

# Chapter 13

## Functionally Graded Materials in Additive Manufacturing

### ABSTRACT

*This chapter provides a summary of progress in the field of FGAM. Given that this field is of recent origin, the methods and techniques to produce property grading is still fledgling. Therefore, the data to be presented for progress in two fields pertaining to the functional grading of metallic objects. These. Whereas, the 2nd<sup>o</sup> Categories are labeled according to the ingredients of the resulting object. As such, the first category pertains to efforts in producing Functionally Graded objects with only two ingredients. Whereas, the second category concerns objects made of multi-materials (more than two ingredient components)*

### INTRODUCTION

Functionally graded materials (FGM) denote a novel class of composite materials that is designed with a gradual composition or micro-structure changes that vary with position, or length scale, within an object. The dependence of the variation in composition, and or the resulting microstructure, on the location gives rise to grading of material properties. Conventional composite materials, i.e., materials which are formed by combining two materials of different properties, exhibit properties which may be, at least theoretically, more functionally efficient. This is because the resulting composite materials, a gain at least theoretically, can reflect properties that are a combination of the those of the ingredients. However, in practice, and due to drawbacks in traditional manufacturing methods, sharp transitions between dissimilar components may take place. The transitions practically act as barriers that are similar, and their effect on performance, to discontinuities within the bulk of a material. The presence of transitions potentially may induce a high state of stress concentration. Transitions may also cause the layers of the material to detach, i.e., the laminate upon the material being subject to multi-mode multi-axis loading. Mostly, the discontinuity within the material, or the sharp interface, may be eliminated efficiently by introducing a gradient-interface within the material. This is facilitated by appropriate grading of the

mixture that composes both material components. That is, efficiently grading the mixtures of the component materials leads to obtaining an FGM.

The class of Functionally Graded Materials is a member of the category of advanced materials. This category of materials reflects deliberate gradation-variation in both composition and structure in relation to changing their volume. The variation with respect to volume reflects on the properties of the material and how they value within a given domain of interest. The term material properties, to be noted, is not confined to traditional mechanical, thermal, and physical properties. Rather, change in properties may include shape changing properties. These may be purposely induced to manifest a preconceived variation behavior in relation to a specific set of application functions. The material can also manifest targeted she variation upon being subject to certain application conditions.

Variation in the functional performance of this group of materials, FGM, depends on their microstructural phases. Multi-functional aspects of this class of advanced materials, therefore, can be induced by introducing smooth transitions between the constituent phases. Introducing smooth transitions allow for a wide range of functional grading that suits a wide range of applications. Examples of such applications may include targeted response to particular stimuli (as in applications of 4-D printing). They also may entail targeted desire behavior in response to shocks (mechanical, thermal, and electric). Additional responses also include targeted responses to thermal loads, controlled expansion, and relaxation of thermal stresses.

The technology of 4-D printing builds on the foundation of the now familiar, 3-D printing. Initially it was defined in terms of time evolution of 3D printed structures, where the shape, property, or functionality of a 3D printed structure can change as a function of time. Although of very recent origin, a comprehensive definition has evolved with intense research. The emerging definition encompasses the promise of the technology as a feasible mean to achieve self-assembly, multi-functionality, and self-repair. Thus, in essence, it is a time dependent, printer-independent predictable technology.

Technically, the fourth dimension stands for enabling a printed object to morph in space along the preconceived path. This path is predesigned based on material choice and the environment dominant around the object. The foundation concept of morphing has evolved into a more generalized concept that projects a broader scope of the fourth dimension. This generalization extends to pre-control of property gradients while printing an object to grantee a pre-desire behavior. Control of properties, therefore, is the enabling tool that sets the path for the evolution of the objects and allow for morphing of shape in response to a triggering constraint (or stimulant).

The fundamental role of targeted grading of material properties is in effect the key to potential evolution of 4-D printing into maturity (given that the majority of the technical problems are overcome). In fact, functional grading has the potential to transform 4-D printing technology from a technology that produces objects that respond to specific stimuli to the production of objects of dynamic behavior that respond to a domain of changing operation conditions.

The conventional view of Additive Manufacturing (AM), concerns production of shapes using 3-D printing by means of a layer-by-layer material deposition scheme. Thus, traditionally, AM is concerned with the production of Three-Dimensional Objects of a predetermined shape. Functional Grading Additive Manufacturing (FGAM) is of a fundamentally wider and deeper scope. FGAM focuses on realizing a three-dimensional object of predesigned shape, however in contrast to “conventional” 3-D printing, the prime focus is on realizing a shape that manifests a predetermined structure-property relationship. Thus, the process of FGAM emphasizes simultaneous syntheses and densification of the 3-D object within prescribed guiding boundaries that realizes a pre-organized variation in the micro-structure, and

42 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:

[www.igi-global.com/chapter/functionally-graded-materials-in-additive-manufacturing/356037](http://www.igi-global.com/chapter/functionally-graded-materials-in-additive-manufacturing/356037)

## Related Content

---

### Innovative Business Models: Integrating Social, Economic, and Environmental Goals in Rural Manufacturing

Muhammad Usman Tariq (2025). *Rural Social Entrepreneurship Development: Network-Based Manufacturing System Model* (pp. 147-174).

[www.irma-international.org/chapter/innovative-business-models/373561](http://www.irma-international.org/chapter/innovative-business-models/373561)

### The Effects of Public Relations, Brand Image, and Identity on Small and Medium-Sized Enterprises: The Role of Reputation

Ebenezer Asare Effah, Michael Addai, Elikem Chosniel Ocloo, Divine Mawuli Akwensivieand Isaac Sewornu Coffie (2025). *Rural Social Entrepreneurship Development: Network-Based Manufacturing System Model* (pp. 465-492).

[www.irma-international.org/chapter/the-effects-of-public-relations-brand-image-and-identity-on-small-and-medium-sized-enterprises/373572](http://www.irma-international.org/chapter/the-effects-of-public-relations-brand-image-and-identity-on-small-and-medium-sized-enterprises/373572)

### Innovations in Device-to-Device Communication for Mechanical Tool Optimization

P. Sreenivas, Divakar Harekal, T. K. S. Rathish Babu, Sudheer Kumar Battulaand J. Ramya (2025). *Using Computational Intelligence for Sustainable Manufacturing of Advanced Materials* (pp. 511-532).

[www.irma-international.org/chapter/innovations-in-device-to-device-communication-for-mechanical-tool-optimization/376708](http://www.irma-international.org/chapter/innovations-in-device-to-device-communication-for-mechanical-tool-optimization/376708)

### AI-Enabled Robotics

A. Gobinath, Manjula Devi, P. Rajeswari, A. Srinivasanand Pavithra Devi (2024). *Using Real-Time Data and AI for Thrust Manufacturing* (pp. 1-19).

[www.irma-international.org/chapter/ai-enabled-robotics/343290](http://www.irma-international.org/chapter/ai-enabled-robotics/343290)

### Development of Nature-Inspired Algorithms for Intelligent Manufacturing Systems

Jatin Soniand Kuntal Bhattacharjee (2025). *Using Computational Intelligence for Sustainable Manufacturing of Advanced Materials* (pp. 205-236).

[www.irma-international.org/chapter/development-of-nature-inspired-algorithms-for-intelligent-manufacturing-systems/376696](http://www.irma-international.org/chapter/development-of-nature-inspired-algorithms-for-intelligent-manufacturing-systems/376696)