Chapter 2
Functionally Graded Materials

ABSTRACT

This chapter introduces the concept of FGMs, along with a review of applications of such materials, their history, and the "traditional" methods used for the production of such a class of materials. The problems and the potential of this class of materials within additive manufacturing (printing of metals), with particular reference to 4-D printing, would be the subject of the later chapters. The chapter also provides a targeted exposition of the methods used to process FGMs with a focus on powder processing-based methods due to their essential role in additive manufacturing.

INTRODUCTION

A functionally graded materials is a single, solid piece of material, which exhibits spatially varying material properties. In a functionally graded material, FGM, the properties change gradually with position. The term "functionally graded", therefore, implies an active interaction between functionality and property grading. It extends beyond a single material flow the term grading, yet it implies a single entity of which property grading targets specific functionality. Property grading is caused by a position-dependent chemical composition, microstructure, or atomic order. In the case of a position dependent chemical composition the gradient can be defined by the so-called transition function which describes the concentration of the components as a function of position. Thus, in essence, an FGM is a customized material that displays different tailored properties at different locations within the solid bulk. The properties are tailored to meet a target gradient variation profile in one property (or several properties) in order to fit a predesigned performance profile of an object. Typically, the perceived gradients, within such materials, aim at achieving gradual, and not abrupt changes, in the values of targeted properties. Gradual, and not abrupt, changes in material properties can contribute efficiently towards the reduction of failure and cancel contribute to preserving the structural integrity of surface and subsurface layers in many applications. As such, in principal engineering an FGM allows or avoiding, or normalization, of adverse effects arising during application in harsh environments. (e.g., stress concentration, thermal shock, thermal stress, etc.)

The design of materials for real life applications aims at meeting, or overriding, the effects of constraints that take place due to forces influencing the object within its operation environment (depending on the environmental conditions). In many applications, contact loads, and rubbing speed of an object lead to different sets of forces, and associated effects, may lead to failure of the material (and thereby

DOI: 10.4018/978-1-6684-5638-5.ch002

the object being used). In friction applications for example, a sliding object is subject to both static and dynamic forces. These arise because of contact loading, and friction forces. In addition, due to motion the friction forces release the energy associated with the work done due to sliding or rubbing. The material layers at the interface basically are subject to degradation due to the influence of these forces, their energy release, and the rate of that energy release. In addition, a sliding interface would undergo both mechanical and thermal strain, temperature rise, among other degrading effects. Meanwhile, due to the penetration of the thermal energy, temperature gradients toward the bulk of the material will take place. The temperature will affect the strength of the material and its subsurface layers, and depending on the rate of energy release, and consequently the temperature rise, a degradation in both thermal and mechanical properties will take place. The resulting gradients will affect load bearing limits, thermal transport mechanisms, and local failure limits. Assuming that the sliding material was originally of acceptable homogeneous composition, continuous sliding will lead to the evolution of inhomogeneity within the affected sliding layers. This inhomogeneity can locally limit the failure thresholds. Thus, local failure mode thresholds may vary considerably below the nominal failure limits of the particular material. A parallel scenario takes place in almost every field of application. This is because the physio-mechanical properties of materials are in essence affected by the active fundamental thermodynamic forces and the rate of application, or transmission, to each of the material layers affected in the particular application. Such an occurrence causes a wide variety of symptoms of material failure, both on the bulk and on the local levels.

This problem, therefore, have occupied designers and material developers since perhaps the dawn of engineering. Accordingly, there have been continuous efforts for remedies, both practical and conceptual, in order to enhance the structural integrity of objects and to meet harsh performance constraints.

The commodity of the developed solutions, their efficiency, practicality, and suitability for application or further development, depended on the technological level of the particular era. However, in essence, all solutions have shared a common fundamental principal: local customization of the active properties of the particular material to meet application constraints and their evolution. Diversity, however, came in attempts to materialize such a principle. This is because the level of application and quality of development, be it introduction of a new material, alloy, etc., or customization of the foundation structure of the particular material on the technological capabilities and the know-how level of the particular time.

In all, the concept of property customization is as ancient as engineering. Meanwhile, the level of sophistication has always depended on the technological level of the era. Is also to be noted, that as the technological level advanced, the quality and accuracy of the functionalization process itself leaped. This allowed more applications of the concept, and the new developed bulk materials, and many industrial venues, and across the board of material classes (e.g. metals, ceramics, polymers, etc.). Currently, the use of FGMs is being emphasized upon because of the effectiveness of materials designed along the guidelines of such constant. Applications range from aerospace to military and biomedical fields. Moreover, because of the advances in additive manufacturing, many entities are emphasizing the role the layer-by-layer deposition technique can play in materializing through benefits of FGMs.

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