Research Article

Effect on Strength of Different Fiber Orientation Angles of the Composite Plate Under Out of Plane Load

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(First received September 20, 2022 and in final form December 21, 2022)

Reference: Yılmaz, E. Effect on Strength of Different Fiber Orientation Angles of the Composite Plate Under Out of Plane Load. The European Journal of Research and Development,2(4), 192-202.

Abstract

Composite materials obtained by combining two or more materials macroscopically; It is expressed as a new type of material with low specific gravity, high strength and high rigidity properties. Composite materials are materials that are used under different loads and can be produced in various constructions. In this study, the effects of fiber orientation angle degrees on stress and deformation in composite plates with different fiber materials were investigated using the finite element method. Graphite, glass and aramid as fiber materials; Epoxy was chosen as the matrix material. According to the analysis results, while the stress and deformation values increased as the fiber angle increased in the graphite and aramid fiber epoxy matrix composite plates, the stress and deformation values did not change at different fiber angles in the glass fiber epoxy matrix composite plate.

Keywords: *Graphite fiber composite, Glass fiber composite, Aramid fiber composite, Deformation analysis, Stress Analysis.*

1. Introduction

Composite materials are macroscopic combinations of two or more materials that differ in structure and chemical composition and are essentially insoluble in each other. Composites consist of materials dispersed in a matrix that can have a unique or complex composition, and the fibers or particles are called reinforcing materials. These materials are produced by physically combining a discontinuous phase, which can be in the form of fibers, particles, or meshes, with a continuous phase called a matrix. Laminate composite is a suitably bonded combination of fiber and resin. One of the unique properties of composite laminate is its high specific resistance.

Properties of composite are a function of properties of its components and geometry of reinforcing layers, which includes shape, size, quantity, distribution and orientation of the fibers or particles. Matrix gives composite material its structure, provides load distribution by the fibers and protects their surface. Ease of processing (design flexibility) combined with its low density (and chemical resistance) make composite polymer matrix materials now materials with a wider range of applications and are required for further development. There is a high degree of versatility in mechanical properties of composite materials reinforced with continuous fibers. With choice of strength, type, shape, proper fiber orientation, and location of control fiber concentration, there can be significant differences in different areas of composite. In addition, physical properties of fiberglass composite such as electrical conductivity, corrosion resistance and thermal stability can be changed by changing processing conditions of composite and choosing appropriate matrix material [8] [17] [18].

Bahei-El-Din & Dvorak [1] studied mechanical behavior of symmetrical metal matrix composite sheets under certain load. Bienias & Jakubczak [2] studied impact damage in carbon fiber aluminum composite sheets. Eltaher et al. [3] studied energy distribution in dispersed composite layers under out-of-plane loading. Finn et al. [4] investigated delaminations experimentally in composite sheets under transverse impact loads. Fuller & Wisnom [5] studied strength properties of carbon epoxy thin-ply angle layers. Gonzalez et al. [6] studied impact strength properties of ply clusters of polymer-based composite sheets. Guillamet et al. [7] studied extent of damage at edges of unfolded thin composite sheets under off-axis loading. Kim et al. [10] studied damage resistance of composite material under out-of-plane loading. Mikkor et al. [12] investigated damage amount of composite panel under effect of a certain force using finite element method. Rad et al. [13] studied effects of creep load of angled glass fiber epoxy composite sheets on material. Rathnasabapathy et al. [14] studied impact damage of metal fiber layers under pressure load. Rathnasabapathy et al. [15] studied impact damage of metal fiber composite sheet under certain force. Shyr & Pan [16] studied impact strength properties of glass fiber reinforced composite sheets with different fiber angles. Sousa et al. [18] investigated mechanical properties of glass fiber reinforced composite sheet according to different fiber angles experimentally. Wagih et al. [19] studied behavior of polymer-based composite layers under out-of-plane load according to different thicknesses and load levels. Wagih et al. [20] studied impact behavior of composite layers under out-of-plane load. Yamada et al. [21] studied mechanical properties of thin-layer metal fiber composite sheets under out-of-plane loading. Yılmaz [22] studied mechanical behavior of steel fiber reinforced composite plates under axial load. Yokozeki et al. [23] investigated strength and damage resistance properties of thin-layer fiber epoxy layers experimentally. Yokozeki et al. [24] studied damage characterization of thin-layer composite layers under out-of-plane loading. Yuan et al. [25] investigated strength properties of thin-layered CFRP angled composite layer using finite element method. Yuan et al. [26] experimentally investigated behavior of composite layer with different carbon fiber angles. Zhang et al. [27] studied impact damage of carbon fiber composite plates. Zhang et al. [28] studied failure mechanisms of CFRP and C/C composite joints under out-of-plane load.

In this study, effect on mechanical behaviors of cantilever under out-of-plane load graphite fiber epoxy matrix, glass fiber epoxy matrix and aramid fiber epoxy matrix composite plates of different fiber angles were investigated.

2. Materials and Methods

The cantilever composite plate under the out-of-plane total P load analyzed in figure 1.

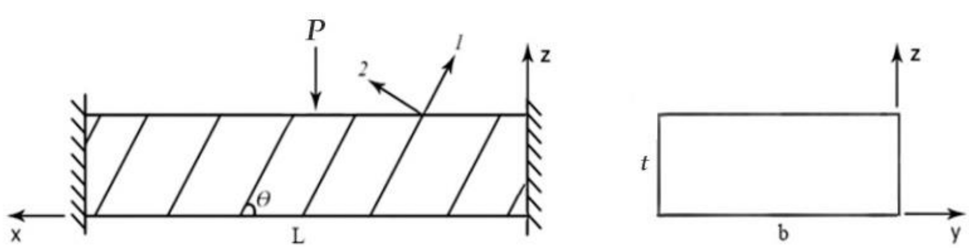

Figure 1: Composite Plate Under Out of Plane Load

In Figure 1, ϴ represents the fiber orientation angle, and axes 1-2 represent the principal axes of the fibers. Structure of composite plate is sandwich composite type.
Load and dimension properties of the analyzed layer are given in Table 1; The mechanical properties of graphite fiber, glass fiber, aramid fiber and epoxy materials are given in Table 2.

Table 1: Dimensional properties of the loaded composite plate

P (kN)	L (mm)	b (mm)	t (mm)
10	300	150	15

Table 2: Mechanical properties of the fiber and matrix materials [9]

Mechanical Properties	Graphite Fiber	Glass Fiber	Aramid Fiber	Epoxy Matrix
Longitudinal module (GPa)	230	85	124	3.4
Transverse module (GPa)	22	85	8	3.4
Longitudinal poisson's ratio	0.30	0.20	0.36	0.3
Transverse poisson's ratio	0.35	0.20	0.37	0.3
Longitudinal shear module (GPa)	22	35.42	3	1.308
Longitudinal tensile strength (MPa)	2067	1550	1379	72
Longitudinal compressive strength (MPa)	1999	1550	276	102
Transverse tensile strength (MPa)	77	1550	7	72

Transverse compression strength (MPa)	42	1550	7	102
Shear strength (MPa)	36	35	21	34

2.1. Nodal Parameters and Displacement Functions

Figure 2 shows quadratic multilayer plate element. Displacement components of a typical node j consist of the in-plane displacements u_{0j} and v_{0j} of reference x-y plane lateral displacements w_j and normal rotations Θ_{xij} in each layer. These may be listed by vector [11]

$$\{\delta_j\} = \{u_{0j}, v_{0j}, w_j, \theta_{x1j}, \theta_{y1j}, \theta_{x2j}, \theta_{y2j}, ..., \theta_{xmj}, \theta_{ymj}\}^T \tag{1}$$

and element displacement by vector

$$\{\delta\} = \{\delta_1, \delta_2, ...\delta_8\}^T \tag{2}$$

where m is total number of layers.

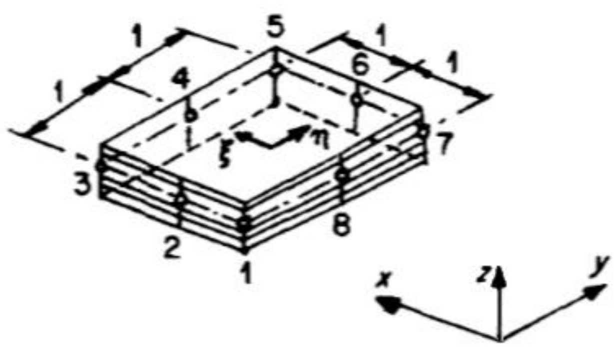

Figure 2: Quadratic multilayer plate element [11]

A shape function description is then adopted to define the displacements of any point (x, y, z) in *i*th layer in terms of the nodal displacements as follows [11]

$$u = \sum_{j=1}^{8} N_j \left\{ u_{0j} - qt_1\theta_{x1j} - \sum_{p=2}^{i-1} t_p \theta_{xpj} - \left(\frac{1}{2} t_i + z_i \right) \theta_{xij} \right\} \quad (3)$$

$$v = \sum_{j=1}^{8} N_j \left\{ v_{0j} - qt_1\theta_{y1j} - \sum_{p=2}^{i-1} t_p \theta_{ypj} - \left(\frac{1}{2} t_i + z_i \right) \theta_{yij} \right\} \quad (4)$$

$$w = \sum_{j=1}^{8} N_j w_j \quad (5)$$

where Nj are simple isoparametric shape functions given in terms of the normalized coordinates ξ and μ by the following equations. At corner nodes [11]

$$N_j = \frac{1}{4}(1+\xi_0)(1+\mu_0)(\xi_0+\mu_0-1) \quad (6)$$

2.2. Finite Element Analysis

The plate analyzed by the finite element method in SolidWorks Simulation program is shown in Figure 3. Boundary conditions in Table 1 and material properties in Table 2 were used. The plate was cantilevered on both sides by applying an out-of-plane total load P. In the analysis, 2 mm trigonal mesh was applied on the plate and Von Mises was used as yield criterion.

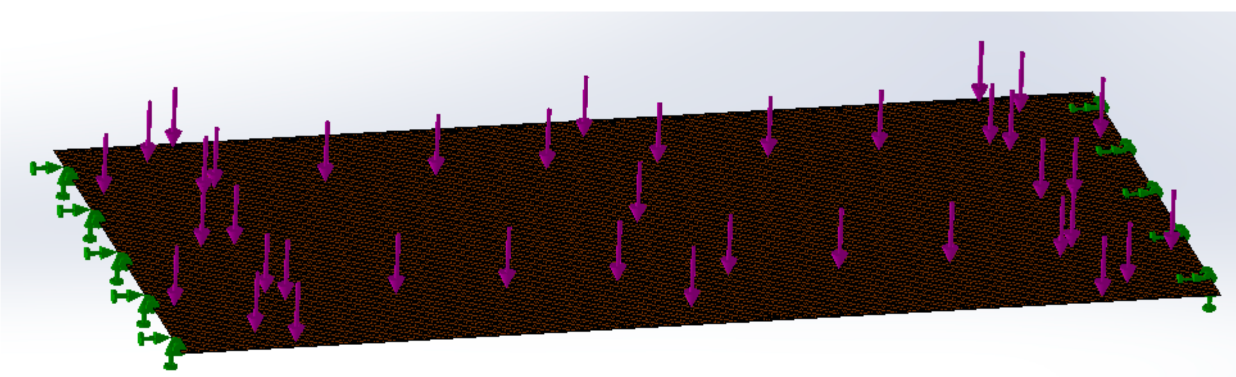

Figure 3: Composite plate with boundary conditions applied in SolidWorks Simulation

3. Results

Maximum stress results for fiber angles are in table 3 and graphic figure 4 of these results, maximum deformation results for fiber angles are in table 4 and graphic figure 5 of these results.

Table 3: Maximum stress for fiber angles

Fiber Angle (degree)	Graphite Fiber Epoxy Matrix (MPa)	Glass Fiber Epoxy Matrix (MPa)	Aramid Fiber Epoxy Matrix (MPa)
0	11.360	95.620	10.530
30	19.150	95.620	21.210
45	33.420	95.620	27.410
60	55.700	95.620	31.830
90	89.640	95.620	68.160

Table 4: Maximum deformation for fiber angles

Fiber Angle (degree)	Graphite Fiber Epoxy Matrix (mm)	Glass Fiber Epoxy Matrix (mm)	Aramid Fiber Epoxy Matrix (mm)
0	1.475	2.921	2.187
30	2.252	2.921	3.044
45	3.093	2.921	3.895
60	3.871	2.921	4.678
90	4.431	2.921	5.351

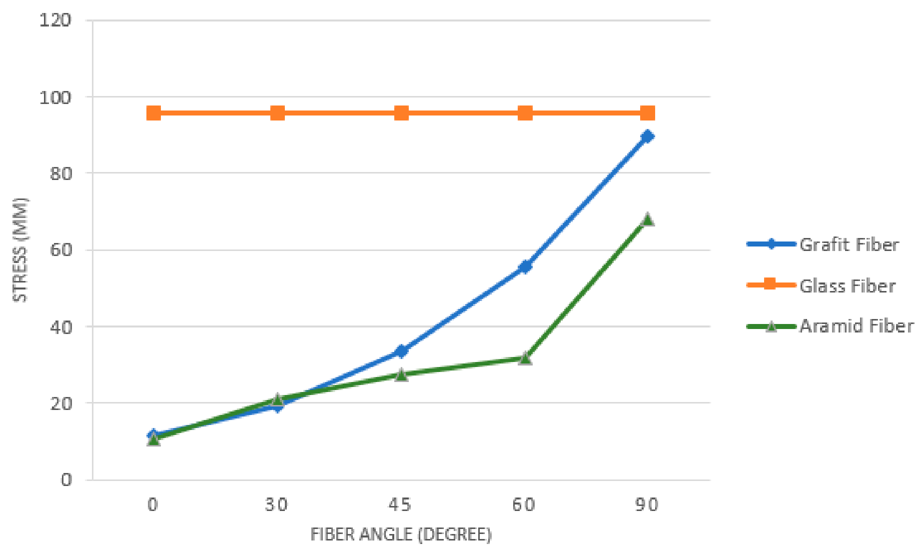

Figure 4: Variation of stress for fiber angles

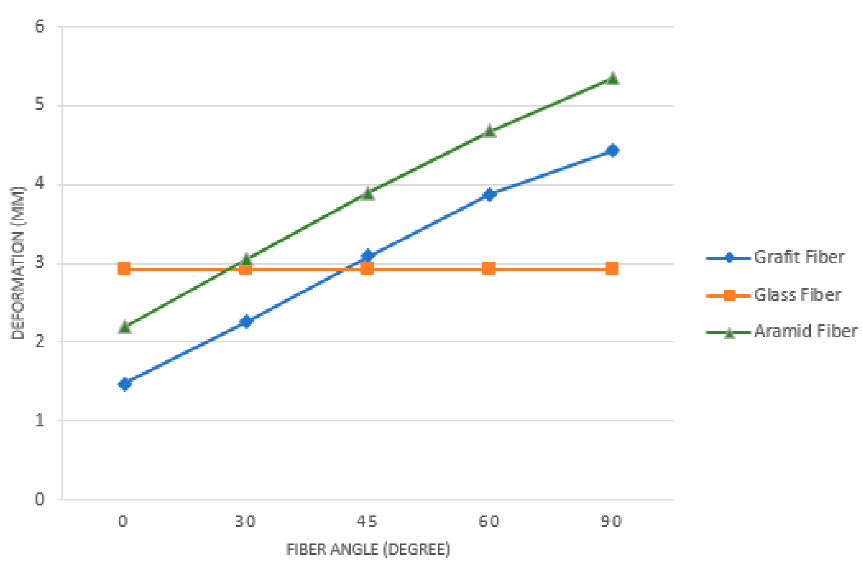

Figure 5: Variation of deformation for fiber angles

4. Discussion and Conclusion

According to the analysis results (Table 3 and Table 4):

- Minimum stress of the Graphite Fiber Epoxy Matrix composite plate is 11.360 MPa at 0 degree fiber angle, maximum stress is 89.640 MPa at 90 degree fiber angle
- Stress of the Glass Fiber Epoxy Matrix composite plate is 95.620 MPa at different fiber angles
- Minimum stress of the Aramid Fiber Epoxy Matrix composite plate is 10.530 MPa at 0 degree fiber angle, maximum stress is 68.160 MPa at 90 degree fiber angle
- Minimum deformation of the Graphite Fiber Epoxy Matrix composite plate is 1.475 mm at 0 degree fiber angle, maximum deformation is 4.431 mm at 90 degree fiber angle
- Deformation of the Glass Fiber Epoxy Matrix composite plate is 2.921 mm at different fiber angles.
- Minimum deformation Aramid Fiber Epoxy Matrix composite plate is 2.187 mm at 0 degree fiber angle, maximum deformation is 5.351 mm at 90 degree fiber angle.

As the fiber angle values of graphite fiber epoxy matrix composite plate and aramid fiber epoxy matrix composite plate under the effect of out-of-plane load increase, stress and deformation increase, while stress and deformation remain constant at different fiber angles for glass fiber epoxy matrix composite plate. According to this study, under the effect of out-of-plane load; for graphite fiber epoxy composite plate, glass fiber epoxy composite plate and aramid fiber epoxy composite plate, no angle should be applied to fibers when maximum strength of material is required in relevant design.

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