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Aditivna proizvodnja - Snovanje - Funkcijsko razvrščena aditivna proizvodnja (ISO/ASTM PRF TR 52912:2020)

Additive manufacturing - Design - Functionally graded additive manufacturing (ISO/ASTM PRF TR 52912:2020)

Technischer Bericht für die Gestaltung von additiv gefertigten, gradierten Bauteilen (ISO/ASTM PRF TR 52912:2020)

Fabrication additive - Conception - Fabrication additive à gradient fonctionnel (ISO/ASTM PRF TR 52912:2020)

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TECHNICAL REPORT

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Additive manufacturing — Design — Functionally graded additive manufacturing

Fabrication additive — Conception — Fabrication additive à gradient fonctionnel

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

ASTM International
100 Barr Harbor Drive, PO Box C700
West Conshohocken, PA 19428-2959, USA
Phone: +610 832 9634
Fax: +610 832 9635
Email: khooper@astm.org
Website: www.astm.org

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

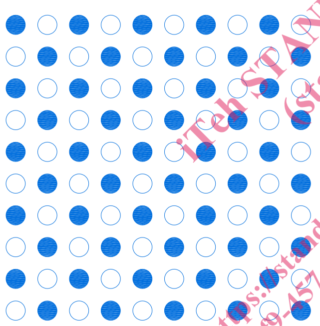
This document was prepared by ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM F 42, *Additive manufacturing technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on additive manufacturing and in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 438, *Additive manufacturing*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

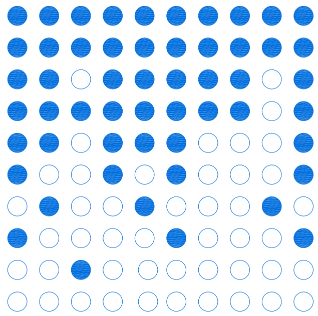
Introduction

Functionally Graded Materials (FGMs) were developed in 1984 for a space plane project to sustain high thermal barriers to overcome the shortcomings of traditional composite materials (AZO Materials, 2002). Traditional composites [Figure 1 a)] are homogeneous mixtures, therefore involving a compromise between the desirable properties of the component materials. Functionally Graded Materials (FGMs) are a class of advanced materials with spatially varying composition over a changing dimension, with corresponding changes in material properties built-in[56]. FGMs attain their multifunctional status by mapping performance requirements to strategies of material structuring and allocation [Figure 1 b)].

The manufacturing processes of conventional FGMs include shot peening, ion implantation, thermal spraying, electrophoretic deposition and chemical vapour deposition. Since additive manufacturing processes builds parts by successive addition of material, they provide the possibility to produce products with Functionally Graded properties, thereby introducing the concept often known as Functionally Graded Additive Manufacturing (FGAM). As this area of work is new, driven by academic research, and lacks available standardisation, there have been multiple different names proposed by different researchers in different publications as terms for this area, for example, functionally graded rapid prototyping (FGRP)[56], varied property rapid prototyping (VPRP)[57] and site-specific properties additive manufacturing[72]. However, even if there clearly is a great need for clarification of key terms associated with FGAM, this document does not include any attempts of alignment in terminology. This document is an overview of state of the art and the possibilities for FGAM enabled by present AM process technology and thus a purely informative document. Since this overview is based on available publications, and in order to facilitate cross referencing from these publications, this document has used the terms concerning FGAM as they are used in the original publications.



a) **Traditional composite**



b) **FGM composite**

Figure 1 — Allocation of materials in a traditional composite and an FGM composite

Additive manufacturing — Design — Functionally graded additive manufacturing

1 Scope

The use of Additive Manufacturing (AM) enables the fabrication of geometrically complex components by accurately depositing materials in a controlled way. Technological progress in AM hardware, software, as well as the opening of new markets demand for higher flexibility and greater efficiency in today's products, encouraging research into novel materials with functionally graded and high-performance capabilities. This has been termed as Functionally Graded Additive Manufacturing (FGAM), a layer-by-layer fabrication technique that involves gradationally varying the ratio of the material organization within a component to meet an intended function. As research in this field has gained worldwide interest, the interpretations of the FGAM concept requires greater clarification. The objective of this document is to present a conceptual understanding of FGAM. The current-state of art and capabilities of FGAM technology will be reviewed alongside with its challenging technological obstacles and limitations. Here, data exchange formats and some of the recent application is evaluated, followed with recommendations on possible strategies in overcoming barriers and future directions for FGAM to take off.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Abreviations

AM	Additive Manufacturing (see ISO/ASTM 52900)
AMF	Additive Manufacturing Format, see 8.4.2.1 (see ISO/ASTM 52900)
CAD	Computer Aided Design[48]
CAE	Computer Aided Engineering[14]
DED	Directed Energy Deposition, see Clause 6 (see ISO/ASTM 52900)
DMLS	Direct Metal Laser Sintering, the name for laser-based metal powder bed fusion process by EOS Gmbh[40]

EBM	Electron Beam Melting, the name for electron beam based metal powder bed fusion process by Arcam AB[40]
FAV	Fabricatable Voxel, see 8.4.2.2[19]
FEA	Finite Element Analysis[48]
FEF	Freeze-form Extrusion Fabrication, a material extrusion process based on the extrusion of feedstock in the form of pastes and application of freeze drying to form a green body which can be consolidated to the desired material properties by sintering. Presently only used for research and development projects.[34]
FEM	Finite Element Method[18]
FDM	Fused Deposition Modelling, name for material extrusion processes by Stratasys Ltd.[39]
FGAM	Functionally Graded Additive Manufacturing[61]
FGMs	Functionally Graded Materials[61]
FGRP	Functionally Graded Rapid Prototyping, name for FGAM used by Neri Oxman in some publications.[56]
LMD	Laser Metal Deposition, a common name for directed energy deposition processes that uses laser as the source of energy to melt and fuse metallic materials as they are being deposited, see Clause 6.[21]
LOM	Laminated Object Manufacturing, name of sheet lamination processes originally developed by Helisys Inc.[42]
MMAM	Multi-Material Additive Manufacturing, name used for AM when using more than one material in the same process.[61]
MM FGAM	Multi-Material Functionally Graded Additive Manufacturing, name for FGAM when the functional grading is based on building parts using more than one material in the same process, and the composition of the different material components is controlled by the computer program.[43]
PBF	Powder Bed Fusion (ISO/ASTM 52900)
SHS	Selective Heat Sintering, name of a powder bed fusion process that fuse polymer powder by means of a thermal printhead instead of the more common laser. The process was originally developed by Blueprinter but has been withdrawn from the market following the bankruptcy of this company.[40]
SLM	Selective Laser Melting, name for laser-based metal powder bed fusion process originally developed in collaboration between Realizer Gmbh and Fraunhofer Institute for Laser Technology. This name is currently a registered trademark of SLM Solutions Group AG but is also used by several other companies by license agreement.[40]
SLS	Selective Laser Sintering, name for powder bed fusion process originally developed by DTM Corp, but which has been assumed by 3D Systems by the acquisition of this company. Since this was the first powder bed fusion process to be commercialized, it has sometimes been used synonymously for all powder bed fusion processes.[40]
STL	Stereolithography, name for a digital file format for three dimensional solid models originally developed for the Stereolithography process by 3D Systems, hence the name. Since this conversion to this format has been commonly available in several CAD programs this file format has until present times effectively been functioning as a de-facto standard for AM processes. (see ISO/ASTM 52900)

UAM	Ultrasonic Additive Manufacturing, name for a metal sheet lamination process by Fabrisonic LLC. The process fuses thin sheets (or ribbons) of metal by ultrasonic vibrations.[43]
VDM	Vague Discrete Modelling[8]
VPRP	Variable Property Rapid Prototyping, name for FGAM used by Neri Oxman in some publications.[57]
3MF	3D Manufacturing Format, a digital file format for three dimensional solid models in additive manufacturing, developed by the 3MF consortium, see 8.4.2.3.[3]

4 The concept of Functionally Graded Additive Manufacturing (FGAM)

4.1 General

Additive Manufacturing (AM) is the process of joining materials to make *parts* from 3D model data, usually *layer* upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies (ISO/ASTM 52900). AM enables the direct fabrication of fine detailed bespoke components by accurately placing material(s) at set positions within a design domain as a single unit[76]. The use of AM has given opportunity to produce parts using FGM, through a process known as Functionally Graded Additive Manufacturing (FGAM). AM technologies suitable for the fabrication of FGMs include Material Extrusion, Direct-Energy Deposition, Powder Bed Fusion, Sheet Lamination[43] and PolyJet technology.

Functionally Graded Additive Manufacturing (FGAM) is a layer-by-layer fabrication technique that intentionally modify process parameters and gradationally varies the spatial of material(s) organization within one component to meet intended function.

FGAM offers a streamlined path from idea to reality. The emergence of FGAM has the potential to achieve more efficiently engineered structures. The aim of using FGAM is to fabricate performance-based freeform components driven by their graduated material(s) behaviour. In contrast to conventional single-material and multi-material AM which focuses mainly on shape-centric prototyping, FGAM is a material-centric fabrication process that signifies a shift from contour modelling to performance modelling. Having the performance-driven functionality built-in directly into the material is a fundamental advantage and a significant improvement to AM technologies. An example includes highly customizable internal features with integrated functionalities that would be impossible to produce using conventional manufacturing[5]. The amount, volume, shape and location of the reinforcement in the material matrix can be precisely controlled to achieve the desired mechanical properties for a specific application[18].

Reference [57] describes the concept of FGAM as a Variable Property Rapid Prototyping (VPRP) method with the ability to strategically control the density and directionality of material substance in a complex 3D distribution to produce a high level of seamless integration of monolithic structure using the same machine. The material characteristics and properties are altered by changing the composition, phase or microstructure with a pre-determined location. The potential material composition achievable by FGAM can be characterised into 3 types:

a) variable densification within a homogeneous composition;

b) heterogeneous composition through simultaneously combining two or more materials through gradual transition;

c) using a combination of variable densification within a heterogeneous composition.

These three types of characteristics are described in 4.2 and 4.3.