon, co-author N. Carrère); an alternative approach to anisotropic damage via critical plane concept (Z. Mróz, *IPPT PAN*, Warsaw, co-author J. Maciejewski) and a formal description of damage induced anisotropy (J. Grabacki, *Cracow University of Technology*, Kraków).

Part II *Phenomenological- and micro-mechanical-based approaches to anisotropic damage and fracture in brittle materials* includes Chapters 5–7 on: anisotropic elastic-brittle damage and fracture description based on irreversible thermodynamics (J. J. Skrzypek, *Cracow University of Technology*, Kraków, co-author H. Kuna-Ciskał); experimental and theoretical investigations of anisotropic damage in concrete and fiber reinforced concrete (A. Litewka et al., *Universidade da Beira Interior*, Covilha) and micro-mechanical damage model in rock-like solids (M. Basista, *IPPT PAN*, Warsaw).

Part III *Damage induced creep anisotropy of metallic materials under thermo-mechanical loadings* consists of Chapters 8–10 on: an extension of isotropic creep-damage theories to anisotropic materials (H. Altenbach, *Martin-Luther-Universität, Halle-Wittenberg*); experimental investigations of creep fracture anisotropy in weld metal at elevated temperature (T. H. Hyde et al., *University of Nottingham, Nottingham*) and non-classical problems of coupled thermo-damage fields (A. Ganczarski, *Cracow University of Technology, Kraków*).

To summarize the scope of this book as well as to briefly present other directions of research and future trends we decided to include to the book additional concluding remarks (M. Życzkowski, *Cracow University of Technology, Kraków*).

Acknowledgements

The editors of this book express their appreciations to all Invited Lecturers of the ABDM Symposium for a thorough work done when preparing chapters to this book, and for showing new directions for future development in the field of damage and fracture mechanics.

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- Prof. Z. Mróz (AMAS Co-ordinator) and Prof. W. Nowacki (Head of the IPPT PAN) for their invaluable supporting of the idea of the ABDM Symposium and the present monograph;
- Prof. H. Altenbach (Dean FB Ingenieurwissenschaften, Martin-Luther-Universität Halle-Wittenberg) for assistance when preparing the ABDM Symposium Program;
- Prof. M. Życzkowski (Cracow University of Technology) for preparing closing section of the ABDM monograph;
- Prof. J. Nizioł (Head of the Institute of Mechanics and Machine Design, CUT).

Special appreciations are offered to members of local organizing team, our colleagues from Solid Mechanics Division, Institute of Mechanics and Machine Design, Cracow University of Technology and in particular to: Dr. E. Cegielski for technical assistance to organize the ABDM Symposium; Dr. J. Bielski, who built the ABDM conference website <http://www.mech.pk.edu.pl/~m-1/abdm>; Dr. hab. B. Bochenek, who was responsible for the ABDM Symposium materials and publications; Dr. A. Wróblewski, the technical editor of this book as well as conference proceedings on CD. Finally, we express our gratitude to Ms. D. Skrzypek and Ms. E. Grzesik for their work done in the ABDM Symposium secretary.

Kraków, October, 2002

Jacek J. Skrzypek and Artur Ganczarski
Editors and ABDM Symposium Coordinators

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