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Foreword

The new edition of *ASM Handbook, Volume 8, Mechanical Testing and Evaluation* is a substantial update and revision of the previous volume. This latest edition of Volume 8 contains over 50 new articles, and the scope of coverage has been broadened to include the mechanical testing of alloys, plastics, ceramics, composites, and common engineering components such as fasteners, gears, bearings, adhesive joints, and welds. This new scope is also complemented by substantial updates and additions in the coverage of traditional quasi-static testing, hardness testing, surface testing, creep deformation, high strain rate testing, fracture toughness, and fatigue testing.

The efforts of many people are to be commended for creating this useful, comprehensive reference on mechanical testing. The ASM Handbook Committee, the editors, the authors, the reviewers, and ASM staff have collaborated to produce a book that meets high technical standards for the benefit of engineering communities everywhere. To all who contributed to the completion of this task, we extend our sincere thanks.

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Policy on Units of Measure

By a resolution of its Board of Trustees, ASM International has adopted the practice of publishing data in both metric and customary U.S. units of measure. In preparing this Handbook, the editors have attempted to present data in metric units based primarily on *Système International d'Unités* (SI), with secondary mention of the corresponding values in customary U.S. units. The decision to use SI as the primary system of units was based on the aforementioned resolution of the Board of Trustees and the widespread use of metric units throughout the world.

For the most part, numerical engineering data in the text and in tables are presented in SI-based units with the customary U.S. equivalents in parentheses (text) or adjoining columns (tables). For example, pressure, stress, and strength are shown both in SI units, which are pascals (Pa) with a suitable prefix, and in customary U.S. units, which are pounds per square inch (psi). To save space, large values of psi have been converted to kips per square inch (ksi), where 1 ksi = 1000 psi. The metric tonne ($\text{kg} \times 10^3$) has sometimes been shown in megagrams (Mg). Some strictly scientific data are presented in SI units only.

To clarify some illustrations, only one set of units is presented on artwork. References in the accompanying text to data in the illustrations are presented in both SI-based and customary U.S. units. On graphs and charts, grids corresponding to SI-based units usually appear along the left and bottom edges. Where appropriate, corresponding customary U.S. units appear along the top and right edges.

Data pertaining to a specification published by a specification-writing group may be given in only the units used in that specification or in dual units, depending on the nature of the data. For example, the typical yield strength of steel sheet made to a specification written in customary U.S.

units would be presented in dual units, by the sheet thickness specified in that specification might be presented only in inches.

Data obtained according to standardized test methods for which the standard recommends a particular system of units are presented in the units of that system. Wherever feasible, equivalent units are also presented. Some statistical data may also be presented in only the original units used in the analysis.

Conversions and rounding have been done in accordance with ASTM Standard E 380, with attention given to the number of significant digits in the original data. For example, an annealing temperature of 1570 °F contains three significant digits. In this case, the equivalent temperature would be given as 855 °C; the exact conversion to 854.44 °C would not be appropriate. For an invariant physical phenomenon that occurs at a precise temperature (such as the melting of pure silver), it would be appropriate to report the temperature as 961.93 °C or 1763.5 °F. In some instances (especially in tables and data compilations), temperature values in °C and °F are alternatives rather than conversions.

The policy of units of measure in this Handbook contains several exceptions to strict conformance to ASTM E 380; in each instance, the exception has been made in an effort to improve the clarity of the Handbook. The most notable exception is the use of g/cm^3 rather than kg/m^3 as the unit of measure for density (mass per unit volume).

SI practice requires that only one virgule (diagonal) appear in units formed by combination of several basic units. Therefore, all of the units preceding the virgule are in the numerator and all units following the virgule are in the denominator of the expression; no parentheses are required to prevent ambiguity.

Preface

At least three major trends have occurred since the last edition of Volume 8 in 1984. First, concurrent engineering is growing in importance in the industrial world, and mechanical testing plays a major role in concurrent engineering through the measurement of properties of product design, as well as for deformation processing. *ASM Handbook*, Volume 20, *Materials Selection and Design* (1997) reflects this focus in concurrent engineering and the broadening spectrum of involvement of materials engineers. Second, new methods of measurement have evolved such as strain measurement by vision systems and ultrasonic methods for measurement of elastic properties. This area will continue to grow as miniaturized sensors and computer vision technologies mature. Third, computer modeling capabilities, based on fundamental continuum principles and numerical methods, have entered the mainstream of everyday engineering. The validity of these computer models depends heavily on the availability of accurate material properties from mechanical testing.

Toward this end, this revision of *ASM Handbook*, Volume 8 is intended to provide up-to-date, practical information on mechanical testing for metals, plastics, ceramics, and composites. The first section, "Introduction to Mechanical Testing and Evaluation," covers the basics of mechanical behavior of engineering materials and general engineering aspects of mechanical testing including coverage on the accreditation of testing laboratories, mechanical tests in metalworking operations, and the general mechanical tests of plastics and ceramics. The next three sections are organized around the basic modes of loading of materials: tension, compression bending, shear, and contact loads. The first four modes (tension, compression, bending, and shear) are the basic simple loading types for determination of bulk properties of materials under quasi-static or dynamic conditions.

The third section, "Hardness Testing," describes the various methods for indentation testing, which is a relatively inexpensive test of great importance in manufacturing quality control and materials science. This section includes new coverage on instrumented (nano-indentation) hardness testing and the special issues of hardness testing of ceramics. Following the section on hardness testing, the fourth section, addresses the mechanical evaluation of surfaces in terms of adhesion and wear characteristics from point loading and contact loading. These methods, often in conjunction with hardness tests, are used to determine the response of surfaces and coatings to mechanical loads.

The next four sections cover mechanical testing under important dynamic conditions of slow strain rates (i.e., creep deformation and stress relaxation), high strain rate testing, dynamic fracture, and fatigue. These four sections cover the nuances of testing materials under the basic loading types but with the added dimension of time as a factor. Very long-term, slow rate of loading (or unloading) in creep and stress relaxation is a key factor in many high-temperature applications and the

testing of viscoelastic materials. On the opposite end of the spectrum, high strain rate testing characterizes material response during high-speed deformation processes and dynamic loading of products. Fracture toughness and fatigue testing are the remaining two sections covering engineering dynamic properties. These sections include coverage on the complex effects of temperature and environmental degradation on crack growth under cyclic or sustained loads.

Finally, the last section focuses on mechanical testing of some common types of engineering components such as gears, bearings, welds, adhesive joints, and mechanical fasteners. A detailed article on residual stress measurements is included, as residual stress from manufacturing operations can be a key factor in some forms of mechanical performance such as stress corrosion cracking and fatigue life analysis. Coverage of fiber-reinforced composites is also included as a special product form with many special and unique testing and evaluation requirements.

In this extensive revision, the end result is over 50 new articles and an all-new Volume 8 of the *ASM Handbook* series. As before, the key purpose of this Handbook volume is to explain test set-up, common testing problems and solutions, and data interpretations so that reasonably knowledgeable, but inexperienced, engineers can understand the factors that influence proper implementation and interpretation. Easily obtainable and recognizable standards and research publications are referenced within each article, but every attempt is made to provide sufficient clarification so that inexperienced readers can understand the reasons and proper interpretation of published industrial test standards and research publications.

In this effort, we greatly appreciate the knowledgeable guidance and support of all the section editors in developing content requirements and author recommendations. This new content would not have been possible without their help: Peter Blau, Oak Ridge National Laboratory; James C. Earthman, University of California/Irvine; Brian Klotz, General Motors Corporation; Peter K. Liaw, University of Tennessee; Sia Nemat-Nasser, University of California, San Diego; Todd M. Osman, U.S. Steel Research; Gopal Revankar, Deere & Company; Robert Ritchie, University of California at Berkeley. Finally, we are all especially indebted to the volunteer spirit and devotion of all the authors, who have given us their time and effort in putting their expertise and knowledge on paper for the benefit of others. This work would not have been possible without them.

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