CHAPTER 1

INTRODUCTION

1.1 FUNCTIONALLY GRADED MATERIALS

Functionally graded material (FGM) is an inhomogeneous material or heterogeneous composite material, in which the material properties are varied continuously from point to point. For example, a plate structure used as a thermal barrier may be graded through the plate thickness from ceramic on the face of the plate to metal on the other face. This is achieved by varying the volume fraction of the constituents, i.e., ceramic and metal in a predetermined manner. The ceramic constituent of the material provides the high temperature resistance due to its low thermal conductivity. The ductile metal constituent, on the other hand, prevents fracture caused by stresses due to high temperature gradient in a very short period of time. A mixture of the ceramic and a metal with a continuously varying volume fraction can be easily manufactured. This eliminates interface problems and thus the stress distributions are smooth. The advantage of using these materials is that they can work in environments with high temperature gradients, while maintaining structural integrity.

1.2 FGM AND COMPOSITES

FGMs are improved materials from the composites. Fiber-reinforced composites have a mismatch of mechanical properties across an interface due to two discrete materials bonded together. As a result, the constituents of fiber-matrix composites are prone to debonding at extremely high thermal loading. Further, cracks are likely to initiate at the interfaces and grow into weaker material sections. Additional problems include the presence of residual stresses due to the difference in coefficients of thermal expansion of the fiber and matrix in the composite materials. These problems can be avoided or reduced by gradually varying the volume fraction of the constituents rather than abruptly changing them across an interface. This gradation in properties of the material reduces thermal stresses, residual stresses, and stress concentration factors. Furthermore, the gradual change of mechanical properties can be tailored to different applications and working environments. Such materials, termed functionally graded materials (FGMs), were first introduced by a group of scientists in Sendai, Japan in 1984.

1.3 APPLICATIONS OF FGM

FGMs are used in a wide variety of specific application requirements. Two of the most widely used applications are as follows (Liu etal 2001):

- In a rocket motor casing, the inside is made of a refractory material, the outside is made of a strong metal, and the transition from the refractory material to the metal is gradual through the thickness.

- Gas turbine blades having inner cross section made of ceramic material to withstand temperature upto 1400°C and outer cross section made of metal to withstand very high pressure upto 250 N / mm^2.

1.4 BASIC STRUCTURE OF FUNCTIONALLY GRADED MATERIAL

The general structure of the FGM is shown in Figure 1.1. It consists of two material phases. The top surface is made of pure ceramic to withstand high temperature and the bottom surface is made of pure metal to withstand mechanical loading. Figure 1.2 shows the linear variation of the volume fraction of the constituents i.e., metal and ceramic, from one face to the other face (Reddy 1999).

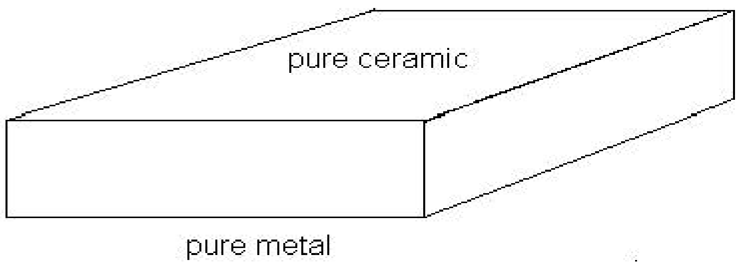

Figure 1.1 Basic structure of functionally graded material plate

Various types of graded microstructure of FGM are listed below:

(i) Continuously graded microstructure

(ii) Discretely graded microstructure

(iii) Multiphase graded microstructure

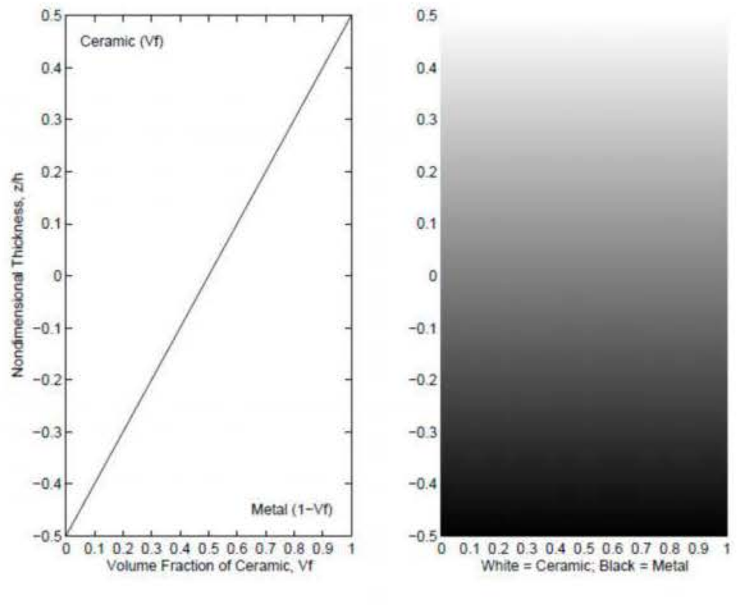

Figure 1.2 Variation of volume fraction of constituents across thickness of FGM

1.4.1 Continuously Graded Microstructure

In the continuously graded microstructure, the ceramic phase is 100% at the top and the metallic phase is 100% at the bottom. The ceramic matrix with metallic inclusions and metallic matrix with ceramic inclusion are shown in Figure 1.3 (Reddy 2005). The law of variation of constituents can be expressed as shown in equation (1.1) (Reddy 2005), where 'n' is referred as index for variation of metal across ceramics or material constant.

$$P_e(z) = P_C V_C + P_M (1 - V_C) \qquad (1.1)$$

where $V_C = \left(0.5 + \frac{z}{h}\right)^n \quad (-h/2 \le z \le h/2,\ 0 \le n \le \infty)$

V_c = Volume fraction of ceramic constituents

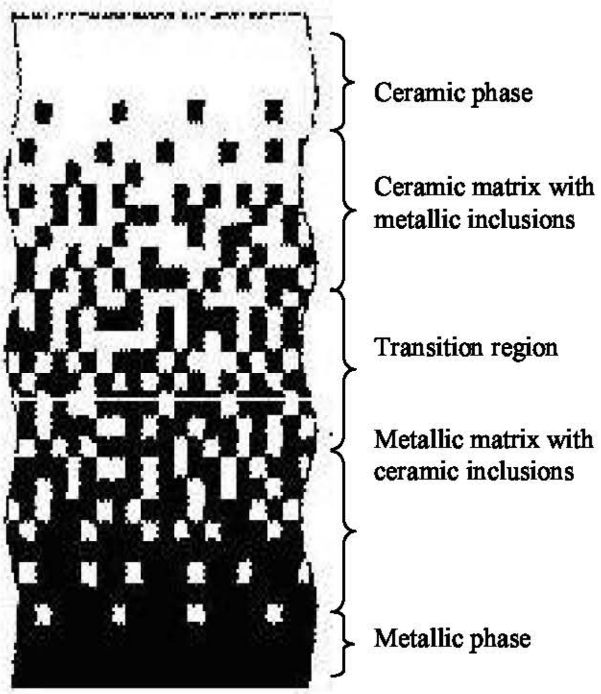

Figure 1.3 Continuously graded microstructure

In the equation (1.1), z is referred as coordinate in the thickness direction of the plate. P_e is the effective material property of the FGM. P_C and P_M are the properties of ceramic and metal respectively. 'h' is the thickness of the FGM plate. 'n' is the volume fraction exponent. It is known that the material is isotropic within the plane, which is normal to the z-axis. In case of isotropic ceramic n = 0 and $P_e = P_C$ and in case of isotropic metal $n = \infty$ and $P_e = P_M$. Figure 1.4 shows the variation of the volume fraction function with respect to non-dimensional thickness (z/h) for different values of index 'n'.

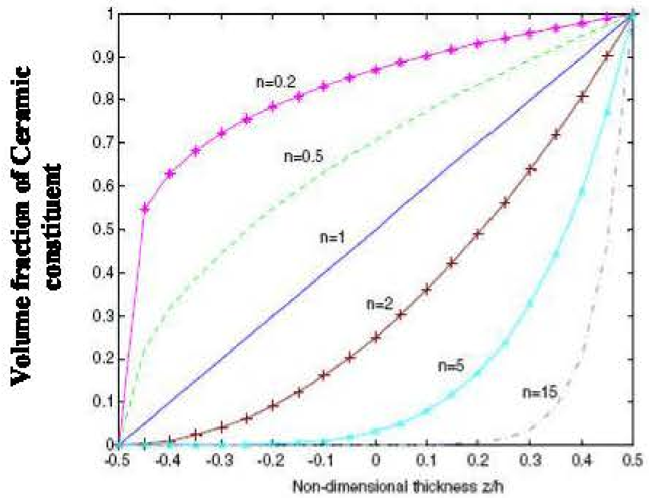

Figure 1.4 Variation of the volume fraction with respect to non-dimensional thickness

1.4.2 Discretely Graded Microstructure

The discretely graded microstructure is shown in Figure 1.5 (Reddy 2005). The functionally graded microstructure is obtained by the inclusion of the ceramic in the metallic matrix in a discrete manner.

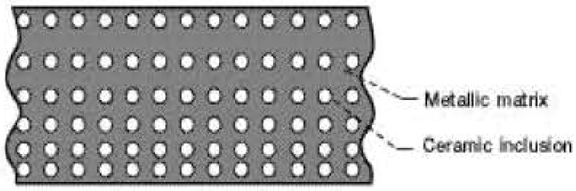

Figure 1.5 Discretely graded microstructure

1.4.3 Multiphase Graded Microstructure

The multiphase graded microstructure is obtained by inclusion of the metallic material in different phases. The multiphase graded microstructure is shown in Figure 1.6 (Reddy 2005).

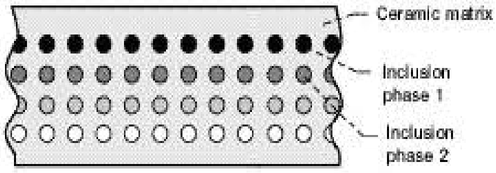

Figure 1.6 Multiphase graded microstructure

In order to compare the present results with the available results in the literature, analysis of FGM with continuously graded microstructure is attempted in the present study.

1.5 THERMO MECHANICAL ANALYSIS

In general, the FGMs are subjected to thermo-mechanical loads. The thermo-mechanical analysis of functionally graded materials involves the calculation of deflection, mid-plane stresses, mid-plane temperature and natural frequency of vibration due to the application of thermal, mechanical or thermo-mechanical loadings. Presently finite element methods and some of the mesh free methods are being used for solving the governing equations of these problems.

The results from the finite element methods are an approximate solution and the order of approximation will increase with the complexity of the problem domain and geometry whereas mesh free methods are more suitable for regular geometry of the problem domain.

1.6 ORIGIN AND BACKGROUND OF THE PROBLEM

Plates and shells are common engineering structures. Tapered plates are used in places where strength is to be added by reducing the weight. An example is a tapered cantilever beam.