STRAIN OF FGM PLATE UNDER THERMOMECHANICAL LOAD SUBJECT TO VARIOUS BOUNDARY CONDITIONS

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Abstract **:** Functionally graded materials (FGM) are made ceramic and metal with a gradual variation of material composition. The gradual variation in composition of FGM makes it suitable for the applications where high thermal resistance and mechanical strength is required. The application areas of FGM include design of aerospace structures, heat engine components, nuclear power plants. The assessment of thermo-mechanical deformation behavior of functionally graded plate structures considerably depends on the plate model kinematics. In the current paper FGM simply supported square plate has been studied under thermal and thermomechniacal loading. The results are presented in terms of strain and shear strain. The strain and shear strains are compared for P-FGM, S-FGM and E-FGM.

Keywords **- FGM, Thermomechancial, Strain, Shear strain**

1. INTRODUCTION

Functionally graded materials (FGM) are made ceramic and metal with a gradual variation of material composition. The gradual variation in composition of FGM makes it suitable for the applications where high thermal resistance and mechanical strength is required. The application areas of FGM include design of aerospace structures, heat engine components, nuclear power plants. The assessment of thermo-mechanical deformation behavior of functionally graded plate structures considerably depends on the plate model kinematics. Qian and Batra (2004), Ferreira et. al. (2005), used third first order theory in which transverse shear stresses were represented as quadratic function through the thickness and hence the effect of shear correction factors has been removed. They derived equations of motion for higher order displacement model using principle of virtual work. Qian et. al. (2004) solved the problem by using a higher order shear and normal deformable plate theory (HOSNDPT). In the HOSNDPT the transverse normal and shear stresses are computed from equation of the plate theory rather than by integrating the balance of linear momentum with respect to the thickness coordinate. The order of the theory was adjusted to predict accurate results for thick plates. Ashraf and Daoud (2010) presented Sinusoidal shear deformation plate theory (SPT) to obtain the buckling of the plate under different types of thermal loads. Shyang and Yen (2006), Mahdavian (2009) obtained series solutions based on the Classical Plate Theory (CPT) and Fourier series expansion. Also they obtained equilibrium and stability equations for FGMs on the basis of classical plate theory under uniform in-plane compression. Senthil and Batra (2003) employed the uncoupled quasi-static linear thermo-elasticity theory. They solved the elasticity problem for each instantaneous temperature distribution by using displacement functions. Dai et. al. (2005) analyzed the FGM plate with the help of mesh-free element free Galerkin (EFG) method under the mechanical loading as well as thermal gradient. It was shown that in the EFG method no element connectivity is required. They used the moving least square (MLS) method to construct the shape functions. It was reported that the relations between the deflection and the volume fraction exponent are quite different under the two loadings. Talha and Singh (2010) obtained the numerical results for different thickness ratios, aspect ratios, volume fraction index and temperature rise with different loading and boundary conditions. Bhandari and Purohit (2014) used various volume fraction laws for FGM plate and presented comparative results of non dimensional parameters. Mostapha et. al. (2012) reported that the critical buckling temperature difference for the FGM plate is increased by increasing the aspect ratio and are generally lower than the corresponding values for homogeneous plates. Fekrar A et. al. (2012) analyzed the critical buckling temperatures of simply supported homogeneous and inhomogeneous FGM plates. It was concluded that both the transverse shear deformation and the material gradient index have considerable effect on the critical buckling temperature difference of FGM plate for a thick plate with large aspect ratio. Srinivas et.al. (2013) investigated the behavior of FGM plate under thermo-mechanical loading with specific boundary conditions. Bhandari and Purohit (2015) employed various boundary conditions and volume fraction laws on FGM plate to determine various nondimensional parameters. Sharma et.al. (2016) investigated the thermo-mechanical buckling behavior of simply-supported FGM plate under Generalized plate theory (GPT), which includes classical plate theory (CPT), first order shear deformation theory (FSDT) and higher order shear deformation theory (HSDT) as special cases. Moita et. al. (2018) presented a formulation for buckling and geometrically nonlinear analysis of functionally graded plates under thermo-mechanical loading. The influence of high temperature environment on deflections due to mechanical loading as well the deflections produced by thermal loads acting alone or combined with mechanical loads is analysed.

In the current paper FGM simply supported square plate has been studied under thermal and thermomechniacal loading. The results are presented in terms of strain and shear strain. The strain and shear strains are compared for P-FM, S-FGM and e-FGM.

2. Thermal and Thermomechanical Analysis

The thermo-mechanical analysis is conducted for FGM made of Aluminum and Zirconia. The Young's modulus for Aluminium is 70 GPa and that for Zirconia is 151 GPa. The coefficient of thermal expansion for Aluminium is $23x10^{-6}$ /°C and that for Zirconia is $10x10^{-6}$ /°C. The Poisson's ratio for both the materials was chosen to be 0.3. The effect of Poisson's ratio on the deformation is much less as compared to that of Young's modulus. The FGM plate is subjected to various boundary conditions which are made of combination of Clamped (C), Simply supported (S) and Free (F). The thickness of the plate (h) is taken 0.02m. Thermal analysis was performed by applying thermal load on the FGM plate. The ceramic top surface is exposed to a temperature of 100 °C. The lower metallic surface and all the edges are kept at a temperature of 0 °C. The thermomechanical analysis has been performed by applying uniformly distributed load (udl) alongwith thermal load. The value of udl (p_o) chosen was equal to $1Xl0^6$ N/m^2. The analysis is performed for various values of the volume fraction exponent (n) in P-FGM and S-FGM. The results are presented in terms of Strain (e_x) and Shear strain (e_{xy}).

3. Results

3.1 Effect of Boundary Conditions in Constant Thermal Environment

In this section the results of analysis performed on a simply supported square (a/b =1) FGM plate with various boundary conditions under constant thermal environment are reported and discussed. The results are presented in terms of non-dimensional parameters i.e. strain (e_x) and shear strain (e_{xy}).

3.1.1 Strain (e_x)

Table 1 and Table 2 show the variation of Strain (e_x) for various boundary conditions of a square plate under constant thermal environment for P-FGM & E-FGM and S-FGM respectively. The comparison of results for various values of volume fraction exponent 'n' for P-FGM and S-FGM has been presented.

Table 1. Strain(e_x 1000) for various boundary conditions of a square plate in thermal environment for P-FGM and E-FGM.

Boundary condition	Values of volume fraction exponent 'n' for P-FGM										E-FGM
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝	
SSSS	1.3	0.2	0.2	0.4	0.7	0.9	1.0	1.2	1.2	1.3	0.6
CCCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCSC	1.6	0.2	0.2	0.5	0.9	1.1	1.3	1.5	1.5	1.7	0.7
CFCF	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CCFF	2.9	0.4	0.5	0.8	1.6	2.0	2.4	2.7	2.8	3.1	1.3
CCSS	1.5	0.2	0.2	0.4	0.9	1.1	1.3	1.4	1.5	1.6	0.7
SSFF	2.4	0.4	0.4	0.7	1.3	1.7	2.0	2.3	2.4	2.6	1.1
SSSC	1.5	0.2	0.2	0.4	0.9	1.1	1.3	1.5	1.5	1.6	0.7
SSSF	2.8	0.4	0.4	0.8	1.6	1.9	2.3	2.7	2.8	3.0	1.3
SSCF	2.8	0.4	0.4	0.8	1.6	1.9	2.3	2.7	2.8	3.0	1.3

Table 2. Strain(e_x X 1000) for various boundary conditions of a square plate in thermal environment for S-FGM.

Boundary condition	Values of volume fraction exponent 'n' for S-FGM									
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝
SSSS	1.3	0.6	0.7	0.7	0.7	0.8	1.0	1.1	1.2	1.3
CCCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCSC	1.6	0.7	0.8	0.8	0.9	1.0	1.2	1.4	1.5	1.7
CFCF	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CCFF	2.9	1.4	1.5	1.6	1.6	1.8	2.2	2.5	2.7	3.1

CCSS	1.5	0.7	0.8	0.8	0.9	1.0	1.2	1.3	1.4	1.6
SSFF	2.4	1.1	1.3	1.3	1.3	1.5	1.9	2.1	2.3	2.6
SSSC	1.5	0.7	0.8	0.8	0.9	1.0	1.2	1.3	1.5	1.6
SSSF	2.8	1.3	1.5	1.5	1.6	1.8	2.2	2.4	2.7	3.0
SSCF	2.8	1.3	1.5	1.5	1.6	1.8	2.2	2.5	2.7	3.0

By investigating Tables 1 and 2 one can conclude the following:

(a) The Strain (e_x) is found to increase with increasing value of volume fraction exponent 'n'.

(b) The maximum Strain (e_x) is obtained for clamped-free (CCFF) boundary conditions and the same is minimum for clamped (CCCC) boundary condition amongst all the cases considered here, which is quite obvious. The maximum strain for clamped-free (CCFF) boundary conditions and P-FGM is 0.0031 and that for S-FGM is 0.0026. It is also observed that second highest strain is obtained in SSSF and SSCF boundary conditions.

3.1.2 Shear Strain (e_{xy})

Tables 3 and 4 show the variation of shear strain (e_{xy}) for various boundary conditions of a simply supported square plate under constant thermal environment for P-FGM & E-FGM and S-FGM respectively. The comparison of results for various values of volume fraction exponent 'n' for P-FGM and S-FGM has been presented.

Table 3. Shear Strain (e_{xy} X 1000) for various boundary conditions of a square plate in thermal environment for P-FGM and E-FGM.

Boundary condition	Values of volume fraction exponent 'n' for P-FGM										E-FGM
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝	
SSSS	20.9	9.5	10.7	13.6	16.7	18.0	19.1	19.3	19.9	22.0	15.8
CCCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCSC	13.4	6.1	6.9	8.7	10.7	11.6	12.2	12.7	13.1	14.1	10.1
CFCF	9.0	4.1	4.6	5.9	7.2	7.8	8.3	8.6	8.8	9.5	6.8
CCFF	8.5	3.9	4.4	5.6	6.8	7.4	7.8	8.1	8.3	9.0	6.5
CCSS	13.6	6.2	7.0	8.9	10.9	11.8	12.5	13.0	13.3	14.3	10.3
SSFF	8.2	3.7	4.2	5.3	6.5	7.1	7.5	7.8	8.0	8.6	6.2
SSSC	23.3	10.6	11.9	15.2	18.6	20.1	21.3	22.1	22.8	24.5	17.6
SSSF	20.6	9.3	10.6	13.5	16.4	17.8	18.8	19.6	20.2	21.7	15.6
SSCF	11.1	5.0	5.7	7.2	8.8	9.5	10.1	10.5	10.8	11.6	8.4

Table 4. Shear Strain(e_{xy} X 1000) for various boundary conditions of a square plate in thermal environment for S-FGM.

Boundary condition	Values of volume fraction exponent 'n' for S-FGM									
	0	0.1	0.2	0.5	1	2	5	10	100	∝
SSSS	20.9	13.6	14.2	15.4	16.7	17.7	18.3	19.2	20.2	22.0
CCCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCSC	13.4	8.7	9.1	9.9	10.7	11.3	11.7	12.3	12.9	14.1
CFCF	9.0	5.9	6.1	6.7	7.2	7.7	7.9	8.3	8.7	9.5
CCFF	8.5	5.5	5.8	6.3	6.8	7.2	7.5	7.8	8.2	9.0
CCSS	13.6	8.9	9.2	10.1	10.9	11.6	12.0	12.6	13.2	14.3
SSFF	8.2	5.3	5.5	6.0	6.5	6.9	7.2	7.5	7.9	8.6

SSSC	23.3	15.2	15.8	17.2	18.6	19.7	20.4	21.4	22.5	24.5
SSSF	20.6	13.4	14.0	15.2	16.4	17.5	18.1	19.0	19.9	21.7
SSCF	11.1	7.2	7.5	8.1	8.8	9.4	9.7	10.2	10.7	11.6

The effect of Boundary conditions on shear strain (e_{xy}) is given below:
(a) The shear strain is maximum for the case of pure metal (n = ∞) and pure ceramic (n = 0). The shear strain is comparable for pure metal and pure ceramic. The reason is already explained in previous section.
(b) The shear strain increases with increasing volume fraction exponent 'n'.
(c) It is also found that the maximum shear strain occurs for simply supported-clamped (SSSC) boundary conditions, and the same is minimum for clamped (CCCC) boundary condition. The maximum shear strain for simply supported-clamped (SSSC) boundary conditions and P-FGM is 0.023 and that for S-FGM is 0.022. However second highest shear strain is obtained at SSSS and SSSF boundary conditions.
(d) The non-dimensional shear strain for S-FGM remains closer for various values of volume fraction exponent 'n' as compared to that of the P-FGM.

3.2 Comparison of P-FGM, S-FGM, E-FGM, ceramic and metal

The comparison of various parameters like strain and shear strain for ceramic, metal and FGM's following Power law, Sigmoid and Exponential distribution is presented. In this study for FGM plate the comparison has been made for constant value of volume fraction exponent 'n'. The Fig. 1 and Fig. 2 show the comparison graphs for pure ceramic (n=0), pure metal (n=∞), P-FGM (n=2), P-FGM (n=0.5), S-FGM (n=2), S-FGM (n=0.5) and E-FGM.

3.2.1 Strain (e_x)

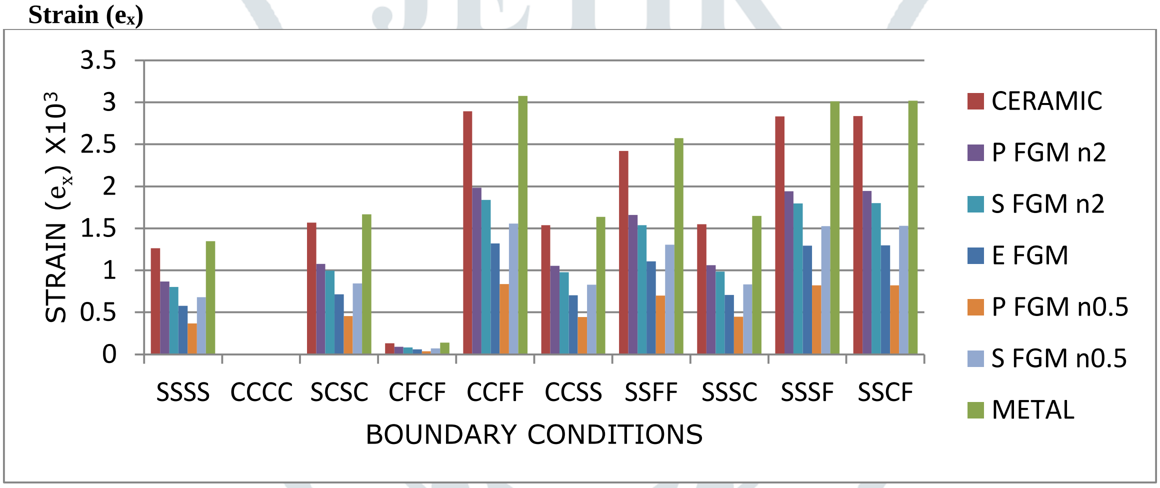

Fig. 1: Effect of boundary conditions on strain (e_x) of a square plate under constant thermal environment for various FGM's, ceramic and metal

3.2.2 Shear Strain (e_{xy})

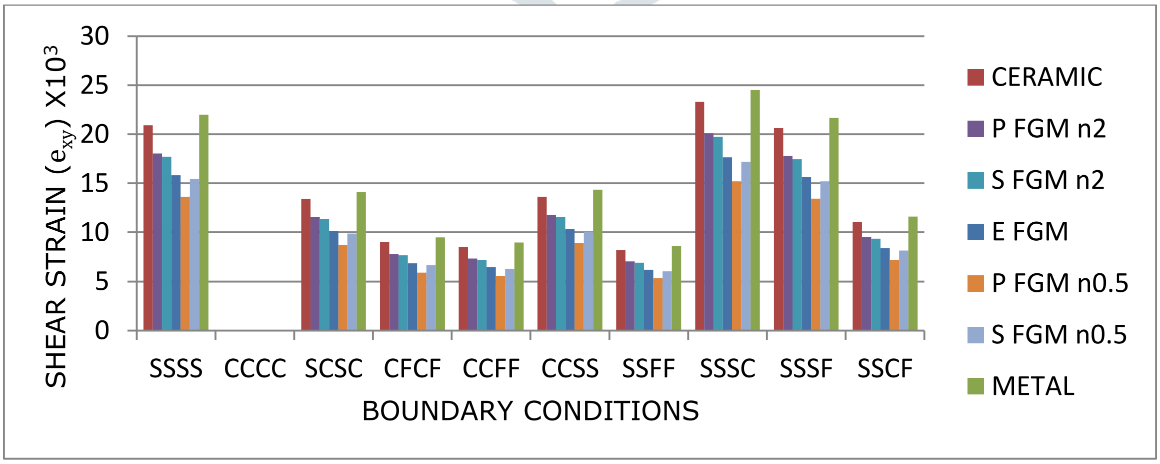

Fig. 2: Effect of boundary conditions on shear strain (e_{xy}) of a square plate under constant thermal environment for various FGM's, ceramic and metal

The comparison of pure ceramic (n=0), pure metal (n=∞), P-FGM (n=2), P-FGM (n=0.5), S-FGM (n=2), S-FGM (n=0.5) and E-FGM for aspect ratio (a/b=1) reveals the following:

(i) For both ceramic and metal plate strain and shear strain are found to be maximum.

(ii) The strain (e_x) under CCFF in case of P-FGM-n2 (e_x = 0.0019) is found to be greater than S-FGM-n2 (e_x=0.0018). At the same time the strain (e_x) in case of P-FGM-n0.5 (e_x = 0.0009) is found to be less than S-FGM-n0.5 (e_x =0.0015).

(iii) The shear strain (e_{xy}) under SSSC in case of P-FGM-n2 (e_{xy} = 0.02) is found to be greater than S-FGM-n2 (e_{xy}=0.019). At the same time the shear strain in case of P-FGM-n0.5 (e_{xy} = 0.013) is found to be less than S-FGM-n0.5 (e_{xy} =0.015).

3.3 Effect of boundary conditions in constant thermal environment under mechanical load

In this section the results of analysis performed on a simply supported square (a/b =1) FGM plate with various boundary conditions subject to constant uniformly distributed load in constant thermal environment are reported and discussed. The results are presented in terms of non-dimensional parameters i.e. strain (e_x) and shear strain (e_{xy}).

3.3.1 Strain (e_x)

Tables 5 and 6 show the variation of Strain (e_x) for various boundary conditions of a square plate under uniformly distributed load in constant thermal environment for P-FGM & E-FGM and S-FGM respectively. The comparison of results for various values of volume fraction exponent ‘n’ for P-FGM and S-FGM has been presented.

Table 5. Strain (e_x X 1000) for various boundary conditions of a square plate under constant thermo-mechanical load for P-FGM and E-FGM

Boundary condition	Values of volume fraction exponent ‘n’ for P-FGM										E-FGM
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝	
SSSS	6.3	3.2	3.1	3.8	4.6	5.3	5.7	5.8	6.1	6.5	4.2
CCCC	0.7	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.7	0.5
SCSC	3.4	1.3	1.4	1.7	2.2	2.7	2.8	3.2	3.4	3.6	1.9
CFCF	14.5	7.6	7.8	8.5	9.2	9.9	11.0	12.0	13.9	15.2	9.3
CCFF	50.2	26.8	27.4	29.2	31.2	33.5	37.5	41.6	48.7	52.9	32.1
CCSS	11.6	6.3	6.6	7.2	7.9	8.6	9.4	10.2	11.4	12.2	8.0
SSFF	24.8	13.2	14.2	17.4	21.0	22.4	22.8	24.1	25.0	26.1	19.2
SSSC	4.3	1.8	1.9	2.4	2.9	3.5	3.8	4.0	4.2	4.5	2.6
SSSF	24.5	13.1	14.0	16.3	18.9	21.2	22.6	23.3	24.5	25.8	17.9
SSCF	24.5	12.8	13.3	14.4	15.6	16.8	18.6	20.4	23.4	25.8	15.8

Table 6. Strain (e_x X 1000) for various boundary conditions of a square plate under constant thermo-mechanical load for S-FGM

Boundary condition	Values of volume fraction exponent ‘n’ for S-FGM									
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝
SSSS	6.3	4.0	4.1	4.3	4.6	5.0	5.3	5.4	5.4	6.5
CCCC	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7
SCSC	3.4	2.1	2.1	2.1	2.2	2.3	2.4	2.4	2.4	3.6
CFCF	14.5	8.9	9.0	9.1	9.2	9.2	9.3	9.3	9.6	15.2
CCFF	50.2	29.4	30.0	30.6	31.2	31.7	32.5	33.4	35.4	52.9
CCSS	11.6	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	12.2
SSFF	24.8	17.0	17.4	18.5	21.0	22.1	24.0	24.4	24.5	26.1
SSSC	4.3	2.6	2.7	2.8	2.9	3.1	3.3	3.3	3.4	4.5
SSSF	24.5	16.9	17.2	18.0	18.9	19.9	20.7	20.9	21.0	25.8
SSCF	24.5	14.1	15.0	15.4	15.6	16.0	16.4	17.4	18.3	25.8

Comparing Tables 5 and 6, one can conclude the following:

(a) The strain is comparable for pure metal and pure ceramic. The strain becomes higher with increasing volume fraction exponent 'n'. It is observed that, when thermal effect is induced, the bending response of the functionally graded plate is not necessarily intermediate to those of the metal and the ceramic plate.

(b) It is also found that the maximum strain occurs for clamped - free (CCFF) boundary conditions and minimum for simply supported and clamped (SCSC) boundary condition amongst all the cases considered here. The maximum strain in case of clamped-free (CCFF) boundary conditions for P-FGM is 0.048 and that for S-FGM is 0.035.

(c) The value of strain under thermo-mechanical load is less than that of under pure mechanical load. In case of simply supported boundary condition, the strain under pure mechanical load, for P-FGM-n100, is 0.00644 whereas under thermo-mechanical load it is 0.00613. The strain for S-FGM remains closer for various values of 'n' as compared to that of the P-FGM.

3.3.2 Shear Strain (e_{xy})

Tables 7 and 8 show the variation of shear strain (e_{xy}) for various boundary conditions of a square plate under uniformly distributed load in constant thermal environment for P-FGM and S-FGM respectively. The comparison of results for various values of volume fraction exponent 'n' for P-FGM and S-FGM has been presented.

The effect of Boundary conditions on Shear strain (e_{xy}) is given below:

(a) The shear strain is maximum for the case of pure metal ($n = \infty$) and pure ceramic ($n = 0$). Further for the FGM plates the shear strain increases with increasing value of volume fraction exponent 'n'.

(b) It is also found that the maximum shear Strain (e_{xy}) occurs for simply supported - free (SSFF) boundary conditions and minimum for clamped (CCCC) boundary condition for all the cases considered here. The maximum shear strain in case of simply supported - free (SSFF) boundary conditions for P-FGM is 0.084 and that for S-FGM is 0.022.

(c) The value of shear strain under thermo-mechanical load is more than that of under pure mechanical load. In case of simply supported boundary condition, the shear strain under pure mechanical load, for P-FGM-n100, is 0.0169 whereas under thermo-mechanical load it is 0.0277.

Table 7. Shear Strain (e_{xy} X 1000) for various boundary conditions of a square plate under constant thermo-mechanical load for P-FGM and E-FGM

Boundary condition	Values of volume fraction exponent 'n' for P-FGM										E-FGM
	n=0	0.1	0.2	0.5	1	2	5	10	100	∝	
SSSS	28.0	15.6	17.1	20.6	24.0	26.4	27.3	27.3	27.7	28.2	22.7
CCCC	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.3
SCSC	12.4	6.9	7.6	9.1	10.7	12.1	7.0	13.2	13.2	13.0	10.0
CFCF	13.3	7.4	8.0	9.5	10.9	12.2	13.1	13.4	13.7	14.0	10.4
CCFF	26.6	14.7	15.8	18.3	21.1	23.5	25.2	25.9	27.0	28.0	20.2
CCSS	12.7	7.0	7.7	9.3	10.9	12.4	13.4	13.5	13.5	13.3	10.2
SSFF	94.8	49.8	51.5	65.7	76.5	84.4	85.6	87.2	88.3	99.7	72.3
SSSC	24.9	14.4	15.8	19.0	22.0	24.4	25.3	25.5	25.8	26.2	20.9
SSSF	32.1	18.7	20.4	24.5	28.4	31.2	32.1	32.2	32.9	33.8	26.9
SSCF	10.8	6.3	6.8	8.1	9.4	10.4	10.9	11.0	10.9	11.3	8.9

Table 8. Shear Strain (e_{xy} X 1000) for various boundary conditions of a square plate under constant thermo-mechanical load for S-FGM

Boundary condition	Values of volume fraction exponent 'n' for S-FGM									
	0	0.1	0.2	0.5	1	2	5	10	100	∝
SSSS	28.0	20.3	20.9	22.4	24.0	25.5	26.5	26.7	26.7	28.2
CCCC	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5
SCSC	12.4	9.8	10.0	10.4	10.7	10.9	11.0	10.9	10.9	13.0

CFCF	13.3	10.0	10.1	10.5	10.9	11.3	11.5	11.5	11.5	14.0
CCFF	26.6	19.1	19.5	20.2	21.1	21.9	22.5	22.7	22.8	28.0
CCSS	12.7	10.0	10.2	10.6	10.9	11.1	11.2	11.1	11.1	13.3
SSFF	94.8	61.2	63.1	67.5	76.5	81.2	84.5	85.2	85.2	99.7
SSSC	24.9	18.9	19.5	20.7	22.0	23.3	24.1	24.3	24.3	26.2
SSSF	32.1	24.0	24.7	26.5	28.4	30.2	31.6	31.9	31.9	33.8
SSCF	10.8	8.1	8.3	8.7	9.4	10.1	10.7	10.9	10.9	11.3

3.4 Comparison of P-FGM, S-FGM, E-FGM, ceramic and metal:

The comparison of various parameters like strain and shear strain for ceramic, metal and FGM's following Power law, Sigmoid and Exponential distribution is presented. In this study for FGM plate the comparison has been made for constant value of volume fraction exponent 'n'. The Fig.3 and Fig. 4 show the comparison graphs for pure ceramic (n=0), pure metal (n=∞), P-FGM (n=2), P-FGM (n=0.5), S-FGM (n=2), S-FGM (n=0.5) and E-FGM.

The comparison of pure ceramic (n=0), pure metal (n=∞), P-FGM (n=2), P-FGM (n=0.5), S-FGM (n=2), S-FGM (n=0.5) and E-FGM for aspect ratio (a/b=1) reveals the following:

(i) The non-dimensional parameters e.g. strain and shear strain are maximum for the ceramic and metal.

(ii) The strain (e_x) under CCFF in case of P-FGM-n2 (e_x = 0.034) is found to be greater than that of S-FGM-n2 (e_x=0.032). At the same time the strain (e_x) in case of P-FGM-n0.5 (e_x = 0.029) is found to be less than that of S-FGM-n0.5 (e_x =0.031).

(iii) The shear strain (e_{xy}) under SSFF in case of P-FGM-n2 (e_{xy} = 0.083) is found to be greater than that of S-FGM-n2 (e_{xy}=0.081). At the same time the non-dimensional tensile stress in case of P-FGM-n0.5 (e_{xy} = 0.062) is found to be less than that of S-FGM-n0.5 (e_{xy} =0.064). The above mentioned details show that the variation of strain and shear strain is more in case of P-FGM than S-FGM.

3.4.1 Strain (e_x)

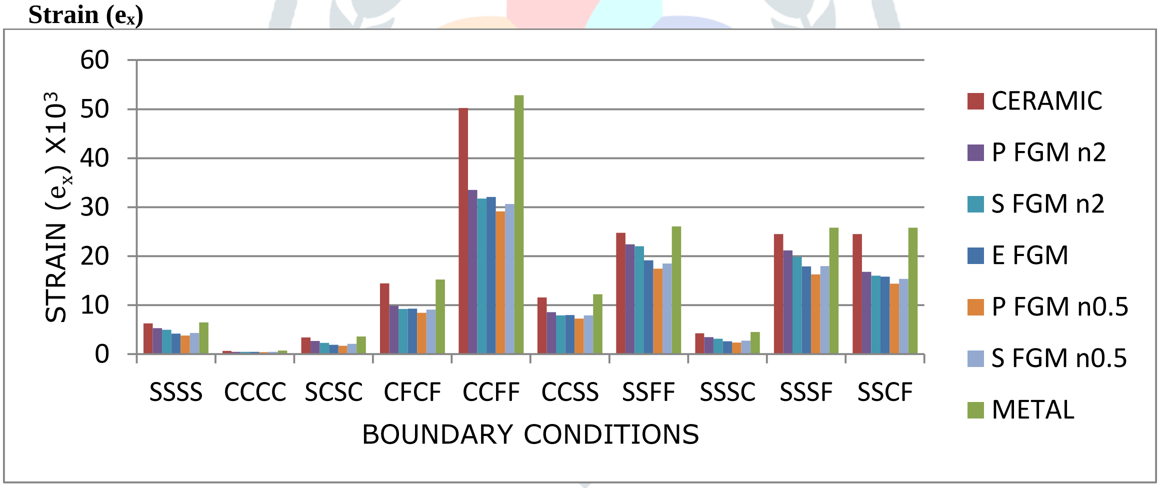

Fig. 3: Effect of boundary conditions on strain (e_x) of a square plate under constant thermo-mechanical load for various FGM's, ceramic and metal

3.4.2 Shear Strain (e_{xy})

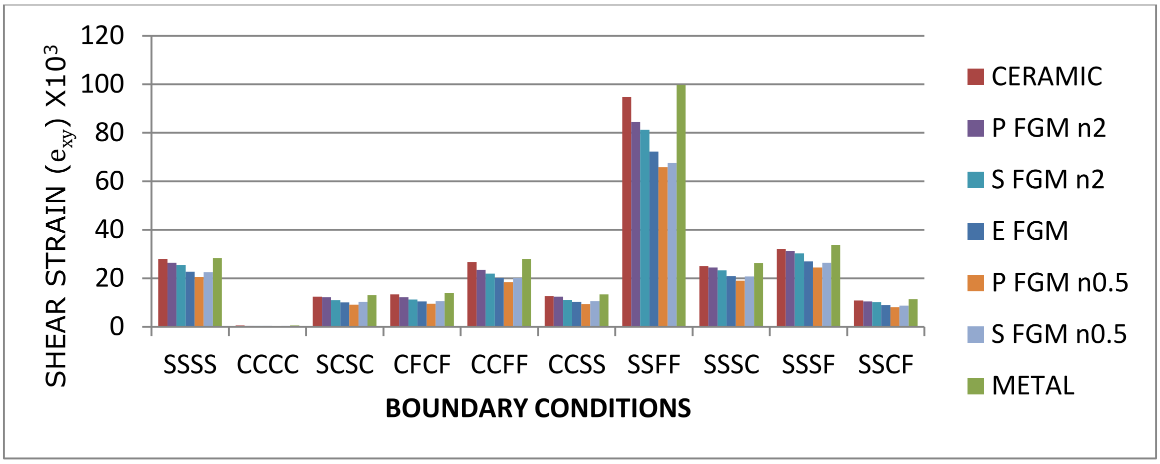

Fig. 4: Effect of boundary conditions on shear strain (e_{xy}) of a square plate under constant thermo-mechanical load for various FGM's, ceramic and metal

4. Conclusions

The behaviour of FGM plate under thermo-mechanical environment was studied. The work includes parametric study performed by boundary conditions. The close investigation of the values of strain and shear strain reveals the following information:

(a) P-FGM (n=0.5) plate has the smallest strain among all kinds of FGM plate. The reason is that the stiffness of the P-FGM (n=0.5) plate is more than that of E-FGM plate and stiffness of the E-FGM plate is more than that of P-FGM (n=2).

(b) It is also found that the maximum shear Strain (exy) occurs for simply supported - free (SSFF) boundary conditions and minimum for clamped (CCCC) boundary condition for all the cases considered here. The maximum shear strain in case of simply supported - free (SSFF) boundary conditions for P-FGM is 0.084 and that for S-FGM is 0.022.

(c) The strain (e_x) under CCFF in case of P-FGM-n2 (e_x = 0.034) is found to be greater than that of S-FGM-n2 (e_x=0.032). At the same time the strain (e_x) in case of P-FGM-n0.5 (e_x = 0.029) is found to be less than that of S-FGM-n0.5 (e_x =0.031).

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