A 2D FEM model to show the variation in particle distribution in a Functionally Graded Materials (FGMs) with random distribution of particles

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Abstract

The properties of FGMs are being investigated experimentally as well as by the modeling techniques in the recent past. The estimation of local as well as global properties of FGMs with the help of a simple model is still a challenge. A reliable estimation of deformation behavior of FGMs is important to make these materials popular for industrial use. FGMs have also been modeled in the past using the unit cell models, originally developed for the uniform composites. FGMs also have more or less random microstructure at the local scale like uniform composites. Particles are distributed randomly on the local scale. The type of gradation in the particle content is also important in context to FGMs. The global as well as local behavior of FGMs should depend on the type of gradation in FGMs. In this context it is important to suggest a model for FGM which incorporate the variation in particle distribution with random distribution of particles. Functionally Graded Material models with randomly distributed particles containing different amounts of particles have been obtained in the present modeling technique.

Keywords: Functionally Graded Material, Modeling, FEM, Polynomial

Introduction

In many demanding applications such as aviation, spacecraft, automobile, electronics and cutting tools, there are often contradictory property requirements in components like very high hardness, heat resistance and high wear resistance along with fairly good ductility and toughness. Homogenous materials like monolithic alloys may not be suitable because different properties may be required in different locations in the components. For example, wear resistance is required in the surface region which may require high hardness but if the same hardness is there even in the bulk the toughness and ductility may be seriously impaired. Thus, surface modification or coating evolved for imparting the required properties at the surface, distinctly different from that of the bulk. But this type of combination of surface and bulk often has different deformation characteristics resulting in development of intense shear stress leading to failure. The recent catastrophe in the space shuttle Columbia due to detachment of ceramic tiles reminds us of danger of combining two materials of dissimilar thermal and mechanical characteristics.

Functionally graded metal-ceramic metal matrix composites or functionally graded materials (FGMs), selectively reinforced at one surface by ceramic particles are a promising response to these specific application requirements. FGMs provided with heat-resistance and hard ceramics on the high-temperature side and tough metals with high thermal conductivity on the low-temperature side and gradual change from ceramic to metal in between, are capable of withstanding severe thermo-mechanical loadings. Weight saving is another prime requirement in the aerospace applications. Functionally graded aluminum-ceramic MMCs may be the appropriate materials for these requirements.

Modeling of Functionally Graded Materials

For modeling the functionally graded materials, a square area with an edge length 5 mm is considered. This area is meshed with four node plane42 square elements, with an edge length of 50 μm. Thus the whole model consists of 10000 square elements with 50 μm edge length. Out of these elements 10000*V_f elements are randomly selected in a way that the concentration of these elements in the model is as per the gradation of the particles desired. Here, V_f is the average particle volume fraction in the FGM. These selected elements are assigned particle material property and the rest of the elements are assigned the matrix material property.

In the present model different particle distribution may be obtained for modeling the variation in particle concentration of the Functionally Graded Materials. The following equation governs the variation in the form of polynomial distribution of particle volume fraction in x-axis direction.

$$c(x) = a_1 + (a_2 - a_1)\left(\frac{x}{l}\right)^n \qquad (1)$$

Where l is the length of the specimen in x-axis direction. $c(x)$ is local particle content in vol% at a distance x from one end. a_1 and a_2 are concentration of particles in percentage at $x=0$ and $x=l$ respectively.

If the average particle content in the FGM model is p vol% the constant n is given by the equation

$$n = \frac{(a_2 - a_1)}{(p - a_1)} - 1 \qquad (2)$$

Polynomial variation in particle concentration along both the directions of x-axis and y-axis may be obtained with the help of the following equation

$$c(xy) = a(xy)^n \qquad (3)$$

with no particles at the corner $(0,0)$ and similar variation in both x-axis and y-axis directions. With

100% particle concentration at the other corner (l, l) of the square FGM model with edge length l, the equation for particle content at location (x, y) may be simplified as

$$c(xy) = 100 \frac{(xy)^n}{l^{2n}} \quad (4)$$

For an average particle vol% p, the constant n is given by

$$n = \sqrt{\frac{100}{p}} - 1 \quad (5)$$

For modeling a FGM with polynomial distribution of particles, 10000 square elements of size 50 μm x 50 μm are generated as discussed. Corresponding to the location of the element, local volume fraction is obtained using either Eq. 1 or Eq. 3. Simultaneously a random number between 0 and 1 is generated for each element. If the random number is less than or equal to the local volume fraction at the centroid of the element, then the element is assigned the properties of the reinforcement. **Figure 1** shows the variation of local vol% *c(x)* of particles in x-axis direction from 0% particles at x=0 to 100 % particles at x=l for different average particle contents. **Figure 2** shows a FGM model with variation in particle content in x-axis direction from 0 vol% of particles at one end to 100 vol% of particles at the other end with an average particle content of 30 vol%. **Figure 3** shows a FGM model with variation in particle content in both x-axis and y-axis directions but containing an average particle content of 30 vol%.

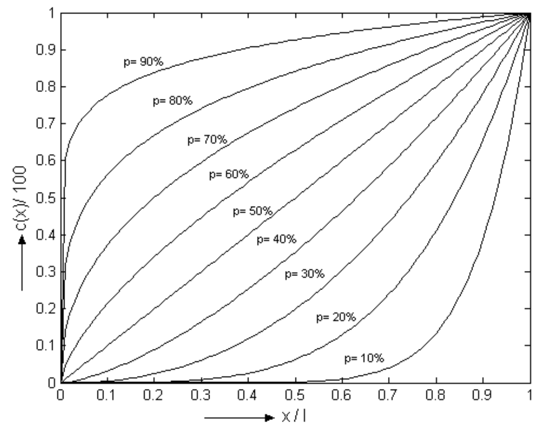

Fig. 1 Polynomial variations of local particle content, *c(x)* in vol %, in x-axis direction from 0 vol% at x = 0 to 100 vol% at x = l for different average particle contents of p vol %.

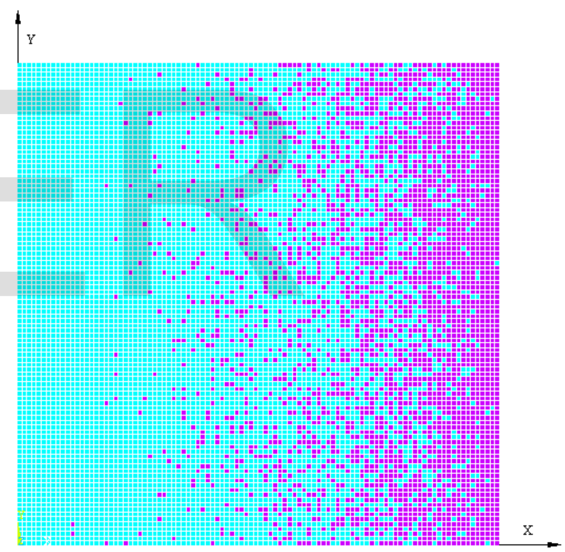

Fig. 2 A schematic of FGM model with polynomial variation in particle content in x-axis direction from 0 vol% at one end to 100 vol% at the other end with average particle content of 30 vol%. Particles are randomly distributed. Turquoise colour shows aluminum matrix and dark lavender colour shows alumina particles.

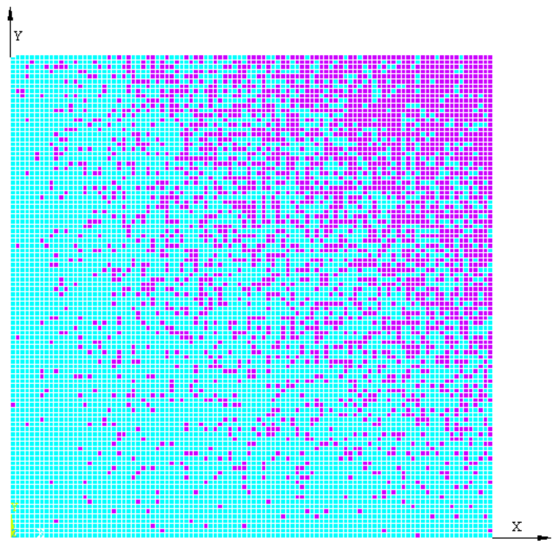

Fig. 3 A schematic of FGM model with polynomial variation in particle content in both x-axis and y-axis directions from 0 vol% at one corner (0, 0) to 100 vol% at the other corner (*l*, *l*) with average particle content of 30 vol%. Particles are randomly distributed over the whole matrix. Turquoise colour shows aluminum matrix and dark lavender colour shows alumina particles.

Conclusions

Functionally Graded Material models with randomly distributed particles containing different amounts of particles may be obtained with the help of present modeling technique. These models will show an important difference with the unit cell models in respect of particle clustering, particularly at higher particle contents, as obtained in a 2-D square having an edge length of 5 mm, divided into grids of 50 µm, which is the size of the particle.

References

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