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Volume 14B Metalworking: Sheet Forming

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Foreword

ASM Handbook Volume 14B on sheet forming is the second of two volumes on metalworking technology, following the publication of Volume 14A on forging and bulk forming in 2005. These two volumes reflect the continuing mission of the *ASM Handbook*[®] series to provide in-depth and practical engineering knowledge in areas of technological significance.

Like many major manufacturing operations, the technology of sheet-metal fabrication is being transformed in response to the competitive demands of a global economy and computer-aided engineering. Product and process design are becoming more integrated, and all stages of processing are being enhanced by computer technologies that help implement process-control strategies to reduce scrap and achieve net-shape forming capability on the shop floor. These advances involve the efforts of various technical communities, and ASM International is pleased to help disseminate their knowledge for the benefit of others in the economical manufacturing of effective products.

Thanks are extended to all the contributors and especially to Lee Semiatin, who, as Volume Editor, has championed this entire effort with his tireless devotion. Dr. Semiatin is to be congratulated and lauded for all his efforts in identifying and recruiting authors, directing the editorial activities of review and revision, and responding effectively in the development of both Volume 14A and 14B. His volunteer commitment is enormous, and we are indebted to Lee Semiatin.

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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, but 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 IEEE/ASTM SI-10, 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 IEEE/ASTM SI-10; 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

Since the 1988 publication of Volume 14, *Forming and Forging* (of the 9th Edition *Metals Handbook* series, subsequently renamed the *ASM Handbook* series in 1991), advances in the forming of sheet metals have focused on a number of new or improved processes, new materials, increasing utilization of flexible-manufacturing and rapid-prototyping techniques, and the application of sophisticated process models and process-control strategies. A number of these advances have been driven by the needs of mass production in the automotive industry, but also partly by niche markets such as aerospace. Inexpensive yet powerful, computing resources have emerged as an important element in process design and control, tooling development, and product-process integration.

Innumerable configurations can be produced from sheet by various fabrication operations such as bending, stretching, deep drawing, hole-making, and flanging. These distinct manufacturing processes are performed in various combinations to produce a finished part along with considerations for material savings and manufacturing ease. Currently, improvements in computational capability are having a significant impact on the cost-effective application, *integrated* engineering evaluation, and robust production of sheet-metal products. The increasing utilization of process-control strategies to reduce scrap and achieve net-shape forming capability during all stages of processing is also enhanced by computer technologies implemented on the shop floor.

This Volume provides a broad overview of sheet-metal fabrication technologies and applications. The intent is to cover basic concepts and methods of sheet forming and developments in forming technology. Since the late 1980s, a number of processes have been introduced and/or undergone substantial improvement. These processes include high-production superplastic forming of aluminum, the use of tailor-welded blanks in automotive manufacturing, increasing utilization of rubber-pad (hydro-) forming, and high-velocity metal forming. Recent advances in the forming of sheet metals also include increasing utilization of flexible-manufacturing and rapid-prototyping techniques. New advances are also being made in the forming of advanced high-strength steels and magnesium alloys. In addition, the evaluation and analysis of material formability is improving with new techniques, such as stress-based forming-limit criteria.

It is hoped that this publication provides a useful reference for the many practitioners in this vital industry. Many thanks go to the contributors, who volunteered their time and expertise in this endeavor. This work would not have been possible without them.

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