Thermo-mechanical bending analysis of skew FGM laminated plates

Sanjay Singh Tomar1[a*] and Mohammad Talha2[b]

[a,b] Indian Institute of Technology Mandi, Himachal Pradesh India-175005

1. INTRODUCTION & OBJECTIVE

In recent years, functionally graded (FG) materials have attained a broad acceptance in the aerospace, space shuttle and other industries. Functionally graded materials are inhomogeneous composite material usually consist of ceramic and metal having the graded variation of the material properties from one face to the other face of the structure [1]. Ceramic is used to withstand the higher thermal gradients whereas the metal provides the base to the structure. Initially FG materials were used for the thermal barrier applications whereas development in the advanced manufacturing industries have made them to be used in common structural biomedical and other applications.

FG structure exposed to the sudden changes in the thermal gradient, due to which the metal-ceramic interface shows some distortion. This can be prevented by increasing the homogenous ceramic and metal zones at top and bottom surface of the structure [2]. This construction can be known as FG laminate (Shown in Fig 1). The thermo-mechanical response of the functionally graded structures have acquired quite attention of the research in recent years as FGMs are highly useful for thermal barrier applications.

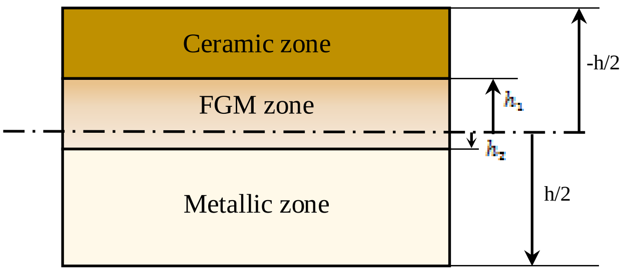

Figure 1: Cross section of FGM laminate

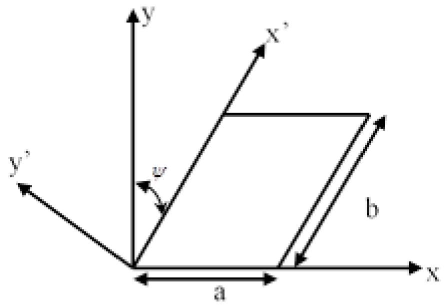

Figure 2: Orientation of Skew edges

The present analysis aims to calculate the thermo-mechanical bending behavior of the skew functionally graded plate. The formulation of the plate have been done with the Reddy's higher order shear deformation theory (HSDT). An isometric C^0 continuous finite element formulation have been adopted to accomplish the results. Plate is assumed to be under various type of loading condition and boundary conditions. Comparison and convergence studies have been performed to show the effectiveness and reliability of the present formulation. Numerical results have been obtained for the various skew angles, aspect ratio, thickness ratios, volume fraction index and boundary conditions.

* Further author information: (Send correspondence to S.S.A)
S.S.A.: E-mail: sanjay_singh_tomar@students.iitmandi.ac.in, Address: School of Engineering Indian Institute of Technology Mandi, and Himachal Pradesh India.

2. MATHEMATICAL FORMULATION

The formulation of the problem is based upon Reddy's HSDT. A C^0 continuous displacement field at a point can be written as,

$$\begin{Bmatrix} U \\ V \\ W \end{Bmatrix} = \begin{Bmatrix} U_0 \\ V_0 \\ W_0 \end{Bmatrix} + f_1(z)\begin{Bmatrix} \phi_x \\ \phi_y \\ 0 \end{Bmatrix} + f_2(z)\begin{Bmatrix} \theta_x \\ \theta_y \\ 0 \end{Bmatrix} \tag{1}$$

Boundaries of the plates are skewed and not considered to be parallel to the global coordinates. Transformed displacement vector can be written as,

$$\Gamma_i = T_g \Gamma_i^l, \tag{2}$$

Where, *Tg* is transformation matrix consist of matrix containing sine and cosine terms with skew angle (ψ), Γ_i *and* Γ_i^l generalized and local displacement vectors at the respective '*i*' node,

$$\begin{aligned} \{\Gamma_i\} &= \{U_0, V_0, W_0, \phi_x, \phi_y, \theta_x, \theta_y\}^T \\ \{\Gamma_i^l\} &= \{U_0^l, V_0^l, W_0^l, \phi_x^l, \phi_y^l, \theta_x^l, \theta_y^l\}^T \end{aligned} \tag{3}$$

The final equilibrium equation for bending analysis can be written as,

$$[K_T]\{q\} = F \tag{4}$$

Where, K_T, *q* and *F* represents the global transformed stiffness matrix, displacement vector and force vector.

3. RESULTS & HIGHLIGHTS OF IMPOINTANT POINTS

In this section, examples have been presented to demonstrate the reliability of the present formulation. Table 1. compares the bending response of the sandwich Al/Al_2O_3 FG plate having the FG core with Neves et al. [3]. The plate is assumed to be under bi-sinusoidal transverse mechanical loading with load $\bar{Q} = Q\sin(\pi x/a)\sin(\pi y/b)$. Following non-dimensional transverse displacement (w*) used in the study

$$w^* = \frac{10h^3 E_c}{a^4 Q} w$$

Table 1. Comparison of transverse displacement parameter (w*)

Mesh size	a/h		
	4	10	100
2x2	1.1027	0.8886	0.8217
3x3	0.8546	0.6979	0.6595
4x4	0.7617	0.6300	0.5985
5x5	0.7617	0.6291	0.5996
6x6	0.7576	0.6279	0.5998
Ref. [3]	0.7417	0.6305	0.6092
(%) differ.	2.1444	0.4036	1.5448

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