RASĀYAN J. Chem.
Vol. 10 | No. 1 |149-152 | January - March | 2017
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

SUSTAINABLE DEVELOPMENT THROUGH FUNCTIONALLY GRADED MATERIALS: AN OVERVIEW

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ABSTRACT
Composite materials have contributed to a very large extent in solving these complex challenges. The reinforcement phase in composite materials is distributed uniformly, which results in homogenous properties. Recently the concept of functionally graded material (FGM) has arisen, where a new composite material is developed by varying the microstructure from one material to another material with a specific gradient. Functionally graded material (FGM) is a type of material whose composition is designed to change continuously within the solid. Hence it becomes a composite material with good specifications of both materials. The use of structures like beams, plates and shells, which are made from FG materials, is increasing because of smooth variation of material properties along preferred directions. This variation provides continuous stress distribution in the FG structures. Therefore an FGM can be effectively used in avoiding corrosion, fatigue, fracture and stress corrosion cracking. This paper presents a review of the recent developments in research carried out in FGMs. A detailed study of types of FGMs depending on nature of gradient is presented. Discussions are also made about the effective utilization of FGMs for sustainable development. In this regard, the focus is made in understanding the specific application of FGMs in civil engineering.
Keywords: Sustainable Development, Functionally Graded Materials, Composite Materials, Application of FGMs.

INTRODUCTION

The lightest weight composite materials with high strength/weight and stiffness/weight ratios have been used successfully in industries and other engineering applications. However, the traditional composite material is not successful when used under high-temperature environments, as there occur a reduction in strength of the metal in the high temperature. Recently, a new class of composite materials known as functionally graded materials (FGMs) has drawn considerable attention. In materials science functionally graded material may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. Within FGMs the different microstructural phases have different functions, and the overall FGMs attain the microstructural status from their property gradation.

Functionally graded materials are graded property materials and are used as medical implants, for thermal protection of space vehicles, as a thermoelectric converter for energy conservation etc. Due to their versatility of behavior, they are now used as Nano, optoelectronic and thermoelectric materials also. Future applications demand materials having extraordinary mechanical, electronic and thermal properties which can sustain different environment conditions and are easily available at reasonable prices. The carbon nanotubes (CNT) reinforced functionally graded composite materials (FGCM) is expected to be the new generation material having a wide range of unexplored potential applications[1] in various technological areas such as aerospace, defense, energy, automobile, medicine, structural and chemical industry. They can be used as gas adsorbents, templates, actuators, catalyst supports, probes, chemical sensors, Nano pipes, Nano-reactors etc. Typical Solids Mechanics equations assume the use homogeneous materials have uniformed properties. Significant research is being done[2] by Industry, Universities, and Federal Agencies to take more FGMs to the marketplace. An example of FGM is shown in figure-1, where spherical or nearly spherical particles are engraved within an isotropic matrix.

Functionally Graded Materials

The structural unit of an FGM is referred to as an element or a material ingredient. It is a conceptual unit for constructing an FGM that includes various aspects of its chemical composition, physical state and geometrical configuration. Generally, there are two main types of FGMs i.e. continuous graded materials and discontinuously graded materials. In the simplest FGMs, two different material ingredients change gradually from one to the other as illustrated in figure-2a. In the second type, the material ingredients change in a discontinuous way such as the stepwise gradation illustrated in figure-2b. A material can be considered to be an FGM even if the gradation of the material ingredients is limited to a specific location in the material[3] such as the interface, a joint, or a surface. As long as the material incorporates the FGM concept it can be categorized as an FGM. Therefore, an FGM can be produced from a homogeneous material and then processed with a different condition such as heat treatment and deformation.

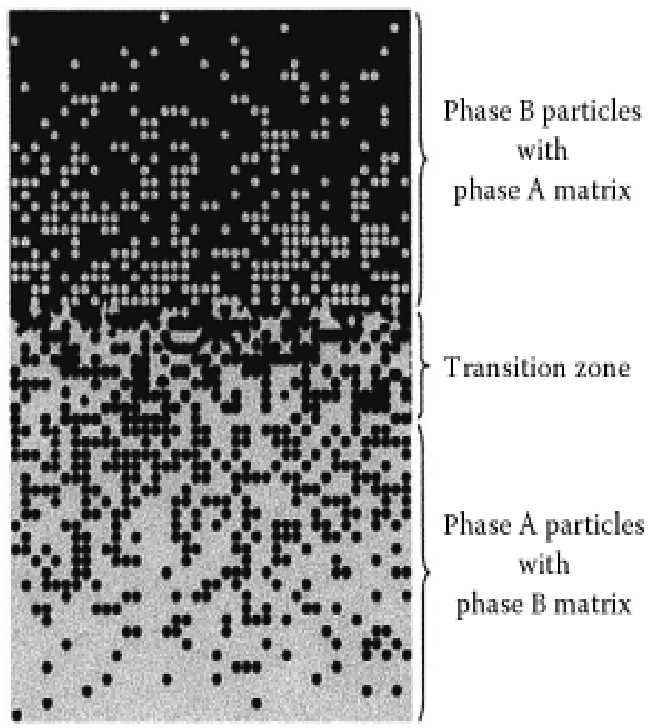

Fig.-1: An FGM with volume fractions of constituent phases graded in the vertical direction.

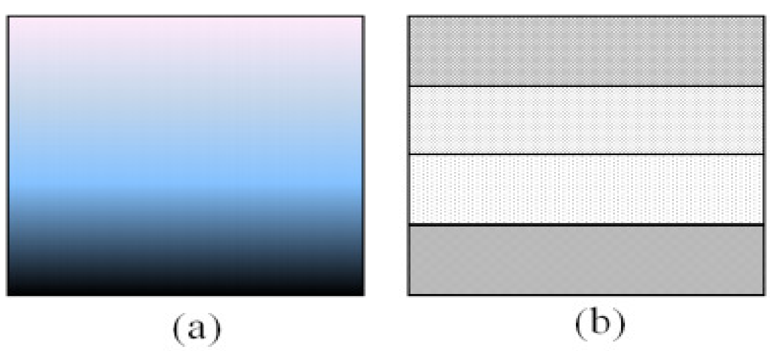

Fig.-2: (a) Continuous and (b) discontinuous.

There is a wide variety of processing methods to fabricate FGMs available today. The processing methods can be classified into those based on constructive processing and those based on mass transport. In the first class, the FGM is constructed layer-by-layer[4] starting with an appropriate distribution of the FGM"s constituents. These techniques are called constructive processes because gradients are literally constructed in space. Meanwhile, in the second class of FGM process, the gradients within a component depend on natural transport phenomena such as the flow of fluid, the diffusion of atomic species, or the conduction of heat. FGMs can be manufactured by centrifugal casting, sequential slip casting, thermal spraying, physical vapor deposition (PVD), chemical vapor deposition (CVD) and laser cladding.

Powder metallurgy, a constructive processing method, is one of the most important methods of producing FGMs. Generally, this method consists of three main steps. At first, materials desired in powder form are weighed and mixed. Next step is stepwise staking of premixed powder according to a predesigned spatial distribution of the composition. The last step is a sintering. By this method, the FGM fabricated usually have the stepwise structure[5] and it is difficult to produce the FGM with a continuous gradient. An example of natural transport phenomena method is a centrifugal method. FGMs are fabricated under a centrifugal force, by which it is possible to produce the FGMs with continuous gradients. Fabrication methods of FGMs under the centrifugal force[6] are classified into three categories, namely centrifugal method (application of centrifugal casting), centrifugal slurry method (centrifugal sedimentation) and centrifugal pressurization method (simple pressurization by the centrifugal force). In the case of the centrifugal method, a centrifugal force applied to a homogeneous molten metal, dispersed with ceramics particles or intermetallic compound particles, drives the formation of the desired gradation. The composition gradient is then achieved primarily by the difference in the centrifugal force produced by the difference in density between the molten metal and solid particles. It is known that the motion of particles in a viscous liquid under a centrifugal force obeys the Stokes' law. In contrast, slurry with two types of solid particles, high-velocity particle and low-velocity particle[7] is subjected to the centrifugal force during the fabrication of FGMs by the centrifugal slurry method. After complete sedimentation occurs, liquid part of the slurry will be removed, and therefore, it does not become a part of FGM. The third one is the centrifugal pressurization method, by which the centrifugal force is only used for simple pressurization. In this method, compositional gradation should be formed prior the application of centrifugal force.

FGMS in Civil Engineering

Nowadays the researches on FGMs have been carried out intensively. FGMs are also a concern in the other fields such as industrial materials, optoelectronics, biomaterials, and energy materials[8]. FGMs offer great promise in applications where the operating conditions are more. Potential applications include those structural and engineering uses that require combinations of incompatible functions such as refractoriness or hardness with toughness or chemical inertness with toughness. Applications of FGMs have significant advantages in civil and mechanical systems[9] including thermal systems (e.g. rocket heat shields, heat exchanger tubes, thermoelectric generators, wear resistant linings, diesel and turbine engines, etc.). Fiber-reinforced polymer (FRP) is another application of FGMs for reinforcing concrete materials as shown in Figure-3. The FRP materials improve the corrosion resistance of the steel and enhance the life cycle of the material strength.

Fig.-3: Fiber-Reinforced Polymer Bridge

Studies have proved that FGMs can be effectively used in multilayered pavement design. Research has also been carried out to obtain exact analytical solutions. Numerous research works have been carried out in vibration and dynamic solution of functionally graded shell panels with rectangular plan form only. The following conclusions are drawn regarding the free and forced vibration response of different types of functionally graded shells by varying different geometric and material parameters.

- Increase in skew angle (α) exhibit higher frequency and hence ensures minimum displacement. Also, shell with skew angle 30º gives the maximum axial stress.
- Spherical skew shell establishes better performance in vibration and transient response compared to the cylindrical skew shell when boundary condition and geometric properties are kept constant.
- Skew shell with clamped boundary shows higher frequency than a shell with simply supported boundary, due to the high rigidity in the first case.

CONCLUSION

The functionally graded material is an excellent advanced material that will revolutionize the manufacturing world. Lots of studies have been conducted on the behavior of functionally graded materials and the literature is very rich on this because of the wide areas of application of this novel material. The cost of producing these materials makes it prohibitive in some applications. A detailed study on types of FGMS, processing methods to fabricate and the advantages of FGMs are given in this paper. Attempts are also made to understand the application of FGMs in various fields of engineering. Recent research work carried out in the field of functionally graded shell panels are also mentioned in this paper. Since the FGMs are produced to achieve a certain property requirement in particular positions of a component, it is preferable to work out an inverse design in developing the functionally gradient materials for the specific application or component. There is long potential for the development of new functionally graded composites and new processing methods. As the processing parameters vary from system to system, there is a wide future to optimize these parameters.

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[RJC-1578/2017]