Behaviour of laminated composite sandwiched structures under thermal conditions

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Abstract: Laminated composite structures with their properties such as high specific strength, low self-weight and high stiffness to weight ratio along with their design flexibility made them widely used in the field of manufacturing of aircraft, structural engineering, aerospace and other engineering field. But the analysis of behaviour of laminated composite structures is very difficult due to their layered structural arrangement. In this study, 3-D finite element based model for the analysis of laminated composite and sandwich structures are developed using ABAQUS software and the behaviour of the model under different thermal stress condition along with various conditions such as aspect ratio thickness ratio and boundary condition is analysed.

Keyword: laminated composite structures, sandwich structures

1. INTRODUCTION

Laminated composite structures are layered structures which are made up of combination of materials which are arranged together to obtain specific structural properties such as high specific strength, low weight, high stiffness to weight ratio etc. with respect to the individual material, laminated composite material made from these individual material, possess superior properties. In advanced composite material, fibrous material which are oriented in different directions is embedded in a resinous matrix which as a whole act integral gives strength and stiffness.[1]

Composite structures are generally subjected to various environmental conditions such as temperature, moisture etc. which will affect their performance in one way or another. It is found that the effect of laminated composite structures exposed to temperature is adverse. The resinous matrix in the laminates will expand or contract with respect to the increase or decrease in temperature which they are exposed to. But the fibres which are embedded it the matrix are not much viable to expansion or contraction because of the temperature variation. This will lead to the development of stress within the laminates. This introduced thermal stress will affect the performance of the laminated composite structures in structural application. Also the increase in temperature leads to the softening of the polymer matrix which will lead to the decrease in stiffness of the material. The effect of thermal condition in the degradation of the structural property of the laminated composite structure made the analysis of laminated composite structure under various thermal condition important.[2][3]

2. MATERIAL PROPERTIES AND MODELLING

The material properties for the laminated composite structures are $E_1=172.4\text{Gpa}$, $E_2=E_3=6.89\text{Gpa}$, $v_{12}=v_{13}=v_{23}=0.25$, $G_{12}=G_{13}=3.45\text{Gpa}, G_{23}=1.378\text{Gpa}, \alpha_1=1.0/k, \alpha_2=\alpha_3=1125.0/k$
Three layered square laminates (0,90,0) having the above given material properties with simply supported boundary condition is modelled.

Aspect ratio (a/h) used in the modelling are 4,10 and 20.

The thermal load considered are the following

1. The top and bottom surface is subjected to sinusoidal implane variation of equal rise;
\[ \Delta T(x, y, \pm \frac{h}{2}) = T_0 \sin \frac{\pi x}{a} \sin \frac{\pi y}{b} \]

2. The top and the bottom surface of the laminated plate is subjected to equal rise and fall to temperature; \[ \Delta T(x, y, \pm \frac{h}{2}) = -\Delta T(x, y, -\frac{h}{2}) = T_0 \sin \frac{\pi x}{a} \sin \frac{\pi y}{b} \]

3. RESULTS AND DISCUSSION

The analysis of laminated composite symmetrical plates modelled under the two thermal conditions for different aspect ratio is carried out. Table 1 represents the results of three layered laminated composite plates of cross ply aligned (0/90/0) for various aspect ratio (4,10,20) under two thermal condition, one with the top and bottom surface is subjected to sinusoidal implane variation of equal rise in temperature(Case A) and the other with the top and the bottom surface of the laminated plate is subjected to equal rise and fall to temperature respectively(Case B). The result obtained is in accordance with the research which was already done on similar model[4].

Table 2 represents the maximum stress(\(\sigma_x, \sigma_y, \tau_{xy}, \tau_{xz}\) and \(\tau_{yz}\)) and the transverse displacement (\(\omega\)) of three layered sandwich plates, obtained from the analysis of three layer sandwich plates(0,core,0) having simply supported boundary condition exposed to thermal condition Case A and Case B. The values obtained from present study with respect to that obtained in similar model [4] is having slight variation and is comparable.

The plot contours principal stresses and traverse displacement on deformed shape obtained for symmetric laminates plates having 1x1m dimension of cross ply arrangement (0,90,0) exposed to thermal condition Case A is shown in the figures given below. The plot contours of principal stress on deformed shape is shown in ‘figure 1’, ‘figure 2’, ‘figure 3’ and ‘figure 4’. Plot contours of traverse displacement on deformed body is shown in ‘figure 5’.

**Table 1.** Maximum stress(\(\sigma_x, \sigma_y, \tau_{xy}, \tau_{xz}\) and \(\tau_{yz}\)) and the transverse displacement (\(\omega\)) of three layered symmetric composite plates (0/90/0) under thermal load Case A : \[ \Delta T(x, y, \pm \frac{h}{2}) = T_0 \sin \frac{\pi x}{a} \sin \frac{\pi y}{b} \]

| S | source | \(\sigma_x\) (a, b, \pm \frac{h}{2}) | \(\sigma_y\) (a, b, \pm \frac{h}{2}) | \(\tau_{xy}\) (0,0,±4h) | \(\tau_{xz}\) (0,0,±4h) | \(\tau_{yz}\) (0,0,±4h) | 10\(\omega\) (a, b, \pm \frac{h}{2}) |
|---|---|---|---|---|---|---|---|
| 4 | Present Kant et al | 79.9875 | 80.7516 | -49.0154 | -49.9119 | -11.2943 | -11.6824 | ±32.9823 | ±33.3088 | ±26.1953 |
| 10 | Present Kant et al | 6.2543 | 6.1090 | -9.9513 | -9.8927 | -0.8067 | -0.8247 | ±5.4854 | ±5.3374 | ±0.6895 |
| 20 | Present Kant et al | 1.2587 | 1.2300 | -2.5839 | -2.5547 | -0.1729 | -0.1614 | ±2.5852 | ±2.5267 | ±0.058 |


Table 2. Maximum stress($\sigma_x, \sigma_y, \tau_{xy}, \tau_{xz}$ and $\tau_{yz}$) and the transverse displacement ($\omega$) of three layered sandwich plates

Case A: $\Delta T(x, y, \pm \frac{h}{2}) = T_0 \sin \frac{\pi x}{a} \sin \frac{\pi y}{b}$

| S | source | $\bar{\sigma}_x (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ | $\bar{\sigma}_y (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ | $\tau_{xy} (0, 0, \pm 0.4h)$ | $\tau_{xz} (0, 0, \pm 0.4h)$ | $\tau_{yz} (0, 0, \pm 0.4h)$ | $10\omega (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ |
|---|---|---|---|---|---|---|---|
| 4 | Present | $\pm 0.4585$ | $\pm 0.5402$ | $\pm 3.8687$ | $\pm 2.4408$ | $\pm 0.4658$ | $\pm 1.1311$ |
| | Kant et al | $\pm 0.4505$ | $\pm 0.5315$ | $\pm 3.8640$ | $\pm 2.4380$ | $\pm 0.4620$ | $\pm 1.1280$ |
| 10 | Present | $\pm 0.0745$ | $\pm 0.0893$ | $\pm 0.6162$ | $\pm 0.4091$ | $\pm 0.7632$ | $\pm 0.2999$ |
| | Kant et al | $\pm 0.0741$ | $\pm 0.0857$ | $\pm 0.6150$ | $\pm 0.4080$ | $\pm 0.7610$ | $\pm 0.0260$ |
| 20 | Present | $\pm 0.0192$ | $\pm 0.025$ | $\pm 0.1572$ | $\pm 0.1028$ | $\pm 0.020$ | $\pm 0.0019$ |
| | Kant et al | $\pm 0.0186$ | $\pm 0.0214$ | $\pm 0.1536$ | $\pm 0.1026$ | $\pm 0.0191$ | $\pm 0.0016$ |

Case B: $\Delta T(x, y, -\frac{h}{2}) = -\Delta T(x, y, \frac{h}{2}) = T_0 \sin \frac{\pi x}{a} \sin \frac{\pi y}{b}$

| S | source | $\bar{\sigma}_x (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ | $\bar{\sigma}_y (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ | $\tau_{xy} (0, 0, \pm 0.4h)$ | $\tau_{xz} (0, 0, \pm 0.4h)$ | $\tau_{yz} (0, 0, \pm 0.4h)$ | $10\omega (\frac{a}{2}, \frac{b}{2}, \pm \frac{h}{6})$ |
|---|---|---|---|---|---|---|---|
| 4 | Present | $\pm 0.6281$ | $\pm 0.7912$ | $\pm 2.745$ | $0.1269$ | $-0.1432$ | $5.6112$ |
| | Kant et al | $\pm 0.6271$ | $\pm 0.7904$ | $\pm 2.7440$ | $0.1259$ | $-0.1425$ | $5.6024$ |
| 10 | Present | $\pm 0.1321$ | $\pm 0.1658$ | $\pm 0.2540$ | $0.0396$ | $-0.04$ | $0.5142$ |
| | Kant et al | $\pm 0.1317$ | $\pm 0.1651$ | $\pm 0.2530$ | $0.0382$ | $-0.0394$ | $0.5139$ |
| 20 | Present | $\pm 0.362$ | $\pm 0.0449$ | $\pm 0.0499$ | $0.0113$ | $-0.0121$ | $0.1016$ |
| | Kant et al | $\pm 0.0351$ | $\pm 0.0441$ | $\pm 0.0494$ | $0.0109$ | $-0.0111$ | $0.1002$ |

Figure 1. Plot contours of major principal stress on deformed shape
Figure 2. Plot contours of implane stress $\tau_{xy}$ on deformed shape

Figure 3. Plot contours of implane stress $\tau_{yz}$ on deformed shape

Figure 4. Plot contours of implane stress $\tau_{xz}$ on deformed shape
4. CONCLUSION

Each of the theory available along with the available possible methods for analysis of laminates under hygro-thermal conditions has its own merits and demerits and is much complex. The use of ABAQUS software which is a finite element based software package reduce the computational efforts for complex structures. Also the model done in ABAQUS software which is found to be applicable in one condition can be applied to other conditions such as varied boundary condition, aspect ratio etc. with minor modifications. The model is applicable to its best under various conditions such as aspect ratio, thickness ratio, boundary conditions etc.

5. SCOPE OF FUTURE STUDY

The present study can be further extended in the following cases

1. Considering the moisture diffusion effect in the laminated composites along with the temperature effect
2. Effect of static and dynamic loads on laminated composite plates in combination with hygro-thermal stresses
3. Analysis of skew laminated composite and sandwich plates under hygro-thermal conditions

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