

Metallographic Polishing by Mechanical Methods

Fourth Edition

Leonard E. Samuels

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About the Author

Leonard E. Samuels is probably best known for his fundamental studies of the mechanisms of grinding and polishing using abrasives and of the role of these processes in producing structural changes in the surface of metals. He has had a special interest in applying the scientific method to the preparation of surfaces for metallographic specimens. His classic treatise, *Metallographic Polishing by Mechanical Methods,* was first published in Australia in 1967. The American Society for Metals (now ASM International) published the third edition in 1982. This book is a welcomed fourth edition.

Leonard E. Samuels

Len Samuels, a native of Australia, studied metallurgical engineering at the University of Melbourne. When World War II broke out, the Australian government instituted strict manpower rules requiring engineering students to continue their studies. In his third year (1942), Singapore fell to the Japanese, and the government realized that it must increase its war production effort. The members of Len's class were asked to volunteer part of their school year at the Munitions Supply Laboratories and to join the staff upon graduation. Over the years, this laboratory has gone through several name changes and is currently known as the Aeronautical and Maritime Research Laboratory (AMRL), Defence Science and Technology Organization, Australia Department of Defence.

In 1943, Samuels received his bachelor's degree in metallurgical engineering and joined this lab. At that time, it was responsible for maintaining physical standards and for performing short-term research on problems related to defense equipment manufacture. AMRL was located, and still is, at Maribyrnong, a Melbourne suburb. But, in 1943, a branch was opened in Sydney (New South Wales), and Samuels was asked to join this facility. At that time, everything was in short supply. The Allied nations helped transfer technology and some of the needed equipment to produce locally what was needed.

By the end of World War II, Len was leading a branch of a large team of young physical metallurgists skilled in short-term research and knowledgeable in advanced materials of that era. But, projects had to be converted to peaceful applications in useful areas. So, at first, they started developing their research skills in specific areas that were believed to be important for the future. One result was publication of numerous papers in peer-reviewed journals. In 1958, the University of Melbourne awarded Samuels its David Syme Research Prize and Medal, which was its most prestigious research award open to scientists from all disciplines. "Sammy" received his M.Sc. degree in 1955 and his D.Sc. degree in 1959 from the University of Melbourne.

Sammy's personal choice for research (he did this part time as he was in charge of the overall organization) was to develop simpler, more reliable, scientifically based methods of metallographic specimen preparation. Although limited use had been made with diamond abrasives in preparing sintered carbides as far back as the 1920s, Sammy was the first, in 1952, to publish a preparation system for general application based on diamond abrasives. His work introduced actual quantified data on material removal rates rather than simply qualitative assessments.

This interest led Sammy and his coworkers to examine the mechanisms of abrasion and polishing processes and their effects on surface structure with the goal of establishing the principles that could be applied to reveal the correct microstructure as simply as possible. Introduction of artifacts during specimen preparation was a problem, and some published studies were based on false conclusions due to their presence. Sammy and his group investigated a number of such cases, always trying to be constructive at the same time. This work led to exploration of abrasive machining, machining in general, and studies of abrasive wear.

The parent laboratory in Maribyrnong did not follow with the same enthusiasm the post-war research trend instituted by Sammy for the Sydney branch but continued largely to draw upon the technology accumulated during the war years. As a result, the laboratory slowly declined in quality and prestige. Subsequently, a new chief superintendent was appointed, and Len was asked to join the parent laboratory and was promoted to superintendent of the Metallurgy Division in 1962. The program was designed to support the purchase and manufacture of defense-related equipment and to conduct vigorous research in the chosen areas of mechanical metallurgy, machining, casting, welding, heat treatment, corrosion and surface protection, and projectile-armor interactions. This division grew to a staff of about 100 engineers and technicians, the largest physical metallurgy group in Australia.

Supervising definitely curtailed Sammy's time to conduct research, but he did manage to write several excellent books. In 1980, the American Society for Metals published his book *Optical Microscopy of Carbon Steels*, which has been succeeded by his books *Metals Engineering: A Technical Guide* (ASM International, 1988) and *Light Microscopy of Carbon Steels* (ASM International, 1999). In 1981, he was appointed chief superintendent of AMRL, and he remained in this position until he retired in 1983. At that time, the laboratory had a staff of about 800 in four scientific divisions. As an internationally recognized metallurgist and metallographer, he has been a visiting staff member of the Australian Administrative Staff College, a Battelle Visiting Professor in Metallurgical Engineering at The Ohio State University, and an invited lecturer at many international conferences.

Among his numerous distinctions, Len Samuels is a former President of the Australian Institute of Metals and has been appointed a Member of the Order of Australia. Besides the Syme Award, he received the Florence Taylor Medal of the Institute of Metals and Materials Australasia in 1959, The Robert S. Leather Award of the American Electroplaters Society in 1960, and the Silver Medal of The Institute of Metals and Materials Australasia in 1972. He is an ASM fellow, the 1980 Sorby Award winner, and two-time recipient of the Buehler Best Paper Award for the best publication in *Metallography/Materials Characterization* (1981 and 1992). Besides ASM, he is a fellow member of the Australian Academy of Technological Sciences and Engineering, and the Institution of Engineers, Australia. In 1994, he was honored with the opening of the Leonard Samuels Laboratory for acoustics and vibrations at AMRL.

We are indebted.

George Vander Voort
November 2002

Preface to the Fourth Edition

Since the third edition of this book was published in 1982, seminal advances have been made in understanding the formation of inhomogeneous structures during the plastic deformation of metals at large strains. This has enabled clarification of a number of features of the formation and structure of the all-important deformed layer present on surfaces formed during metallographic abrasion and polishing processes. In particular, the periodic formation of bands of intense shear is now known to be intrinsic to the formation of machining chips, and it is inevitable that parts of these bands are incorporated in the new surface being generated. This has enabled clarification of a number of significant features of the layers and of the problems that consequently arise in the preparation of truly representative section surfaces. This is a feature that pervades and clarifies the entire text.

It has been known for some time that material removal during metallographic polishing using most abrasives occurs by micromachining, which differs essentially only in scale from that occurring during abrasion and grinding. Surface deformed layers that are shallower but have a similarly severely distorted structure are formed and can obscure the true structure. However, it has more recently been established that, when certain finer grades of diamond abrasive are used for polishing, material removal occurs by an entirely different, but as yet undefined, mechanism. It causes much smaller, almost inconsequential, changes to the structure of the surface. It consequently provides a method of final polishing that is simple to use and produces a surface that, although not perfect, is considerably superior to those obtained by other mechanical process.

A second new polishing process using extremely small spherical particles of silica has come into wide usage in recent years. It also acts by a mechanism different from micromachining, probably by inhibited chemical solution, and can be expected to produce a deformation-free, but slightly etched, surface. The fields of application of this process compared to more conventional mechanical processes are considered.

The net result of these advances is that it is now possible to devise manual preparation procedures that are much simpler than those previously used. Moreover, the structures then observed can be taken with greater certainty to be truly representative.

Apparatus for semiautomatic preparation of metallographic specimens has been a further major development in metallographic practices since the publication of the third edition. This has involved the development of new types of abrasion and polishing devices and new methods of applying abrasive to these devices. Although basic information on the factors that determine the effectiveness of these new processes is still limited, many aspects of their operation and application can be considered in terms of the information available on manual systems. Some principles governing the selection of procedures to use when preparing particular types of specimen materials are elucidated on this basis.

Much of the third edition material also has been updated and clarified where necessary.

L.E.S.
October 2002

Preface to the Third Edition

In its broadest sense, metallography is the study of the internal structure of metals and alloys, and of the relation of structure to composition and to physical, chemical, and mechanical properties. Many methods have been devised to determine internal structure, but microscopical examinations have always been among the more important. For most of the history of metallography, they have been carried out by means of the optical microscope. The optical microscope has been joined in more recent years by the transmission and the scanning electron microscope, both of which now play significant roles. Nevertheless, there still is, and seemingly always will be, a place for optical microscopy in both industry and research, just as there is still a place for the visual examination of hand specimens and macro-examinations at low magnifications.

Any examination to reveal the structure of metals by optical microscopy involves three distinct processes: the preparation of a sectioned surface; the development of the structure on this prepared surface by a suitable etching process; and the actual microscopical examination of the surface. The three stages form an integrated whole, and the achievements of the over-all process are inevitably limited by the lowest standard attained by any one of the three. No one stage can be overlooked, and arguments as to their relative importance are pointless.

This book is concerned with the first of the three stages—namely, surface preparation; even at that, it is concerned only with mechanical methods of surface preparation. The approach is based on the assumption that optical metallography is a sufficiently important laboratory tool to warrant serious attention and that it is a tool that will find its full usefulness only when it is given this serious attention. The over-all objective is to provide an understanding of underlying principles, so that each new problem met with in the laboratory can be solved intelligently rather than by relying on intuition or traditional recipes.

The present book is based on one with the same title previously published by Sir Isaac Pitman and Sons Ltd, editions being published in 1967 and 1971. It is, however, a greatly expanded and revised version, incorporating much new and previously unpublished information.

Acknowledgments

The investigations on which this book is largely based were carried out in a laboratory of the Australian Defence Science and Technology Organization currently known as the Aeronautical and Maritime Research Laboratories. Many colleagues and members of these laboratories made contributions to this work, but I should like particularly to acknowledge those made by the following: Mr. T.O. Mulhearn (deceased), Dr. (later Professor) M. Hatherly, Dr. E.N. Pugh, Dr. D.M. Turley, Dr. R.W. Johnson, Dr. (now Professor) E.D. Doyle, Mr. B. Wallace, and Dr. P.N. Dunn (deceased). Other laboratories have also provided assistance in more recent years, and I should like to record the assistance received from the BHP Melbourne Research Laboratories, the Herman Research Laboratories of the then Victorian State Electricity Commission, and the School of Physics and Materials Science and Engineering of Monash University. Dr. R.C. Gifkins, whose interest in quality light microscopy is at least the equal of my own, was a constant source of encouragement. I also acknowledge with particular gratitude the information and advice received from Mr. G. Vander Voort (Buehler Ltd.), Dr. K. Geels (Struers A/S), and Mr. T. Palmer (Radiometer Pacific Pty. Ltd.) on the operation of automatic preparation machines. A number of investigators have kindly allowed me to reproduce copies of their photographs, and their contributions are acknowledged at the appropriate positions throughout the text. I should like finally to acknowledge the valuable contribution made by the editorial staff of ASM International, particularly Nancy Hrivnak and Kathyrn Muldoon.

L.E.S.