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Effect of Piezoelectric Thickness Ratio on the Deflection of Laminated Hybrid Composite Plates

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Abstract

Piezoelectric materials are one of the smart materials, can respond according to the design requirements of the composite structures autonomously. The effect of variable Piezoelectric thickness ratio on the deflection of laminated hybrid composite plates analyzed. The static deflections of a simply supported laminated composite plate excited by, two surface bonded piezoelectric actuators on both sides of the composite plate, with various sizes of the piezoelectric Actuator are determined. The results validated with the published results by developing the MATLAB code. The code has further extended to study the static deflections under the influence of thickness ratio, applied voltage, size and location of the piezoelectric Actuator. Variation in the lamination scheme and Thickness ratio of the composite plate to the piezoelectric Actuators plays a vital role in the transverse displacements.

Keywords: Analytical solutions, Laminated Hybrid Composite Plates, Piezoelectric Actuators; Simply Supported Plates; Variable Thickness Ratios.

I. INTRODUCTION

Piezoelectric devices used in structural applications, because of flexibility control in shape and vibrations. In smart composite structures, these can be as both sensors and actuators, and these are surface pasted to existing structures to form an online monitoring system or embedded in composite structures without significantly varying the strength of the structure. The advantage of integrating these intelligent materials into the composite design is that the sensing and actuating mechanism can be inherent within the system itself. Structural health monitoring systems adopt these smart materials due to quick response, low power consumption, and high linearity. Bailey and Hubband[1] Proposed first adaptive structure using polyvinylidene fluoride film as actuators to control the structural vibration of a cantilever beam. Her and Lin [2] developed the procedure to calculate the deflections of a simply supported isotropic plate induced by piezoelectric actuators. Her and Lin [3] extended the deflection of isotropic plate procedure to the deflection of simply supported cross-ply laminated composite plate, in this paper effect of sizes and location of piezoelectric are studied. Lin and Nien[4] demonstrated the adaptive modelling and shape control of laminated plates using piezoelectric actuators. Tondreau et al. [5] investigated the point load actuation on plate structures based on triangular piezoelectric patches. Raju and Rao [6] proposed the static response of Quasi-Isotropic laminated plates excited by smart piezoelectric actuators with variable thickness ratios, in this the effect of sizes and applied voltage, location of piezoelectric actuators and thickness ratios. Lamir[7] worked on the optimal control and design of composite laminated piezoelectric plates. Raju and Rao [8] presented the effects of size and location of piezoelectric actuators on the cross-ply laminated composite plates excited by piezoelectric actuators. Sawarkaret al. [9] developed the Semi-analytical solutions for static analysis of piezoelectric laminates. Shiva kumar[10] presented the nonlinear analysis of smart Cross-ply composite plates integrated with a distributed piezoelectric fibre reinforced composite Actuator. Zhao et al. [11] performed the Electro-elastic analysis of piezoelectric laminated composite plates. Zhen-grog and Liying [12] studied the effect of size on electromechanical coupling fields of a bending piezoelectric nanoplate with the surface effects and flexoelectricity. Man et al. [13] proposed the semi-analytical analysis for piezoelectric plate using the scaled boundary finite-element method. Wang et al. [14] presented the Analytical solutions of functionally graded piezoelectric circular plates subjected to axisymmetric loads. P Vidal et al. [15] analyzed the piezoelectric plates with variables separation for static analysis H. Tanzadeh and H Amoushahi [16] performed the buckling and free vibration analysis of piezoelectric laminated composite plates using various plate deformation theories. According to the literature, the deflection analysis of hybrid composite plates by varying the thickness ratio has never performed. Thus, the present study is the first attempt in using an analytical approach to solve the structural behaviour of hybrid composite plates with variation in lamination schemes and thickness ratios. In this present study, a MATLAB code is developed to find the displacements of simply supported hybrid composite plates excited by the surface bonded piezoelectric actuators symmetrically to the plate, with various sizes, locations and applied voltages from Her and Lin [3], Raju and Rao [8]. The variation in a thickness ratio of the composite plate to the piezoelectric Actuators plays a vital role in the transverse displacements of the hybrid composite plates. The hybrid composites can tailor according to our design requirements, and by integrating the smart materials at various locations to become the structure as an intelligent structure

II. THE GOVERNING EQUATIONS OF THE PROBLEM

II.I Stress-Strain Relations of Composite Plate

In this analysis, the bending stiffness matrix of a laminated composite plate evaluated using classical lamination plate theory. To study the static response of a simply supported laminated composite plate excited by two piezoelectric actuators symmetrically surface bonded this methodology extended from the Hook's law the Off-axis, Stress-strain relations for a kth lamina are as follows,

$$\{\sigma_{xy}\} = [\bar{Q}_{12}] \{\varepsilon_{xy}\} \tag{1}$$

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}^k = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}^k \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix}^k \tag{2}$$

where the Off-Axis strain matrix $\{\varepsilon_{xy}\}$ across the thickness of the composite plate due to bending moments are as follows,

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix}^k = Z \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix}^k \tag{3}$$

substituting the equation (3) in equation (2) the Stress-strain relation becomes equation (4) as follows,

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}^k = Z \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{61} & \bar{Q}_{62} & \bar{Q}_{66} \end{bmatrix}^k \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix}^k \tag{4}$$

where the Off-Axis stiffness matrix terms [$\bar{Q}_{12}$]calculated using the Equations (5)-(10)

$$\bar{Q}_{11} = Q_{11}cos^4\theta + 2(Q_{12} + 2Q_{66})sin^2\theta cos^2\theta + Q_{22}sin^4\theta \tag{5}$$

$$\bar{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66})sin^2\theta cos^2\theta + Q_{12}(sin^4\theta cos^4\theta) \tag{6}$$

$$\bar{Q}_{22} = Q_{11}sin^4\theta + 2(Q_{12} + 2Q_{66})sin^2\theta cos^2\theta + Q_{22}cos^4\theta \tag{7}$$

$$\bar{Q}_{16} = (Q_{11} - Q_{12} - 2Q_{66})sin\theta cos^3\theta + (Q_{12} - Q_{22} + 2Q_{66})sin^3\theta cos\theta \tag{8}$$

$$\bar{Q}_{26} = (Q_{11} - Q_{12} - 2Q_{66})cos\theta sin^3\theta + (Q_{12} - Q_{22} + 2Q_{66})cos^3\theta sin\theta \tag{9}$$

$$\bar{Q}_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})sin^2\theta cos^2\theta + Q_{66}(sin^4\theta + cos^4\theta) \tag{10}$$

Where

$$Q_{11} = \frac{E_1}{1 - \vartheta_{12}\vartheta_{21}} \tag{11}$$

$$Q_{12} = \frac{\vartheta_{12}E_2}{1 - \vartheta_{12}\vartheta_{21}} \tag{12}$$

$$Q_{22} = \frac{E_2}{1 - \vartheta_{12}\vartheta_{21}} \tag{13}$$

$$Q_{66} = G_{12} \tag{14}$$

In this investigation, two piezoelectric actuators are surface-bonded symmetrically on the laminated composite plate are excited by applied voltage V, with the polarised direction along Z-axis.

The strains induced in plate due to the electric field are transverse to the surface of piezoelectric actuators.

The strains in terms of the piezoelectric constant d_{31}, applied voltage V and piezoelectric actuator thickness t_{pe} expressed as

$$(\varepsilon_x)_{pe} = (\varepsilon_y)_{pe} = \varepsilon_{pe} = \frac{d_{31}}{t_{pe}} V \tag{15}$$

The bending stresses produced in the host plate due to the strains induced in the actuators expressed as,

$$\sigma_x^k = Z\left[\bar{Q}_{11}^{(k)} k_x + \bar{Q}_{12}^{(k)} k_y + \bar{Q}_{16}^{(k)} k_{xy}\right] \tag{16}$$

$$\sigma_y^k = Z\left[\bar{Q}_{12}^{(k)} k_x + \bar{Q}_{22}^{(k)} k_y + \bar{Q}_{26}^{(k)} k_{xy}\right] \tag{17}$$

$$\tau_{xy}^k = Z\left[\bar{Q}_{61}^{(k)} k_x + \bar{Q}_{62}^{(k)} k_y + \bar{Q}_{66}^{(k)} k_{xy}\right] \tag{18}$$

The stresses produced in the Piezoelectric Actuators by applying the voltage to the actuators are

$$(\sigma_x)_{pe} = \frac{E_{pe}}{1-\nu_{pe}^2}\left[Zk_x + \nu_{pe} Z k_y - (1+\nu_{pe})\varepsilon_{pe}\right] \tag{19}$$

$$(\sigma_y)_{pe} = \frac{E_{pe}}{1-\nu_{pe}^2}\left[Zk_y + \nu_{pe} Z k_x - (1+\nu_{pe})\varepsilon_{pe}\right] \tag{20}$$

$$(\tau_{xy})_{pe} = \frac{E_{pe}}{1-\nu_{pe}^2}\left[Z\left(\frac{1-\nu_{pe}}{2}\right)k_{xy} - \left(\frac{1-\nu_{pe}}{2}\right)\varepsilon_{pe}\right] \tag{21}$$

Where,

$$(D_{11})_{pe} = \frac{E_{pe}}{3(1-\nu_{pe}^2)}\left\{(t+t_{pe})^3 - t^3\right\} \tag{22}$$

$$(D_{22})_{pe} = \frac{E_{pe}}{3(1-\nu_{pe}^2)}\left\{(t+t_{pe})^3 - t^3\right\} \tag{23}$$

$$(D_{66})_{pe} = \frac{E_{pe}}{3(1-\nu_{pe}^2)}\left(\frac{1-\nu_{pe}}{2}\right)\left\{(t+t_{pe})^3 - t^3\right\} \tag{24}$$

$$(B_{11})_{pe} = \frac{E_{pe}}{2(1-\nu_{pe}^2)}\left\{(t+t_{pe})^2 - t^2\right\} \tag{25}$$

From the moment equilibrium equations, bending stiffness matrix [D] of a laminated composite plate can be written as,

$$[D] = \frac{1}{3}\sum_{k=1}^{N}\begin{bmatrix}\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16}\\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26}\\ \bar{Q}_{61} & \bar{Q}_{62} & \bar{Q}_{66}\end{bmatrix}^k (Z_k^3 - Z_{k-1}^3) \tag{26}$$

Where Z_k and Z_{k-1} are the positions of the top and bottom surfaces of the k^{th} lamina in the composite laminated plate.

II.II Bending Moment

From the Moment equilibrium Equations, the sum of the bending moments produced in the composite plate with the surface-bonded piezoelectric actuators at the midplane section (Z=0) is equal to zero. The moment equilibrium equations expressed in the equations (27)-(29) as follows,

$$\int_{-t}^{t}(\sigma_x)Zdz + \int_{-t_{pe}-t}^{-t}(\sigma_x)_{pe}Zdz + \int_{t}^{t+t_{pe}}(\sigma_x)_{pe}Zdz = 0 \tag{27}$$

$$\int_{-t}^{t}(\sigma_y)Zdz + \int_{-t_{pe}-t}^{-t}(\sigma_y)_{pe}Zdz + \int_{t}^{t+t_{pe}}(\sigma_y)_{pe}Zdz = 0 \tag{28}$$

$$\int_{-t}^{t}(\tau_{xy})Zdz + \int_{-t_{pe}-t}^{-t}(\tau_{xy})_{pe}Zdz + \int_{t}^{t+t_{pe}}(\tau_{xy})_{pe}Zdz = 0 \tag{29}$$

The bending stresses produced in the composite plate and piezoelectric actuators from equations (16)-(18) and (19)-(21) substituted in equations (27)-(29), then the moment equilibrium equations become equations (30-32) as follows,

$$[D_{11} + 2(D_{11})_{pe}]k_x + [D_{12} + 2(D_{12})_{pe}]k_y + [D_{12}]k_{xy} = (1+\vartheta_{pe})2(B_{11})_{pe}\varepsilon_{pe} \tag{30}$$

$$[D_{12} + 2(D_{12})_{pe}]k_x + [D_{22} + 2(D_{22})_{pe}]k_y + [D_{26}]k_{xy} = (1+\vartheta_{pe})2(B_{11})_{pe}\varepsilon_{pe} \tag{31}$$

$$[D_{16}]k_x + [D_{26}]k_y + [D_{66} + 2\,(D_{66})_{pe}]k_{xy} = (1-\vartheta_{pe})(B_{11})_{pe}\varepsilon_{pe} \tag{32}$$

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The curvatures k_x, k_y and k_{xy} are express in equation (33) as follows,

$$\begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{a} & \bar{b} & \bar{c} \\ \bar{d} & \bar{e} & \bar{f} \\ \bar{c} & \bar{f} & \bar{g} \end{bmatrix}^{-1} \begin{Bmatrix} \bar{d} \\ \bar{d} \\ \bar{h} \end{Bmatrix} \tag{33}$$

Where,

$$k_x = A_1 \varepsilon_{pe} \tag{34}$$

$$k_y = A_2 \varepsilon_{pe} \tag{35}$$

$$k_{xy} = A_3 \varepsilon_{pe} \tag{36}$$

$$A_1 = \frac{\left(\overline{eg} - \bar{f}^{\,2} + \overline{cf} - \overline{bg} \right) \bar{d} + \left(\overline{bf} - \overline{ce} \right) \bar{h}}{\bar{a}\left(\overline{eg} - \bar{f}^{\,2} \right) - \bar{c}\left(\overline{ce} - 2bf \right) - \left(\bar{b}^{\,2} \right) \bar{g}} \tag{37}$$

$$A_2 = \frac{\left(\overline{cf} - c^{2} - \overline{bg} + \overline{ag} \right) \bar{d} + \left(\overline{bc} - \overline{af} \right) \bar{h}}{\bar{a}\left(\overline{eg} - \bar{f}^{\,2} \right) - \bar{c}\left(\overline{ce} - 2bf \right) - \left(\bar{b}^{\,2} \right) \bar{g}} \tag{38}$$

$$A_3 = \frac{\left(\overline{bg} - \overline{cf} + \overline{bc} - \overline{af} \right) \bar{d} + \left(\overline{ae} - \bar{b}^{\,2} \right) \bar{h}}{\bar{a}\left(\overline{eg} - \bar{f}^{\,2} \right) - \bar{c}\left(\overline{ce} - 2bf \right) - \left(\bar{b}^{\,2} \right) \bar{g}} \tag{39}$$

Where,

$$\begin{aligned} \bar{a} &= D_{11} + 2(D_{11})_{pe} \\ \bar{b} &= D_{12} + 2(D_{12})_{pe} \\ \bar{c} &= D_{16} \\ \bar{d} &= -\left(1 + \vartheta_{pe}\right) 2 (B_{11})_{pe} \\ \bar{e} &= D_{22} + 2(D_{22})_{pe} \\ \bar{f} &= D_{26} \\ \bar{g} &= D_{66} + 2\,(D_{66})_{pe} \\ \bar{h} &= -\left(1 - \vartheta_{pe}\right) 2 (B_{11})_{pe} \end{aligned} \tag{40}$$

The bending moments M_x, M_y and M_{xy} produced in the composite plates per unit length calculated by substituting the curvatures k_x, k_y and k_{xy} in the equation (42) as follows,

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \sum_{k=1}^{N} \left[\int_{Z_{k-1}}^{Z_k} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}^{(k)} dz \right] \tag{41}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \sum_{k=1}^{N} \left[\int_{Z_{k-1}}^{Z_k} \left(\begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{61} & \bar{Q}_{62} & \bar{Q}_{66} \end{bmatrix}^{k} Z \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \right)^{(k)} dz \right] \tag{42}$$

$$M_x = C_1 \varepsilon_{pe};\ M_y = C_2 \varepsilon_{pe};\ M_{xy} = C_3 \varepsilon_{pe} \tag{43}$$

$$C_1 = \left(A_1 D_{11} + A_2 D_{12} + A_3 D_{16} \right) \tag{44}$$

$$C_2 = \left(A_1 D_{12} + A_2 D_{22} + A_3 D_{26} \right) \tag{45}$$

$$C_3 = \left(A_1 D_{16} + A_2 D_{26} + A_3 D_{66} \right) \tag{46}$$

II.III Simply supported composite plate excited by piezoelectric actuators

In this analysis, two piezoelectric actuators are surface-bonded on both sides of a simply supported laminated hybrid composite plate. The bending moments are induced in the composite plate by exciting the actuators with constant applied voltage V. These moments are written in terms of unit step functions as follows,

$$m_x = C_1\varepsilon_{pe}[h(x-x_1)-h(x-x_2)][h(y-y_1)-h(y-y_2)] \tag{47}$$

$$m_y = C_2\varepsilon_{pe}[h(x-x_1)-h(x-x_2)][h(y-y_1)-h(y-y_2)] \tag{48}$$

From the classical lamination plate theory, the plate governing equation is expressed in terms of plate internal moments M_x, M_y, M_{xy} and Actuator induced moments m_x m_y as,

$$\frac{\partial^2(M_x-m_x)}{\partial x^2}+2\frac{\partial^2 M_{xy}}{\partial x\partial y}+\frac{\partial^2\left(M_y-m_y\right)}{\partial y^2}=0 \tag{49}$$

$$P=\frac{\partial^2 m_x}{\partial x^2}+\frac{\partial^2 m_y}{\partial y^2} \tag{50}$$

Composite plate internal moments can be expressed in terms of flexural displacement *w*, and the governing equation (49) becomes equation (51) as follows,

$$D_{11}\frac{\partial^4 w}{\partial x^4}+2(D_{12}+2D_{66})\frac{\partial^4 w}{\partial x^2\partial y^2}+4D_{16}\frac{\partial^4 w}{\partial x^3\partial y}+4D_{26}\frac{\partial^4 w}{\partial x\partial y^3}+D_{22}\frac{\partial^4 w}{\partial y^4} = \frac{\partial^2 m_x}{\partial x^2}+\frac{\partial^2 m_y}{\partial y^2} \tag{51}$$

$$P = C_1\varepsilon_{pe}[\delta'(x-x_1)-\delta'(x-x_2)][h(y-y_1)-h(y-y_2)] + C_2\varepsilon_{pe}[h(x-x_1)-h(x-x_2)][\delta'(y-y_1)-\delta'(y-y_2)] \tag{52}$$

The transverse displacement w (x, y) at any point on simply supported rectangular Cross-ply laminated composite Plate excited by the surface bonded piezoelectric actuators is expressed in equation (53) as follows,

$$w(x\,,y)=\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}W_{mn}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b} \tag{53}$$

Where,

$$W_{mn}=\frac{P_{mn}}{D_{11}\alpha^4+2(D_{12}+2D_{66})\alpha^2\beta^2+D_{22}\beta^4} \tag{54}$$

$$P_{mn}=\frac{4}{a\times b}\int_0^b\int_0^a P(x,y)\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b} \tag{55}$$

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$$P_{mn} = \frac{4}{ab}\left[-\frac{m_y\alpha^2 + m_x\beta^2}{\alpha\beta}(\cos\alpha x_1 - \cos\alpha x_2)(\cos\beta\, y_1 - \cos\beta y_2)\right] \tag{56}$$

$$\alpha = \frac{m\pi}{a};\ \beta = \frac{n\pi}{b} \tag{57}$$

III RESULTS AND DISCUSSIONS

In this analysis, an analytical solution of a simply supported laminated hybrid composite plate excited by the surface bonded piezoelectric actuators developed, and this formulation is validated by writing the MATLAB code. The results validated with the published results from Her and Lin[3].

MATLAB code generated to implement this analytical solution methodology and the flow chart is represented in Fig. 1 as follows,

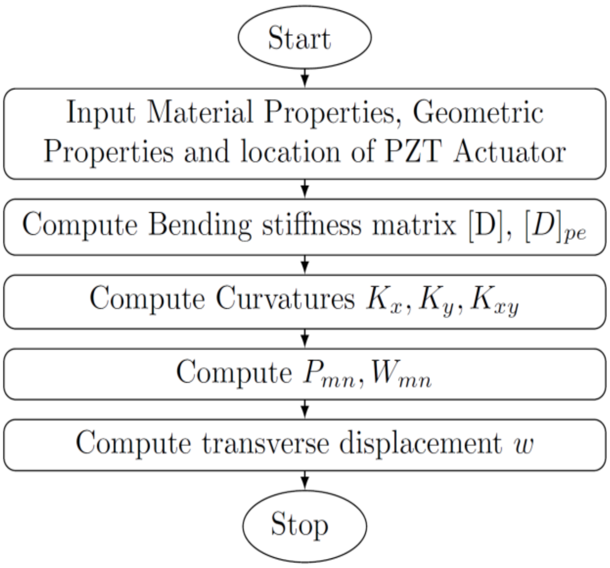

Figure 1. Flow chart of the MATLAB Code

Transverse displacements computed for a simply supported laminated composite plate equipped with piezoelectric actuators (PZT G-1195).

The dimensions of laminated composite plate are are as follows length *a = 380mm*, width *b = 300mm*, Thickness *T =1.5876mm* with the lamination Scheme of [0/90/90/0] throughout this analysis.

The properties of piezoelectric Actuator are Piezoelectric constant d_{31} = 1.9 x 10^{10} V/m, the thickness of piezoelectric actuator t_{pe} = *0.15876mm* and applied voltage = 1V from Her and Lin [3]

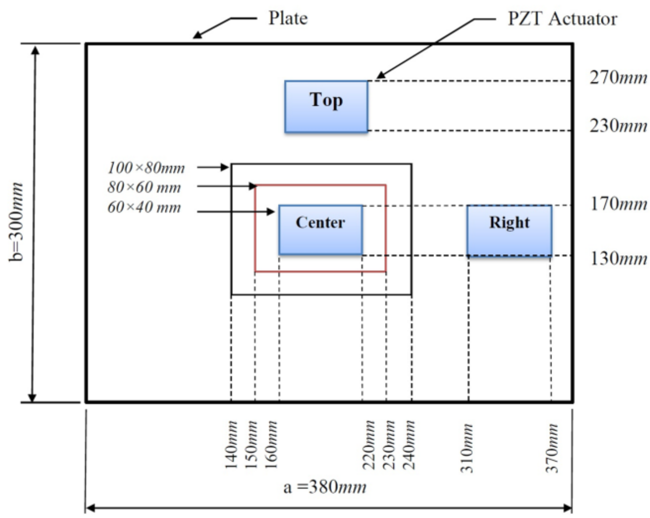

Figure 2. Positions and sizes of piezoelectric Actuators surface bonded on the plate.

The transverse displacement of plates excited by various sizes of piezoelectric actuators and positions evaluated. The present results have a good agreement with the reference [3] as follows

Table 1. Maximum Deflections of Composite Plate induced by placing the Piezoelectric Actuator at different locations in mm

Piezoelectric Actuator	Reference	Present	% Error
Small	0.00159	0.00152	3.77
Medium	0.00273	0.00267	2.56
Large	0.00398	0.00385	3.27
Center	0.00159	0.00152	3.77
Right	0.00080	0.00076	5.00
Top	0.00134	0.00132	1.42

Further, the MATLAB code extended to calculate the displacements of various laminated hybrid composite plates given in the following sections.

III.I HYBRID LAMINATED COMPOSITE PLATES

In this analysis, a four-layered simply supported hybrid composite plates with the combinations of Carbon/epoxy, Graphite/epoxy and Kevlar/epoxy laminas with [0/90/90/0] ply orientation is excited by three different sizes of Piezoelectric Actuators.

The dimensions of the composite Plate are Length of the composite Plate a = 400mm Width of the composite plate b = 300mm, Thickness of the plate T = 1.5678mm. The dimensions of piezoelectric actuators taken from Fig 2. The properties of composite laminas and the piezoelectric actuators considered from Table 2 from [8].

Table 2. Properties of lamina and PiezoelectricActuator

Lamina /Actuator	E_{11} *(GPa)*	E_{22} *(GPa)*	G_{12} *(GPa)*	Poisson's ratio ϑ
Carbon/epoxy [C]	108	10.3	7.13	0.28
Graphite/epoxy[G]	137.9	8.96	7.20	0.30
Kevlar/epoxy [K]	53.8	17.93	8.96	0.56
PZT(G1195)Actuator	63	-	-	0.3

The results represented in Fig (3-8) for the same quantity of graphite-epoxy and kevlar epoxy laminates, [G/K/K/G] lamination Scheme makes soft structure and [K/G/G/K] lamination Schemes makes the rigid structure

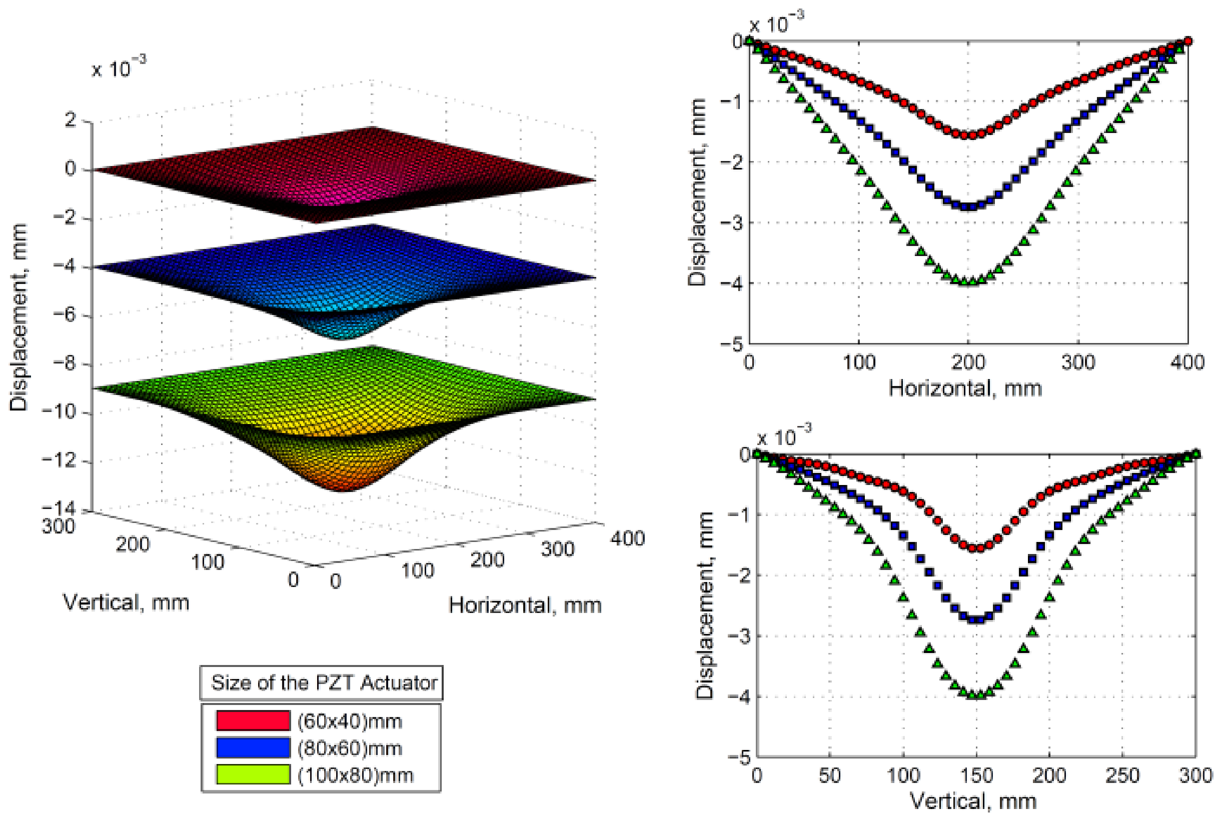

Figure 3. Displacements of [C/C/C/C] composite plate excited by Piezoelectric Actuators

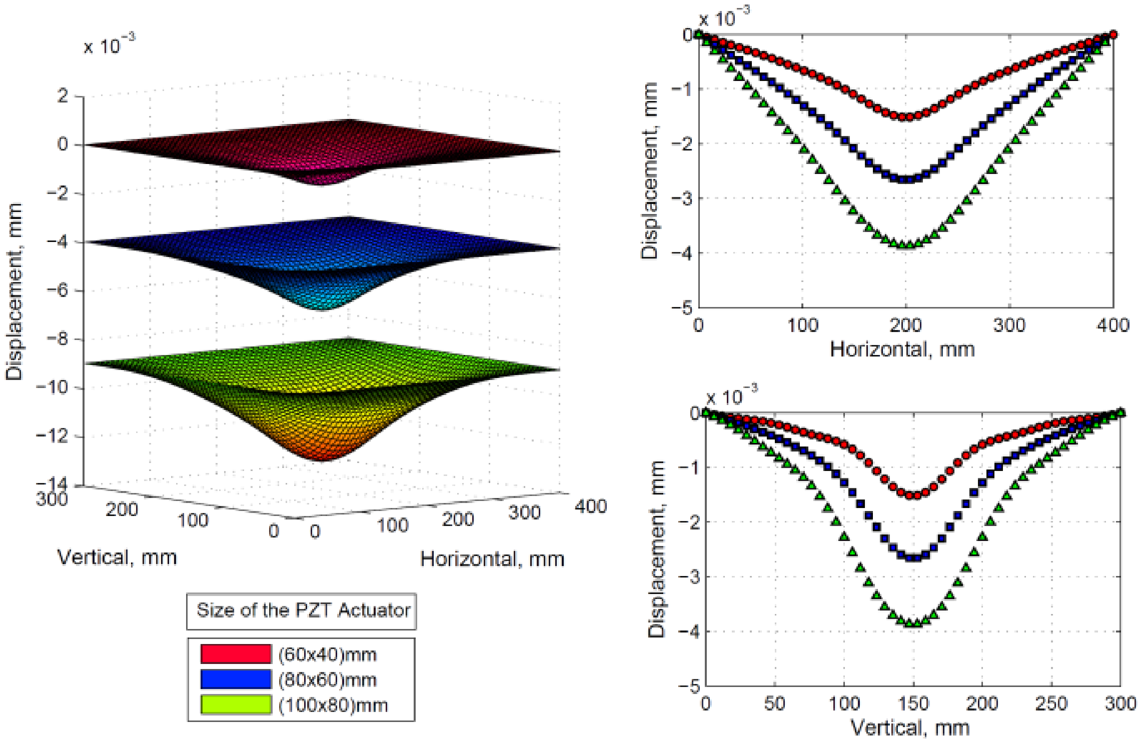

Figure 4. Displacements of [G/G/G/G] composite plate excited by Piezoelectric Actuators

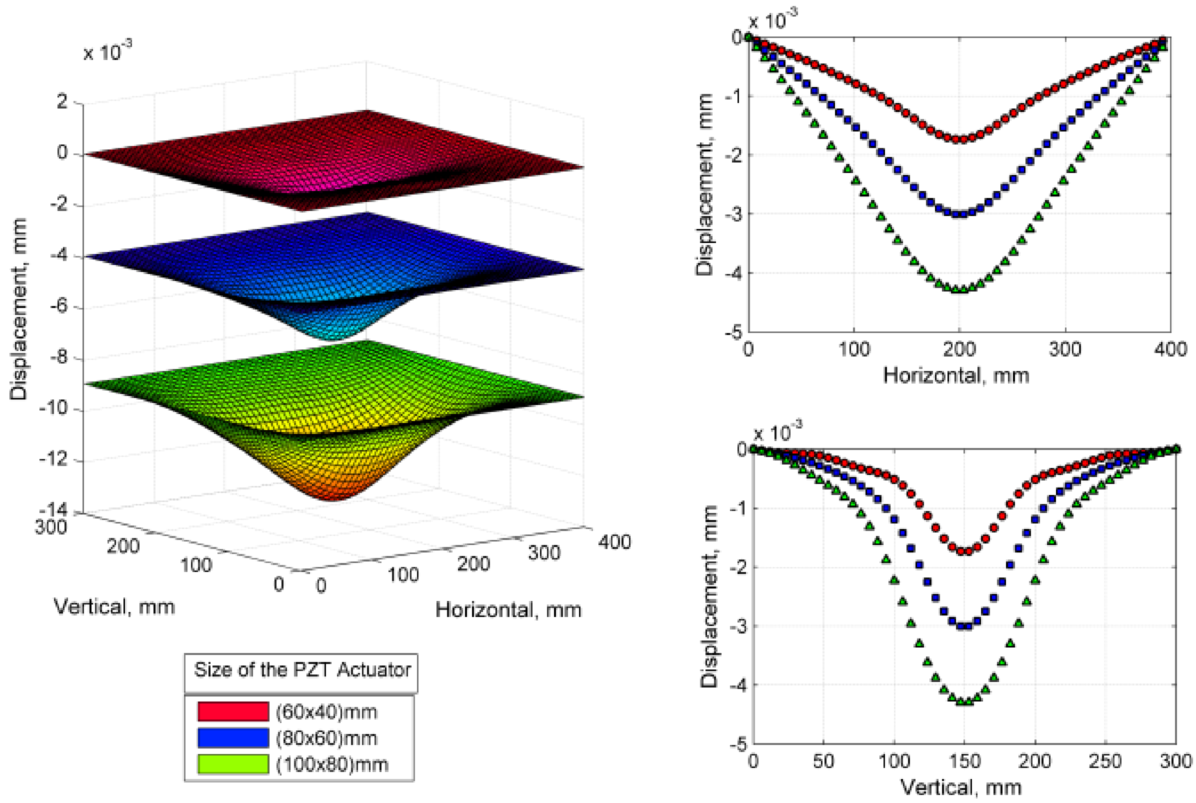

Figure 5. Displacements of [G/K/K/G] composite plate excited by Piezoelectric Actuators

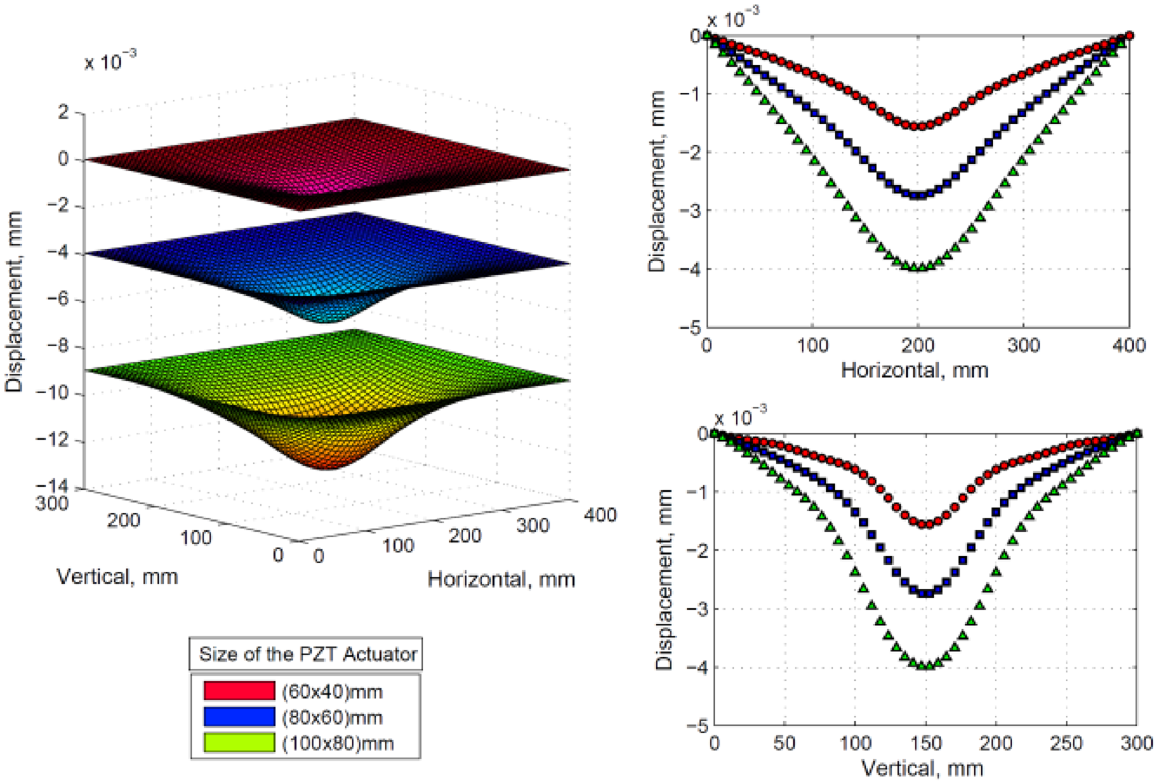

Figure 6. Displacements of [G/K/G/K] composite Plate excited by Piezoelectric Actuators

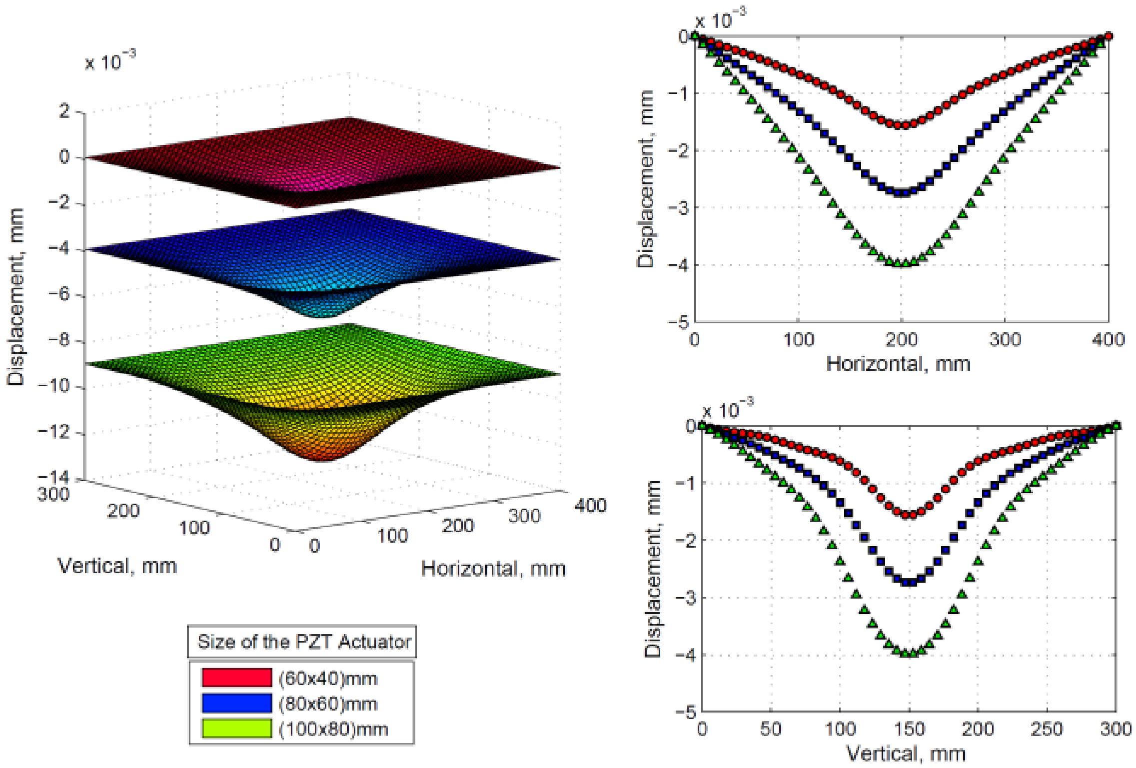

Figure 7. Displacements of [K/G/G/K] composite plate excited by Piezoelectric Actuators

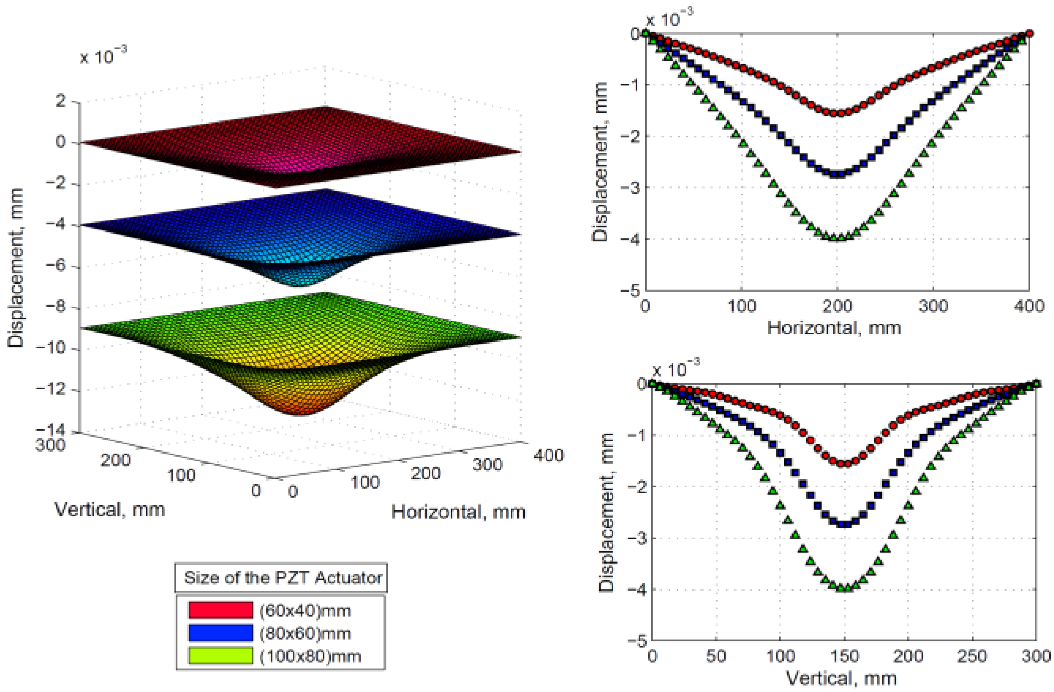

Figure 8. Displacements of [K/K/K/K] composite Plate excited by Piezoelectric Actuators

III.II VARIABLE SIZES OF PIEZOELECTRIC ACTUATORS

The maximum transverse displacements of various combinations of hybrid composite plates excited by three different sizes of piezoelectric actuators at constant applied voltage represented in Fig. 9 and these are varied linearly with the size of the piezoelectric actuators

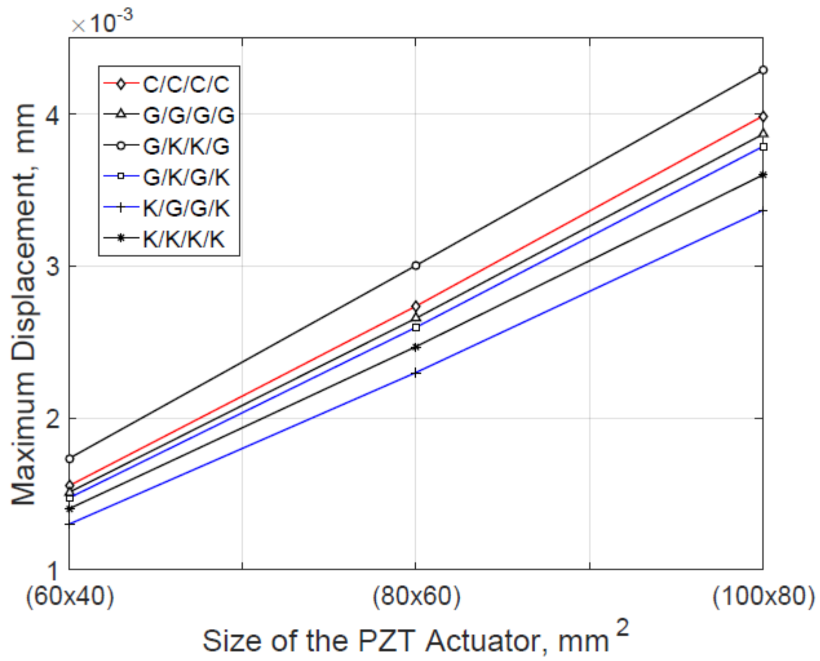

Figure 9. Maximum displacements of hybrid composite plates excited by various sizes of Piezoelectric Actuators

III.III Variable Applied voltage

The maximum transverse displacements of a simply supported Carbon/epoxy laminated composite plates excited by three different sizes of piezoelectric actuators by varying the applied voltage from 1v to 20v. The results represented in Fig. 10, the displacements are changed linearly with the applied voltage.

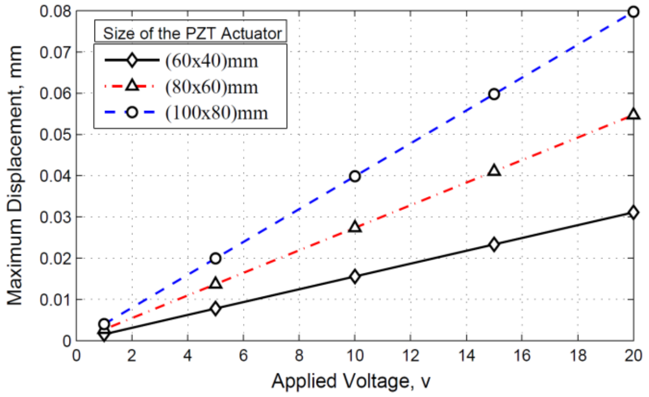

Figure 10. Maximum displacements composite plates with variable applied voltage

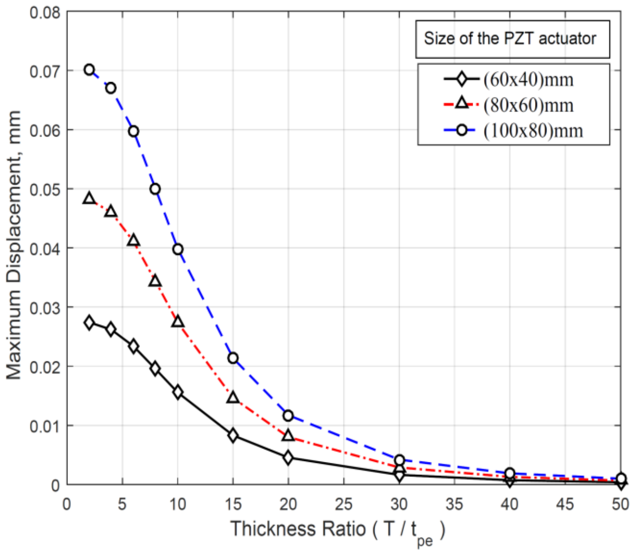

Figure 11. Maximum displacements of a composite plate with variable thickness ratios

III.IV Variable Thickness Ratio (T/t_{pe})

The ratio of a thickness of the composite plate and thickness of the piezoelectric Actuator denoted as Thickness Ratio. In this case, a four-layered carbon/epoxy laminated composite plate of lamination scheme [0/90/90/0] is excited by three sizes of Piezoelectric Actuators with a continuously applied voltage 10v, by varying the thickness ratio from 1 to 50. The maximum displacements calculated and represented in Fig 11. as the thickness ratio increases the maximum displacements are decreases. since the strains induced in the piezoelectric actuators are inversely proportional to the thickness of the piezoelectric Actuator.

CONCLUSION

The focus of this paper is on the static behaviour of hybrid composite plates with the effect of variation in sizes, an applied voltage of the piezoelectric actuators, and the variable thickness ratios. In this analysis, the displacements evaluated with various combinations of hybrid laminated plates and observed that the lamination scheme and ply orientation of hybrid composites plays a vital role in displacements. The stiffness of the composite plate can be controlled not only by varying the lamination scheme and ply orientation but also with the variation in the applied voltage. The transverse displacements are varying linearly with the applied voltage and size of the piezoelectric actuators. This paper makes the first attempt to survey and discuss the effect of thickness ratio on the transverse displacements, and the transverse displacements are varied directly proportional to the thickness ratio.

Nomenclature

a	Length of the composite Plate
b	Width of the composite Plate
T	The total thickness of the composite plate
t_{pe}	The thickness of the Piezoelectric Actuator
t	The thickness of the half of the composite plate
Pe	Piezoelectric Actuator
m_x, m_y	Moments produced by PZT plate
ε_{pe}	Strain in piezoelectric Actuator

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