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Foreword

The inclusion of Volume 5A in the *ASM Handbook* series marks the first time a publication formally sponsored by an ASM International affiliate society has been incorporated into the series.

The Thermal Spray Society (TSS) published the *Handbook of Thermal Spray Technology* in 2004 under direction of the TSS Training Committee. In 2011, the TSS decided to update and revise the book at the same time ASM International wanted to expand *ASM Handbook*, Volume 5*, Surface Technology*. All involved agreed the quality of the TSS book was appropriate for the *ASM Handbook* series.

ASM Handbook, Volume 5A*, Thermal Spray Technology* provides an introduction to modern thermal spray processes including plasma spray, high velocity oxy-fuel, and detonation gun deposition; and a description of coating properties, their wear, corrosion and thermal barrier characteristics. Thermal spray technology helps to sustain our way of life by reducing energy consumption, providing environmental benefits, supporting human comfort, and reducing material waste. Development of more reliable and robust equipment technologies, along with improved particle diagnostic instruments, will help to move the thermal spray process from guesswork to more of a science, giving designers and end users more confidence in the long-term manufacturing capabilities of the thermal spray process. Applications already experiencing such growth include industrial gas turbines, biomedical devices, electronics and semiconductors, automotive, and alternative energy (electrical generation, heating, and transportation).

ASM International is grateful for the work of volunteer editors, authors, and reviewers who dedicated their time and expertise, particularly Robert C. Tucker, Jr. and Mitchell R. Dorfman, whose extensive leadership and knowledge of the thermal spray field have been critical to this project.

ASM International is also thankful to members of the American Welding Society's C2 Committee on Thermal Spray who served as technical reviewers.

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Preface

Thermal spray is a generic term for a group of coating processes used to apply metallic, ceramic, cermet, and some polymeric coatings for a broad range of applications. It is one of the most versatile technologies of the various coating technologies, capable of depositing virtually any material that does not decompose on heating to near or slightly above its melting point or is sufficiently malleable to be deposited at high velocity. Moreover, the coating material can be deposited on most surfaces including metallic, ceramic, many polymeric, and others, without significantly heating, and therefore changing the properties, of that surface. Thermal spray coatings have found applications in most industries, providing economical solutions to a host of wear, corrosion, thermal, and other problems or providing other unique characteristics to a surface.

This *ASM Handbook*, Volume 5A, is intended to provide basic information on thermal spray technology for engineers and technicians new to the field, as well as to serve as a primary reference for experienced practitioners. It should also be a valuable resource for materials, mechanical, aero, chemical, and other design and operations engineers, as well as others seeking solutions to surface engineering problems such as wear, corrosion, thermal or electrical conduction or insulation, or special surface functions such as lubrication, friction, or catalysis.

This *ASM Handbook*, Volume 5A, is an extensive revision and updating of the *Handbook of Thermal Spray Technology* prepared under the direction of the Training Committee of the ASM Thermal Spray Society and published by ASM International in 2004. It is the result of a great deal of time and effort by the TSS member volunteers who served as editors and authors of its divisions, and they are to be highly commended for their commitment and dedication to the project. All of the divisions were peer reviewed by experts in their various fields, and they too are to be commended for their efforts as are the several staff members involved in editing and compiling Volume 5A.

R.C. Tucker, Jr., PhD, FASM, TS HoF
Editor

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 (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.

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