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978-0-521-64684-0 - Fractography: Observing, Measuring and Interpreting Fracture Surface Topography
Derek Hull
Frontmatter
More information

Fractography:
observing, measuring and interpreting fracture structure topography

Fracture surfaces are produced by breaking a solid. The appearance of the surface, particularly the topography, depends on the type of material – for example, metal, polymer, ceramic, biomaterial, composite, rock, etc. – and on the conditions under which it was broken, for example, stress (tensile, shear, creep, fatigue, impact), temperature, environment (air, water, oil, acid), etc. This book describes ways of studying the surface topography using a wide range of techniques, and the interpretation of the topographical features in terms of the microstructure of the material and the way it was tested.

The level of interest and depth of understanding and interpretation in fractography vary from discipline to discipline. For that reason, the material in the book is presented at different levels and in a number of different ways. Each chapter opens with a feature image and an introduction highlighting important aspects treated in that chapter. Each chapter is copiously illustrated with line figures and half-tone images, accompanied by detailed captions describing the techniques used in obtaining the images. The main text is also supplemented by footnotes, which give additional technical details and the sources of information.

Fractography has numerous applications in a wide range of materials, and is particularly relevant in materials science and to inter-disciplinary subjects involving materials science, including physics, chemistry, engineering, biomimetics, earth sciences, biology and archaeology. This book provides the basis for an understanding of deformation and fracture in all solids, for interpreting fracture surface topography, and for design of clear and unambiguous experiments involving many aspects of fracture in a wide range of solids. It will be used by senior undergraduates, graduate students, researchers, industrial scientists and engineers and failure investigation engineers.

DEREK HULL has had a distinguished academic career in the Universities of Liverpool and Cambridge. His early research was carried out in the University of Wales, Cardiff, at the Atomic Energy Research Establishment, Harwell, and at Oxford University. He has held a number of Visiting Professorships and is a Fellow of the Royal Society and a Fellow of the Royal Academy of Engineering. He has consulted widely for government and industrial companies around the world. His two previous books on Dislocations and Composite Materials have been published in new editions with joint authors and are used extensively in undergraduate university courses in many countries. They have been translated into many languages. The present book draws on his research interests and benefits from the work of many of his research students and colleagues in a wide range of materials. He is Emeritus Goldsmiths' Professor of the University of Cambridge and his current affiliations are as Distinguished Research Fellow in the Department of Materials Science and Metallurgy, University of Cambridge and Senior Fellow, Department of Materials Science and Engineering, University of Liverpool, where he is continuing his research in fracture phenomena.

Fractography

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DEREK HULL

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Preface

Fractography is important in many fields of science and engineering. It is intrinsically interesting because it provides insights into the nature of the solid state that are not otherwise accessible. The basic premise is that the topography of a surface created by a growing crack is characteristic of the microstructure of the material and the test conditions. By observing, measuring and interpreting the fracture surface topography it is possible to determine many features of the microstructure of materials and the mechanics of crack growth.

The main result of a fractographic experiment is an 'image' of the fracture surface. This has to be translated into a three-dimensional impression of the surface topography. The process involves subjective factors. The quality of the image is a major factor in determining the effectiveness of the interpretation. In preparing this book every effort was made to obtain high-quality images, from a wide range of sources, and to reproduce them faithfully. The quality of images in books and journals is not always of a high standard and much important detail is lost in reproduction. Many authors kindly provided originals from their work. In some cases, good-quality images, that illustrate important aspects of the subject, are not available. These images are included even though the quality is poor.

The book is for anyone with an interest in the topography of fracture surfaces. The level is appropriate for senior undergraduate students, post-graduate and research students, researchers, teachers, industrial scientists and engineers, failure analysis investigators and lawyers. It includes topics from many disciplines. It is particularly relevant to the materials sciences and to inter-disciplinary subjects involving materials science – physics, chemistry, engineering, biomimetics, earth sciences, biology and archaeology. The book is a basis for understanding the deformation and fracture behaviour of all solids, for interpreting fracture surface topography, and for the design of clear and unambiguous experiments involving many aspects of fracture in a wide range of solids, from conventional engineering structural materials to naturally occurring solids.

The level of interest and depth of understanding and interpretation required in fractography vary from discipline to discipline and within a single discipline. This wide range of interests is accommodated by presenting the subject at different levels. The book should be used with this in mind. The first two pages of each chapter provide an introduction for those unfamiliar with the subject. A feature image highlights an important aspect that is treated in the chapter. Each chapter is illustrated with a large number of line drawings and half-tone images. These give a second level of approach. Extensive use is made of captions to describe the techniques used in obtaining images. The main text provides a third level of using the book. This is supplemented by footnotes. It is not necessary to read the footnotes to follow the text. The footnotes offer a fourth level and include details of sources of the information given in the main text. There is a list of references at the end of the book.

In the first chapter emphasis is given to the subjective nature of fractography and the need to recognise scaling relationships between microstructural features and topographical detail. It includes an introduction to some of the main features of fracture mechanics. In Chapter 2 the representation of fracture surface images in diagrams that illustrate the main features of the surface topography is described. This is essential for communicating fractographic information and for making quantitative measurements. The chapter includes descriptions of some of the main techniques used in fractography by reference to fracture surfaces that are readily interpreted and described because their shapes are familiar. The growth of cracks following three-dimensional, double-curvature surfaces, is described in Chapter 3. Such cracks are a significant feature of the fracture of brittle solids. The growth is constrained by the 'no-twist' rule. An account of the effect of stress fields that tend to cause evolving cracks to 'twist' and produce 'river line' patterns is given in Chapter 4. The influence of stress intensity and crack speed on the roughness of fracture surfaces is described in Chapter 5. The chapter includes an account of methods of measuring surface roughness at different scales.

In the next three chapters the emphasis is on fracture surfaces that are characteristic of materials with particular microstructural features and deformation characteristics; crystallographic cleavage is described in Chapter 6, interface and interphase crack propagation is treated in Chapter 7, and aspects of 'ductile' fracture are covered in Chapter 8. An account of the fractographic features that result when the conditions driving crack growth are alternating, as the crack grows, is given in Chapter 9. These features give direct evidence for the speed of growth and are particularly important in the interpretation of fatigue failures. Finally, in Chapter 10 the applications of fractography, ranging from microstructural analysis to failure analysis, are described.

The emphasis in the book is on the 'principles of fractography'. These relate primarily to the interaction between the stress conditions at the tip of a moving crack and the response of the material in the region of the crack. Many of the underlying concepts are accessible without addressing the detailed mathematical and analytical procedures that provide the foundations to the development of the subject. Because the book is about the principles, and is relevant to all solids, the approach to detail, which is necessary in presenting observations on specific materials, is by way of example. Thus, in Chapter 6 on the fracture of crystalline solids, the examples illustrate concepts that can be applied to a wide range of crystalline materials. Reference is made to sources of images in books and journals, particularly fractographic atlases, that provide a wider collection of images.

The emphasis on principles, and the factors that determine fracture surface topography, has influenced the way that related topics, such as fracture mechanics, microstructure and materials, and the techniques for observing and measuring fracture surface topography, are presented. All these topics are covered and are distributed throughout the book rather than in separate chapters. In this way it has been possible to provide a unified approach that transcends the boundaries determined by material groupings – metals, polymers, ceramics, biomaterials, rocks, composites, etc. and subject disciplines. It has also made it possible to transfer insights from one material discipline to another. Special mention must be made to microstructure. In many respects the detail of the fracture surface is unique to each material that is examined. It is assumed that readers have a knowledge of the microstructure of the materials in which they specialise.

Postscripts

There is a timelessness about fractography. Fracture surface studies have been made for hundreds of years. Even when Arthur C. Clarke's '3001 Odyssey' is fulfilled there will still be a need to evaluate structural failures, develop new materials and explore the inner structure of matter, even if it is on some distant planet.

At a more esoteric level, as with the patterns of nature that have inspired men to speak of God, the images from fracture surfaces reveal their own unique patterns that have a beauty of their own; but 'beauty is in the eye of the beholder'.

I am very conscious that I haven't done full justice to many excellent pieces of research involving fractography, up to this year, 1998. The 'image' of a fracture surface is often the most important experimental result. The advent of electronic imaging offers powerful new ways of collecting and communicating images but there is a real danger that access to high-quality images may be affected adversely.

Derek Hull

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My first thanks must go to the large number of research students and research staff who have worked with me at the Atomic Energy Research Establishment, Harwell, University of Liverpool and University of Cambridge over a period of more than 40 years. Together we have explored the mechanical behaviour of a large number of materials: metals, polymers, ceramics, composites and biomaterials. Fracture surface studies have usually been a small part of the overall research programmes but they have often been very significant. The PhD theses produced by my students provide a rich source of high-quality images of fracture surfaces. And so I offer my warmest thanks to Peter Beahan, Peter Beardmore, Tim Bessell, Mike Bevis, Bill Broughton, Brian Caddock, John Cordwell, Colin Gatward, Ratan Govila, Linda Hoare, Paul Hogg, Sue Huang, Mark Jones, Maciez Kumosa, Adrian Lowe, Ian Mogford, John Murray, Trevor Owen, Nick Price, Yibing Shi, Barry Shortall and Anne Valentine, whose work is represented by images included in this book. Many others of my research students have also contributed to the overall development of the work. Their help is gratefully acknowledged. I have also had the benefit of contributions from PhD students, in other Universities in this country and abroad, who have kindly sent me copies of their theses.

Over this long period my research has been generously supported by a wide range of national and international funding agencies and by industrial partners. Their contributions have made the research possible. I have greatly valued interactions with many colleagues in industry who have influenced the development of my research. My colleagues in the Universities of Cambridge and Liverpool deserve a special mention. One of the joys of University life is the opportunity to discuss research problems with groups of highly gifted people. I have been richly blessed by the friendship and support of so many; to all of them I say, thank you.

The book includes examples of important observations from researchers from all over the world. Many of these scientists and engineers are good friends and they have helped in the production of the book by searching their files for original copies of images and by generously agreeing to allow me to reproduce their work. The details are recorded in the text. I am particularly grateful to Edgar Andrews, Ron Armstrong, Harry Bhadeshia, Tony Ball, Cedric Beachem, Ed Beauchamp, Mike Bevis, Paul Bowen, Norman Brown, Jim Castle, Bill Clegg, John Currey, Athene Donald, John Field, Harvey Flowers, Klaus Friedrich, John Gilman, D. Heikens, Bernard Hockey, Vyvyan Howard, Pentti Kettunen, Wolfgang Knauss, Takao Kobayashi, Brian Lawn, Jack Mecholsky, Dale Meyn, David Oakley, Roy Rice, Rob Ritchie, Joachim Schneibel, Martin Seah, Yukka Seppälä, Don Shockey, Philip Shuff, Erwin Sommer, Kiyoshi Takahashi, Roy Taylor, Tom Thomas, Alexander Vasilev, Julian Vincent, Mark Welland, R. G. Whalley, David Williams, Mitchell Winnik, Bob Young and Jie Zhang. A special word of thanks to Mrs M. M. Plueddemann who graciously agreed to allow me to use images from Ed Plueddemann's work.

Many of the images used in the book were first published in scientific books and journals. The sources are given in full in the text. I am grateful to the following publishers for permission to reproduce these images: Fig. 5.20 Academic Press: Fig. 9.21 American Ceramic Society: Fig. 10.14 American Chemical Society: Fig. 6.10(a) American Institute of Physics: Figs. 5.13, 8.17, 8.40 and 8.41 ASM International®: Figs. 4.31, 5.15 and 9.1 ASTM: Figs. 1.5(a)(i), 1.5(a)(ii), 4.16, 5.16, 7.4(d), 9.10 and 10.32(a) Elsevier Science: Fig. 2.2 University of Chicago Press: Fig. 9.24 Geological Society of America: Fig. 8.23 Inderscience Enterprise Ltd: Fig. 10.5 International Union of Pure and Applied Chemistry: Figs. 6.34 and 6.38 IRSID Groupe Usinor: Fig. 9.8 Japanese Journal of Applied Physics: Figs. 1.5(c)(ii), 4.14(a), 4.21(b), 7.15, 7.16, 8.43 and 10.33 Kluwer Academic Publishers: Fig. 10.44 Institute of Materials: Fig. 10.20 Minerals, Metals and Materials Society: Fig. 7.19 Steinkopff Publishers: Figs. 5.1(a), 5.24, 6.17, 8.8, 8.16 and 9.2 Taylor and Francis: Fig. 6.16 La Revue de Métallurgie: Figs. 2.1, 7.18(a), 8.38 and 10.7 The Royal Society: Fig. 10.6 John Wiley and Sons, Inc.

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D.H.