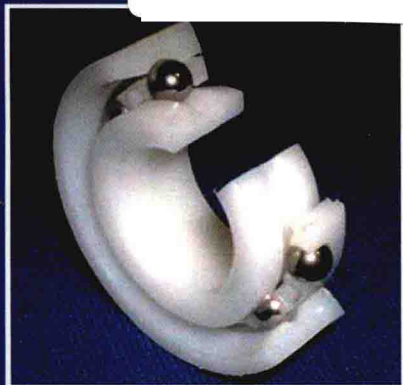


WOODHEAD PUBLISHING IN MATERIALS



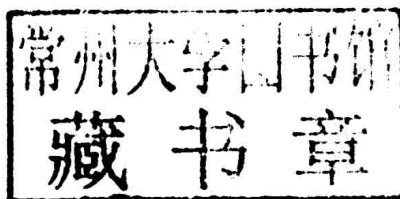
Wear of Polymers and Composites

Ahmed Abdelbary

WP
WOODHEAD
PUBLISHING

Wear of Polymers and Composites

Ahmed Abdelbary



AMSTERDAM • BOSTON • CAMBRIDGE • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Woodhead Publishing is an imprint of Elsevier



Woodhead Publishing is an imprint of Elsevier
80 High Street, Sawston, Cambridge, CB22 3HJ, UK
225 Wyman Street, Waltham, MA 02451, USA
Langford Lane, Kidlington, OX5 1GB, UK

Copyright © 2014 A. Abdelbary. 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, mechanical, photocopying, recording or otherwise without the prior written permission of the publisher. Permissions may be sought directly from Elsevier's Science & Technology Rights Department in Oxford, UK: phone (+44) (0) 1865 843830; fax (+44) (0) 1865 853333; email: permissions@elsevier.com. Alternatively you can submit your request online by visiting the Elsevier website at <http://elsevier.com/locate/permissions>, and selecting Obtaining permission to use Elsevier material.

Notice

No responsibility is assumed by the publisher for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. Because of rapid advances in the medical sciences, in particular, independent verification of diagnoses and drug dosages should be made.

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2014949288

ISBN 978-1-78242-177-1 (print)

ISBN 978-1-78242-178-8 (online)

For information on all Woodhead Publishing publications
visit our website at <http://store.elsevier.com/>

Typeset by RefineCatch Limited, Bungay, Suffolk

Printed in the United States of America



Working together
to grow libraries in
developing countries

www.elsevier.com • www.bookaid.org

Wear of Polymers and Composites

Related titles:

Science and engineering of short fibre reinforced polymer composites
(ISBN 978-1-84569-269-8)

Fail mechanisms in polymer matrix composites
(ISBN 978-1-84569-750-1)

Tribology of natural fiber polymer composites
(ISBN 978-1-84569-393-0)

This work is dedicated to the memory of
Professor M. N. Abouelwafa



Preface

One of the basics in our world is that the strong dominates the weak, not only in living organisms but also in solids. When two solids with relative motion interact with each other, a form of wear of the softer one appears. Wear can be a harmful phenomenon, but in some situations we allow a predetermined amount of wear to achieve desired functional objectives. Whilst it is affected by different factors, wear can be modified by various chemical and physical means to suit particular applications. In particular, wear of polymers and their composites present further complexity, as they are easily affected by operating and environmental conditions.

Presently, polymers and polymer composites have established themselves as valuable materials in numerous tribological applications. They have unique characteristics and represent an area of research interest, where classical tribology is not typically employed. Indeed, wear of polymers and their composites are debated in a limited number of books.

Wear of Polymers and Composites has been basically prepared for use by senior and graduate students of tribology, yet the author hopes the current work will be of interest to a larger pool of readers. The book, therefore, introduces fundamentals of polymer tribology and sliding mechanics. It establishes a link between load parameters and wear response, and shows how they are important in determining the mechanism of fatigue wear. Furthermore, a new approach to explore the effect of surface defects on the wear behaviour of polymers is introduced. On the other hand, it discusses the tribological characteristics of externally and internally lubricated polymers.

Wear of composite materials is also carefully discussed in the light of many publications. Different methods for polymer wear evaluation are described in terms of tribometer configurations, and controlled and measured parameters including procedures recommended in testing wear of polymeric materials. Fundamentals and capabilities of different well-known methods used in predicting wear of polymers are presented. In particular, an intelligent algorithm, in the form of the Artificial Neural

Network has been introduced to map the relationship between wear rate, applied loads, sliding conditions and number of surface cracks.

Overall, the book extends a summary of valuable pioneer and up-to-date publications established by a number of research workers in the field of polymer tribology. At the end of each chapter, relevant important references are presented in order to build a useful index for future needs. Hopefully, this book provides a comprehensive discussion and fair knowledge of the present understanding of wear of polymers and their composites.

A. Abdelbary

The organization of the book

This book is organized into eight chapters, each of which has a list of primary references that can be used from a historical perspective.

Chapter 1

The first chapter reviews the three branches of polymer tribology: *Wear*, *Friction* and *Lubrication*. Mechanisms and factors influencing wear behaviour of polymeric materials are discussed.

Chapter 2

The author discusses the attributes of the most common mechanisms that may accompany sliding wear of polymers. Formation of transfer film, wear debris and wear regimes, etc. are covered in the light of available literature.

Chapter 3

This chapter addresses the importance of fluctuating load parameters on wear of polymers. The effects of surface defects are carefully discussed.

Chapter 4

This chapter evaluates the effect of water lubrication on the sliding wear mechanisms of polymers. Particular emphasis is given to examination of the effect of the aqueous environment on wear resistance of polyamide 66 subjected to different loading modes.

Chapter 5

This chapter introduces a tribological study of internally lubricated polymers. An examination of friction and wear behaviour of polyethylene shows that the tribological characteristics are improved by silicone impregnation.

Chapter 6

This chapter presents a general overview of the definition, classification and failure of polymer composite materials. The author argues the factors

influencing wear behaviour of composites with the aid of available literature.

Chapter 7

This chapter argues the methodology of testing wear and reviews different tribometers. In this context, detailed design of a new reciprocating tribometer is introduced. Typical wear test procedures and preparation techniques are also elucidated.

Chapter 8

The author reviews different mathematical methods to predict wear behaviour of polymers and composites. A particular emphasis is given to the Artificial Neural Networks approach as a good candidate to such models.

Acknowledgments

First and foremost, I would like to express my sincere gratitude to *Prof. Dr. M. N. Abouelwafa* (Faculty of Engineering, Alexandria University), who has been instrumental in completing my post graduate degrees and has been my role model from the moment I started working with him until he died in 2013. He provided with intellectual and emotional support over the past 15 years, and has always been my greatest source of inspiration and encouragement. His contribution to my life is immense and cannot be acknowledged in words. I appreciate especially the manner in which he treated me as a son.

I was fortunate to have assistance from *Dr. Mohamed N. A. Nasr* (Ass. Prof., Faculty of Engineering, Alexandria University) for proof reading this book, and suggesting many changes. His invaluable mentorship and support were instrumental in completing this work.

I would also like to record my gratitude and thanks to *Prof. Klaus Friedrich*. His contribution to this work is immense and cannot be acknowledged in words.

I must also record another special tribute to my family. My parents, thank you for your love and constant support as I satisfy my own curiosity. My wife, *Gigi*, for your unfailing love, sacrifices, encouragement to fulfill my dream and consideration in my everyday life. Indeed, without my family's sacrifices and undying support I could have never fulfilled this work.

A. Abdelbary

Foreword

Tribology, i.e. the study of friction, lubrication and wear of interacting solids, has received increasing attention from the scientific, technical and practical points of view over decades. This is because the operation of many mechanical systems depends on their friction and wear performance. In addition, the annual dissipation of energy and waste of valuable raw materials resulting from high friction and wear is of great economical significance. Correspondingly, potential savings can be expected from improved tribological knowledge. In fact, in recent years, a variety of books have appeared which cover fundamental principles as well as application-related aspects of friction, lubrication and wear of materials.

The study of friction and wear is a very materials related discipline where each material may produce entirely different phenomena during contact sliding. The actual application conditions will decide the materials' performance in terms of the measured quantities such as the coefficient of friction, wear rate and the durability. The fact that tribology is an interfacial phenomenon, it also greatly depends upon the surrounding (environmental) factors such as the presence of contamination, oxide layer on the solid surfaces, thermal heat, external fluids and lubricants, in addition to the intrinsic chemical, physical and mechanical properties of the two interacting bodies and operational conditions of contact pressure and relative speed. There is another factor that may change the tribological performance of two bodies and that is the presence of loose debris materials that is ejected from either of the interacting bodies and this is known as the 'third-body'. With this background, tribology of polymers and their different modifications presents further complexity as polymers are easily influenced by the operating conditions and the prevailing environment. However, tribology of polymers is also a fascinating area because polymers can be modified by various chemical and physical means to suit a particular application. In addition, they are available in liquid, solid or semi-solid forms at room temperature and thus provide opportunities of their use as solid or liquid lubricants, low friction and wear resistant bulk solid or as films.

In fact, polymers and polymers composites are being used increasingly often as engineering materials for technical applications in which tribological properties are of considerable importance. In addition to the traditional fields (i.e. the use of reinforced rubbers for tires and transmission belts or of filled thermosetting resins as brake materials) polymers and polymer composites are well established in the field of bearing and slider materials. They are encountered in many different industries, e.g. automotive, aerospace, mining or biomedical. In all of these examples, a fundamental understanding of the interactions between the polymer-based components and the possible counterfaces can further enhance their potential application. This is why several books have already dealt with the subject of polymer tribology. However, more work needs to be done to reveal the physical and chemical nature of their tribological characteristics and to generate reliable data for design. Besides, most of these books have been mainly written for engineers and scientist who are already active in the field of tribology, and want to broaden and up-date their knowledge towards polymers and composites. On the other hand, there are not too many books especially dedicated to the education of senior and graduate students interested in this important issue.

The new text book by Prof. Ahmed Abdelbary on *Wear of Polymers and Composites* is therefore a good idea to fill this gap. After a comprehensive introduction into the field of polymer tribology, in which the possible types of wear and the factors affecting friction and wear of polymers are described, the author focuses the attention of the reader on the mechanisms occurring especially during sliding of polymers against metallic counterparts (i.e. the case mostly related to many applications). Two other important and application related subjects follow: 'Fatigue wear of unfilled polymers' (Chapter 3), and 'Wear of polymers in wet conditions'. (Chapter 4), Dr. Abdelbary then dedicates two other chapters to filled/reinforced polymers. In fact, polymer composites have been so successful in tribology that nowadays it would probably be hard to find a polymer for tribological application which is not in composite or even hybrid form. This work has further extended to the application of nano-sized fillers such as nano-clay, carbon nanotubes, nano-sized ceramic particles and so on, with further improvements in the friction and/or wear performances (also briefly touched on by the author). In the case of internally lubricated polymers, Dr. Abdelbary concentrates especially on silicone impregnated polyethylenes. The two concluding chapters are focused on the general 'Methodology of testing in wear' and on methods for 'Predicting of wear in polymers and their composites', with special emphasis on the use of artificial neural networks.

As mentioned earlier, this book is mainly intended to teach graduate students in the field of tribology in general and polymer friction and wear in particular. But undoubtedly it will also be of interest to other groups of scientists: (1) those who are active or intend to become active in research on some aspects of polymer composite tribology (material scientists, physical chemists, mechanical engineers); (2) those who have encountered a practical friction or wear problem and wish to learn more methods of solving such problems (designers, engineers and technologists in industries dealing with selection, processing and application of polymer engineering materials); and (3) professors at universities, who want to set-up new courses in this field. This is very important, since by now the average mechanical engineer receives only a few hours of instruction on wear during his university studies.

Kaiserslautern, 14th July 2014

Prof. Dr.-Ing. Dr. h.c. Klaus Friedrich

Retired Professor and Research Consultant

Institute for Composite Materials (IVW GmbH)

Technical University of Kaiserslautern

References

- Bartenev G M, Lavrentev V V (1981), *Friction and Wear of Polymers*, Elsevier, Amsterdam, The Netherlands.
- Bowden F P, Tabor D (1964), *Friction and Lubrication of Solids*, Clarendon Press, Oxford, UK.
- Friedrich K (ed.) (1986), *Friction and Wear of Polymer Composites*, Elsevier, Amsterdam, The Netherlands.
- Friedrich K (ed.) (1993), *Advances in Composite Tribology*, Composite Materials Series, Vol. 8 (series editor: R.B. Pipes), Elsevier Sci. Publ., Amsterdam, The Netherlands.
- Friedrich K, Schlarb A K (eds.), *Tribology of Polymeric Nano-Composites*, 2nd edition, Elsevier Butterworth-Heinemann, Amsterdam, The Netherlands.
- Glaeser D A (1981), *Fundamentals of Friction and Wear of Materials*, American Society for Metals, Metals Park, OH, USA.
- Sethuramiah A (2003), 'Lubricated wear', *Science and Technology*, Tribology Series, Vol. 42 (series editor: D. Dowson), Elsevier Science B.V., Amsterdam, The Netherlands.
- Sinha S K, Briscoe B J (2009), *Polymer Tribology*, Imperial College Press, UK.
- Stachowiak G W, Batchelor A W (2005), *Engineering Tribology*, 3rd edition, Elsevier Butterworth-Heinemann, Oxford, UK.
- Stachowiak G W, Batchelor A W, Stachowiak G B (2004), 'Experimental methods in tribology', Tribology Series, Vol. 42 (series editor: D. Dowson), Elsevier Science B.V., Amsterdam, The Netherlands.

- Uetz H, Wiedemeyer J (1985), *Tribologie der Polymere*, Carl Hanser Verlag, Munich, Germany.
- Yamaguchi Y (1986), *Tribology of Plastic Materials*, Tribology Series, Vol. 16, Elsevier, Amsterdam, The Netherlands.