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Temperature Dependent and Independent Material Properties of FGM Plates

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Abstarct: *In this paper, the evaluation of temperature dependent and independent effective material properties for a Functionally Graded Material (FGM) plate based on Power Law function is presented. The variation of material properties like Young's modulus of elasticity, thermal conductivity and thermal coefficient of expansion are studied for two different cases namely temperature independent and temperature dependent. Parametric studies are performed by varying power-law parameter for a Ti-6Al-4V and aluminium oxide FGM plate and graphical results are presented.*
Keywords: *Functionally Graded Material (FGM), Material properties, Power-Law Function, Temperature Dependent and independent.*

I. Introduction

Functionally Graded Materials (FGMs) are the advanced materials in the group of composites which are mainly designed and developed to withstand extreme temperatures. The concept of FGM was first proposed in 1984 for a space project to create a thermal barrier element. During the process, an innovative idea was adopted to create a new material called Functionally Graded Material or FGM by continuous gradation of two or more constituent phases. For example, a ceramic-metal FGM, carry the advantages of both the materials and exhibit excellent features like high strength, toughness, bonding capabilities, durability along with resistance to heat and oxidation. Major application of these materials are found in high temperature environments like nuclear components, space craft structural members, thermal barrier coatings, etc., which can incorporate extremely incompatible conditions. Therefore, the effect of temperature and evaluation of material properties plays a vital role for accurate and reliable structural analysis.

Most of the analyses of FGM plates are carried out based on position dependent variation of materials. In this method, the properties of the materials vary continuously across the thickness of the plate and without including the effect of temperature. These are called Temperature Independent material properties (TID) which is used by most of the researchers to analyse FGM plates [1-3]. But, high temperature environments have significant effect on constituent materials and hence it has to be considered during the evaluation of material properties across the plate thickness. While evaluating Temperature Dependent properties (TD) both position and temperature dependent material properties are evaluated for modeling the material. Many researchers [4-7] have performed several studies on FGM plates with TD material properties.

In the present investigation, both temperature dependent and independent material properties based on power-law function are evaluated. Parametric studies are performed by varying power law function and extensive graphical results are presented showing the effect of considering temperature while evaluating the material properties.

II. FGM material properties

Temperature independent and dependent material properties are evaluated based on power-law function for the plate geometry given in Fig. 1.

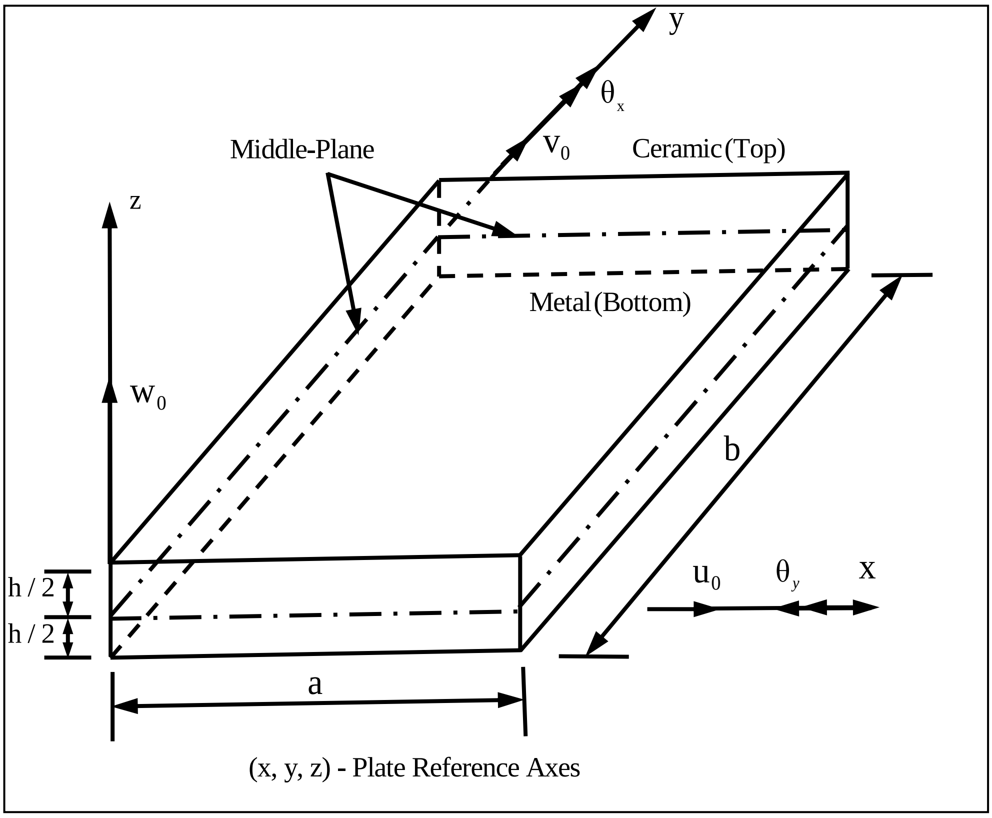

Figure 1: FGM plate geometry with positive set of reference axes and displacement components

The distribution of constituent phases across the plate thickness is called as volume fraction, V_f and is given by (1):

$$V_f = \left(\frac{z}{h} + \frac{1}{2}\right) \tag{1}$$

2.1 Temperature Independent (TID) properties

These are also called as position dependent material properties (P_z) across the plate thickness are evaluated using Rule of mixtures and is given in (2):

$$P_z = P_m + \left(P_c - P_m\right)V_f^p \tag{2}$$

Where, P_m and P_c are the TID material properties like young's modulus of elasticity (E), thermal conductivity (k) and thermal coefficient of expansion (α) of metal and ceramics respectively.

2.2 Temperature Dependent (TD) properties

The material properties are dependent on both temperature and position. Initially, the properties of common structural ceramics and metals are expressed as a function of temperature as given by [8]. Hence, the temperature dependent material properties (P_T) are evaluated as given below:

$$P_T = P_0\left(\frac{P_{-1}}{T} + 1 + P_1 T + P_2 T^2 + P_3 T^3\right) \tag{3}$$

Where, P_0, P_1, P_2 and P_3 are constants in the cubic fit of the material property and T is the temperature. The material properties are expressed in this way so that the higher order effects of the temperature on material properties can be readily discernible.

Both temperature-dependent and position-dependent material properties (P_{TZ}) of FGM plates can be modeled effectively by coupling temperature dependent (P_T) in (3) with position dependent (P_z) in (2) and is given by:

$$P_{Tz} = P_{Tm} + \left[P_{Tc} - P_{Tm}\right]V_f^p \tag{4}$$

Where, P_{Tc} and P_{Tm} are the temperature dependent material properties of ceramics and metals respectively. The material properties in (3) can be evaluated based on the variation of temperature across the plate thickness. The temperature, T is assumed to vary linearly from bottom (metal) surface to the top (ceramic) surface of the plate and is given by:

$$T = T_0 + \left(T_1 - T_0\right) V_f \tag{5}$$

Where, T_0 and T_1 represent the temperatures at bottom (metal) and top (ceramic) surface of an FGM plate.

III. Results and discussions

The TD and TID material properties are examined for a Ti-6Al-4V (metal) and aluminium oxide (ceramic) FGM plate for the data given in Table 1. Comparative studies are carried out for young's modulus of elasticity (E), thermal conductivity (k) and thermal coefficient of expansion (α). TID material properties are evaluated at reference temperature of 300 ^{0}K and is linearly raised to a temperature of 700 ^{0}K for TD properties.

Table1: Temperature dependent and independent properties of Ti-6Al-4V and aluminium oxide. [9].

		P_{-1}	P_0	P_1	P_2	P_3	TID
E (Pa)	Ti-6Al-4V	0	122.56e9	-4.586e-4	0	0	105.7e9
	Aluminium oxide	0	349.55e9	-3.853e-4	4.027e-7	-1.673e-10	320.24e9
k (WmK^{-1})	Ti-6Al-4V	0	1.0	1.704e-2	0	0	6.112
	Aluminium oxide	-1123.6	-14.087	-6.227e-3	0	0	64.989
α (K^{-1})	Ti-6Al-4V	0	7.5788e-6	6.638e-4	-3.147e-6	0	6.9415e-06
	Aluminium oxide	0	6.8269e-6	1.838e-4	0	0	7.203e-6

All the properties are evaluated across the plate thickness from bottom to top surface of the plate for different volume fractions by varying power law function. Parametric studies are performed for p=1,2,4,6 and 10. The variation of Young's modulus of elasticity and thermal conductivity across the plate thickness is shown in Fig. 2 and Fig. 3 respectively. TID method overestimates Young's modulus of elasticity (E_z), while underestimates thermal conductivity (k_z) when compared to TD method of evaluation.

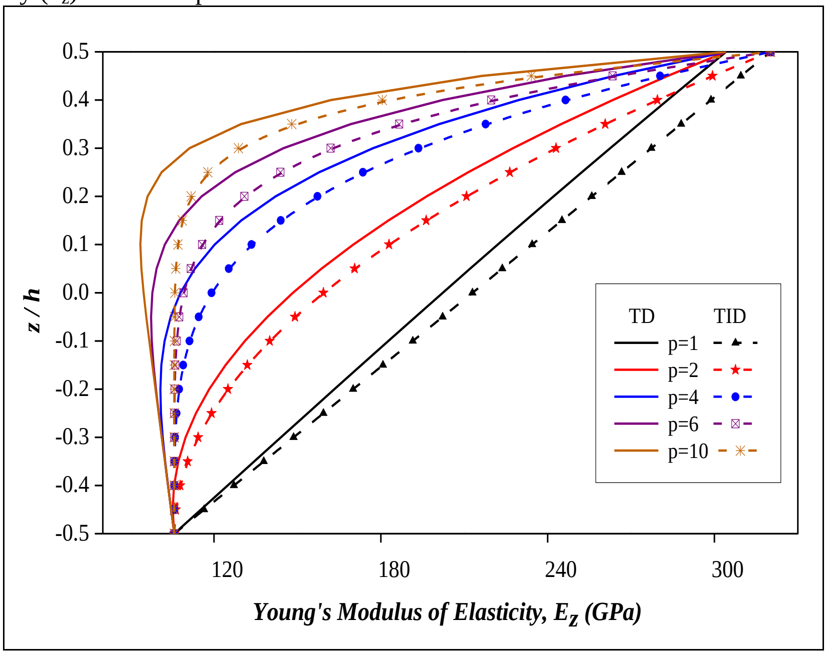

Figure 2: Variation of Young's modulus of elasticity (E_z) across the plate thickness for TID and TD method.

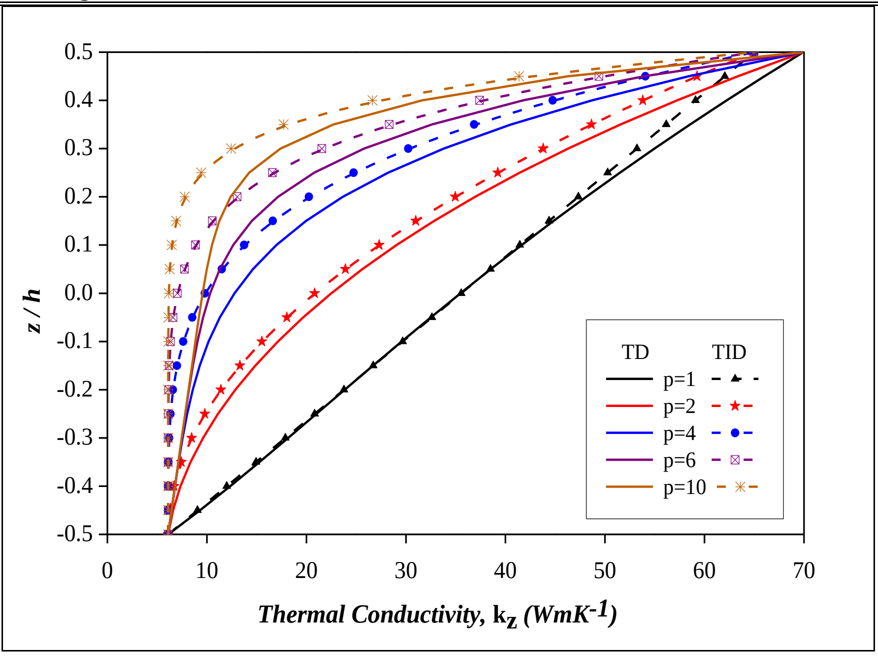

Figure 3: Variation of Thermal Conductivity (k_z) across the plate thickness for TID and TD method.

Fig. 4 shows thermal coefficient of expansion (α_z) evaluated through the thickness of the plate for TD and TID properties. It observed that temperature plays a vital role in defining the nonlinearity of the material more precisely, which helps in computation of stiffness coefficients, strains and stresses more accurately.

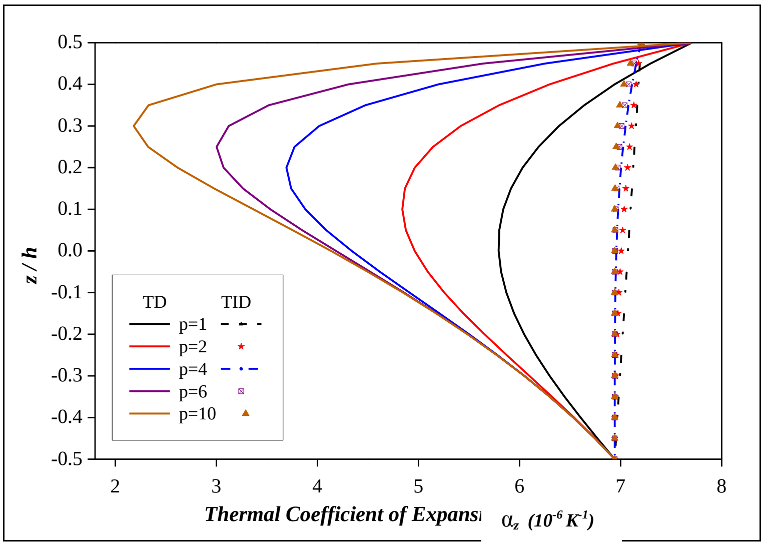

Figure 4: Variation of Thermal Coefficient of Expansion (α_z) across the plate thickness for TID and TD method.

IV. Conclusion

The temperature dependent and independent material properties like young's modulus of elasticity (E), thermal conductivity (k) and thermal coefficient of expansion (α) are studied for various power law parameters. It is observed that the temperature plays a vital role in defining the nonlinearity of the material. The differences in evaluating the TD and TID properties are discussed for various parameters.

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