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Standard Guide for Directed Energy Deposition of Metals[1]

This standard is issued under the fixed designation F3187; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 Directed Energy Deposition (DED) is used for repair, rapid prototyping and low volume part fabrication. This document is intended to serve as a guide for defining the technology application space and limits, DED system set-up considerations, machine operation, process documentation, work practices, and available system and process monitoring technologies.

1.2 DED is an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

1.3 DED Systems comprise multiple categories of machines using laser beam (LB), electron beam (EB), or arc plasma energy sources. Feedstock typically comprises either powder or wire. Deposition typically occurs either under inert gas (arc systems or laser) or in vacuum (EB systems). Although these are the predominant methods employed in practice, the use of other energy sources, feedstocks and atmospheres may also fall into this category.

1.4 The values stated in SI units are to be regarded as standard. All units of measure included in this guide are accepted for use with the SI.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The latest version of the specifications referenced below should be used, unless specifically referenced otherwise in the main document.

2.2 *ASTM Standards:*[2]

B214 Test Method for Sieve Analysis of Metal Powders

C1145 Terminology of Advanced Ceramics

D6128 Test Method for Shear Testing of Bulk Solids Using the Jenike Shear Tester

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E1316 Terminology for Nondestructive Examinations

E1515 Test Method for Minimum Explosible Concentration of Combustible Dusts

F327 Practice for Sampling Gas Blow Down Systems and Components for Particulate Contamination by Automatic Particle Monitor Method

F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing

2.3 *ISO/ASTM Standards:*[3]

52900 Additive Manufacturing—General Principles—Terminology

52921 Standard Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies

2.4 *ASQ Standard*[4]

ASQ C-1 Specification of General Requirement For A Quality Program

2.5 *AWS Standards:*[5]

A3.0/A3.0M Standard Welding Terms and Definitions

A5.01/A5.01M Procurement Guidelines for Consumables—Welding and Allied Processes

A5.02/A5.02M Specification for Filler Metal—Standard Sizes Packaging and Physical Attributes

[1] This guide is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.05 on Materials and Processes.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from American Society for Quality, P.O. Box 3005, Milwaukee, WI 53201-3005.

[5] Available from American Welding Society (AWS), 8669 NW 36 St., #130, Miami, FL 33166-6672, http://www.aws.org.

A5.14/A5.14M Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods
A5.16/A5.16M Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

2.6 *DIN Standard:*
DIN 4188 Screening Surfaces; Wire Screens for Test Sieves, Dimensions

2.7 *ISO Standards:*[6]
ISO 9001 Quality Management Systems: Requirements
ISO 6983-2 Numerical control of machines – Program format and definition of address words – Part 1: Data format for positioning, line motion and contouring control systems
ISO 565:1990 Test sieves – Metal wire cloth, perforated metal plate and electroformed sheet -- Nominal sizes of openings

2.8 *NFPA Standard:*[7]
NFPA 484 Standard for Combustible Metals

2.9 *OSHA Standards:*[8]
CFR Title 29, Chapter XVII, Part 1910 Occupational Safety and Health Standards
OSHA Standards Checklist: Volume 15 Welding, Cutting and Brazing

3. Terminology

3.1 DED Technology draws its terminology from several sources, particularly from the 3D printing and welding industries. Section 3.2 lists the terminology used in this guide, with many definitions referring simply to other standards issued by ASTM, ISO or AWS. Section 3.3 is then provided for the reader's convenience, re-listing some of the definitions most important to an understanding of DED so the reader of this guide does not have to cross-reference numerous other sources of information simply be able to read this guide. Please note, however, that the definitions given in 3.3 are NOT kept up-to-date as the official definitions of these terms. The reader needing the most up-to-date definition should reference the other sources listed.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *active gases, n*—gases, including those containing carbon dioxide, oxygen, hydrogen and, in some cases, nitrogen. Most of these gases, which in large quantities, would damage the deposit, when used in small, controlled quantities, can improve deposit characteristics.

3.2.2 *agglomerates, n*—cluster of primary particles held together by weak physical interactions.

3.2.3 *alloy, n*—see alloy, AWS A3.0/A3.0M.

3.2.4 *arc plasma, n*—an ionized gas, used in all arc welding process, through which an electric current flows.

3.2.4.1 *Discussion*—Arc processes suitable for DED are based ostensibly on the gas shielded processes, namely GTA, PA, PTA, and GMA, and variants thereof.

3.2.5 *as built, adj*—see *as built*, ISO 52900, and 3.3.

3.2.6 *build platform, n*—see *build platform*. **ISO/ASTM 52900**

3.2.6.1 *Discussion*—In ISO/ASTM 52900, the build platform of a machine is defined as the base which provides a surface upon which the building of the part/s is started and supported throughout the build process. In DED, the build platform can also be a component that is to be repaired, and may also be non-planar.

3.2.7 *capture efficiency, n*—fraction of powder ejected from the deposition head that is incorporated into the built structure. Usually expressed in percent.

3.2.8 *carrier gas, n*—gas, typically inert, used to transport the powder from the deposition head to the melt pool and also in some systems to assist the transport of powder from the storage system to the deposition head.

3.2.9 *cast, n—of a wire*, diameter of the circle formed by a length of wire thrown loosely on the floor.

3.2.10 *cladding, n*—see cladding, AWS A3.0/A3.0M.

3.2.11 *cross stream, n*—flow, normally of inert gas, directed perpendicular to the optical axis of the lens being protected.

3.2.12 *cycle, n*—single cycle in which one or more components, features or repairs are built up in layers in the build space of the machine. **ISO/ASTM 52900**

3.2.12.1 *Discussion*—DED is well suited to repair, feature addition and remanufacturing applications. Throughout this guide, the use of the terms "DED Build Cycle" and "DED Deposition Cycle" are synonymous, irrespective of whether a complete part is built, or a portion thereof, or a repair.

3.2.13 *defect, n*—see *defect*, Terminology E1316.

3.2.14 *deposition head, n*—the device that delivers the energy and feedstock to the melt pool.

3.2.15 *deposition rate, n*—see deposition rate, AWS A3.0/A3.0M.

3.2.16 *directed energy deposition (DED), n*—see ISO/ASTM 52900 and 3.3.

3.2.17 *feed, n*—a mechanism which delivers material, in the form of wire or powder, to the melt pool.

3.2.18 *filler metal, n*—see filler metal, AWS A3.0/A3.0M.

3.2.19 *flaw, n*—see *flaw*, Terminology E1316.

3.2.20 *focal spot, n*—see focal spot, AWS A3.0/A3.0M.

3.2.21 *functionally graded material, n*—depostied material that varies spatially in composition or structure, or both, resulting in corresponding changes in the properties of the material.

3.2.22 *gas metal arc (GMA), n*—see gas metal arc welding (GMAW), AWS A3.0/A3.0M.

3.2.22.1 *Discussion*—The word "welding" in the AWS definition conveys the joining of two or more pieces of material. As this is not the case for DED, the word "welding" is dropped. The remaining term characterizes the arc physics.

[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[7] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[8] Available from National Safety Council (NSC), 1121 Spring Lake Dr., Itasca, IL 60143-3201, http://www.nsc.org.