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Investigation of the Effect of Fiber Orientation on Mechanical Properties of Composite Laminate Using Numerical Analysis

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Abstract :

There has been a considerable increase in the use of advanced composite materials in various industries in recent years. The reason for this increase can be attributed to the great improvement of strength to weight or rigidity to weight ratio in the composite materials. The development of composite material with reduced weight and increase strength relative to conventional metals has played a critical role in achieving higher operating performance, long life and reduced cost. One such composite material is glass epoxy. Glass epoxy composite materials are being widely used in a variety of high-performance structures. Reliable use and optimum design requires accurate methods for predicting their mechanical behavior, among other things. In this article, epoxy specimen is manufactured, elastic modulus for matrix material i.e. Epoxy has found experimentally in universal testing machine. And in theoretical background Timoshenko beam deflection theory uses superposition of the bending and shears deflection. Modeling of composite specimen will be carried out and by finite element analysis stress strain behavior of such a specimen is analyzed with ansys software. Thus the effect of change in volume fraction of fibers in a glass epoxy composites is analyzed theoretically, experimentally and by finite element method.

Keywords: Epoxy resin, Glass Fiber, Sandwich beams, Laminated composite beams, Finite element analysis.

1.Introduction

Fiber-reinforced composite laminates are commonly used in the construction of aerospace, civil, marine, automotive and other high performance structures due to their high specific stiffness and strength, excellent fatigue resistance, longer durability as compared to metallic structures, and ability to be tailored for specific applications. Composite materials can be tailored to meet the particular requirements of stiffness and strength by altering layup and fiber orientations. The ability to tailor a composite material to its job is one of the most significant advantages of a composite material over an ordinary material. So the research and development of composite materials in the design of mechanical, aerospace, and civil structures has grown tremendously in the past few decades as studied by [1] and [2]. The main benefit of using the sandwich concept in structural components is its high bending stiffness and high strength to weight ratios [4]. In addition, sandwich constructions are preferred over conventional materials because of its high corrosion resistance, With its many advantages, It has been widely used in the automotive, aerospace, marine and other industrial applications. This composite material also draws a lot of interest in the construction industry and is now beginning to be in use for civil engineering applications [5] and [6].

Effect of fiber orientation on fracture toughness of laminated composite plates Ramazan Karakuzua, Z uleyha Aslanb [8]. Fracture toughness is obtained by determining failure loads. For numerical study, ANSYS is used. Material properties of laminates are calculated with classical laminated plate theory and applied to the finite element model by using plane element. Effect of fiber orientation on mechanical properties of the laminated polymer composites subjected to out-of-plane high strain rate compressive loadings. G.C. Papanicolao, S.P.Zaoutsos, E.A. Kontou [9] The effects of fiber orientation and strain rates in a glass/epoxy composite material under compressive dynamic loading are examined. Moreover, families of compressive stress–strain curves, as well as failure modes, at dynamic strain rates at a series of fiber orientation were determined.

2.Methematical model

Timoshenko beam deflection theory uses superposition of the bending and shears deflection, The general form of equation of Timoshenko beam deflection theory is,

$$\delta = \frac{C_1 PL^3}{EI} + \frac{C_2 PL}{KGA}$$

Mid span strain values was used to determine modulus base on beam theory,

$$E_{strain} = \frac{Mc}{I\varepsilon}$$

From the modulus values calculated using strain and deflection KGA is calculated. The KGA terms from shear deformable beam theory (Timoshenko) the predicted deflection without shear can be found as,

$$Y_{strain} = \left(\frac{L^2}{4} - \frac{L^2}{2} + \frac{a^2}{3} \right) \frac{M}{2E_{strain} I}$$

The measured deflection is combination of this value and shear contribution.

$$Y_{measured} = Y_{shear} + Y_{strai}$$

The above equation is solved for the Y_{shear} based on the known deflection ($Y_{measured}$). KGA is found from following equation

$$Y_{shear} = \frac{PL}{8KGA}$$

Load is applied at one fourth of total span length. For obtaining the value of C1 in Timoshenko beam deflection equation, Macaulay method is used .The bending moment at any section between A and the mid span distant x from A is given by following Macaulay's conventions,

$$EI \frac{d^2 y}{dx^2} = -Wx \ \vdots\ -W(x-a).$$

Therefore, the deflection at any section is given by

$$EI_y = \frac{wx^3}{6} - \frac{wa(l-a)}{2} x \ \vdots - \frac{w(x-a)^3}{6}$$

To find the deflection at the centre, putting x = l/2 in the deflection equation and get,

$$y_{\max} = -\frac{wa(3l^2 - 4a^2)}{24EI}$$

Deflection at any point of total span length is given by,

$$y = \frac{wx^3}{6} - \frac{wa(l-a)x}{2} - \frac{w(x-a)^3}{6}$$

Deflection at one fourth of total span length is given by,

$$y = \frac{wl^3}{96EI}$$

Macaulay method is used to calculate only bending deflection at any point of the beam. But Timoshenko beam deflection theory uses superposition of the bending and shears deflection, it is limited to the linear elastic range of the material. He derives that measured deflection is combination of bending deflection and shear deflection His equation is as follows,

$$Y_{measured} = Y_{shear} + Y_{strain}$$

3.Experimentation Procedure and Simulation

The effective mechanical properties of the skin and the core material of the fiber composite sandwich panel were determined from testing of coupon specimens following the ASTM C393-00 test standards. The aim is fabrication of fiber glass and epoxy resin composite laminate of the size (30cm x 8cm x 1 cm), mould is prepared for the same using acrylic sheet of thickness 5 mm.

Fig 1.Acrylic Sheet

Fig 2. Glass Fiber

Fig 3. UTM Test Specimen

Fig 4. Composite Laminate

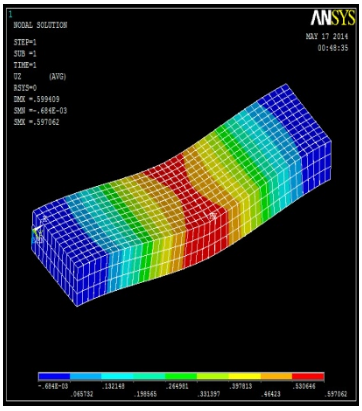


Fig 5. FEA deflection (45º/0º/-45º)

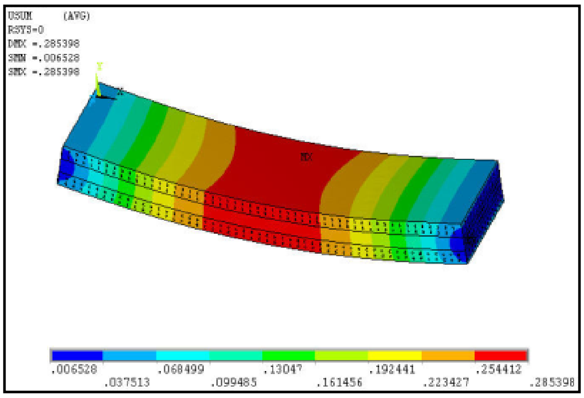


Fig 6. FEA def. (0º/0º/0º)

Three-point bending test using short beam specimen is suitable as a general method of evaluation for the shear properties in fiber-reinforced composites because of its simplicity. This test method was performed in accordance with ASTM C393 standard. and involves loading a short sandwich beam under three-point bending to ensure shear failure of the core.

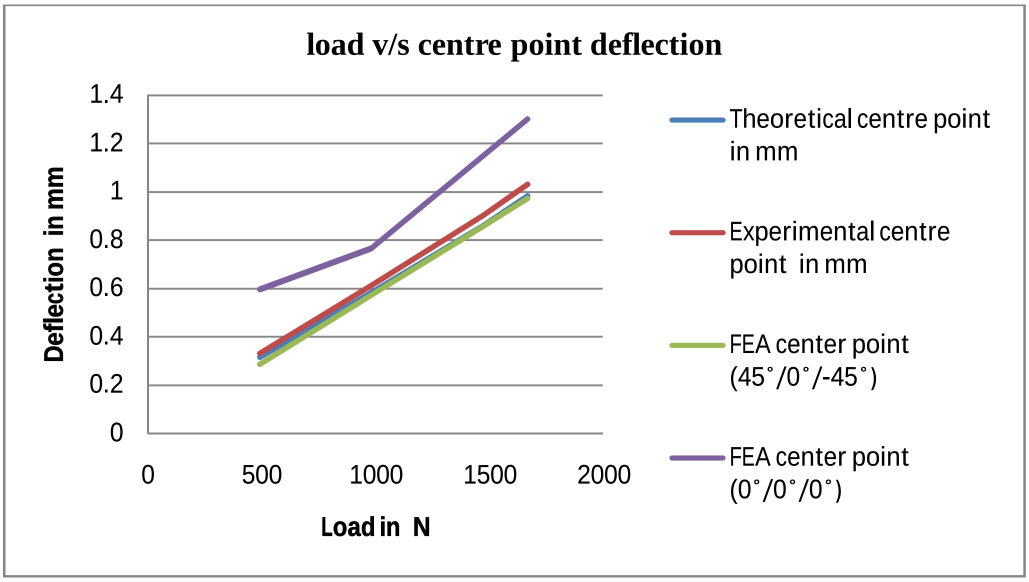
The prepared composite laminate mounted in universal testing machine for four point bending test. On lower side of test specimen two rollers are placed which give reaction in vertical direction. On upper side of test specimen two rollers are placed through acting force is applied to the test specimen Loading with step of 50Kg is applied gradually for each loading deflection and strain indicator readings are measured. When specimen reaches the stage of delamination strain indicator reading become zero Thus load at delamination found out. Loading is continued. The deflections at two points are measured using dial gauge indicator. Observation table is obtained as given below.

4.Result and Discussion

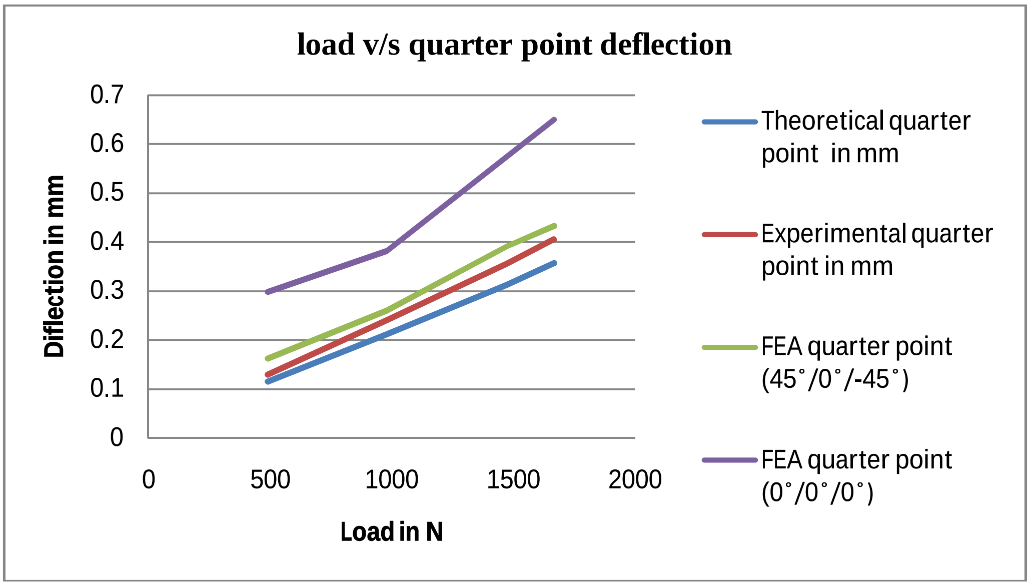
Table No .1 Theoretical Outcomes

Load in N	Theoretical Deflection (MM)		Experimental Deflection (MM)		FEA (45º/0º/-45º)		FEA (0º/0º/0º)	
	centre point	quarter point	centre point	quarter point	centre point	quarter point	centre point	quarter point
490.5 (50)	0.3162	0.1150	0.33	0.129	0.2853	0.1614	0.5970	0.2985
981 (100)	0.5843	0.2125	0.61	0.24	0.5707	0.26	0.7656	0.3828
1471.5(150)	0.8593	0.3125	0.90	0.355	0.8561	0.39	1.148	0.574
1667.7(170)	0.9831	0.3575	1.03	0.405	0.9727	0.4323	1.301	0.6505

4.1 load v/s centre point deflection



4.2 **load v/s quarter point deflection**



5. CONCLUSION

The flexural tensile mechanism comprised fiber ridging, transverse matrix cracking and longitudinal matrix cracking, the flexural compressive mode was caused by micro buckling of fiber. Macaulay method is used to calculate only bending deflection at any point of the beam. But Timoshenko beam deflection theory uses superposition of the bending and shears deflection, it is limited to the linear elastic range of the material. He derives that measured deflection is combination of bending deflection and shear deflection. From the result table it is concluded that deflection found by finite element method of composite laminate and theoretical and experimental deflection value, are approximately same. This is because of shear deflection value. From experimental analysis, when specimen reaches the stage of delamination strain indicator reading becomes zero. Thus model successfully describes delamination prior to fiber failure. It is observe that in compression FEA outcome (45º/0º/-45º) & (0º/0º/0º) and deflection is improved so conclude that orientation (45º/0º/-45º) is better then (0º/0º/0º). In case of ductile material yield point shows failure criteria, whereas in laminated composite material delamination shows failure criteria. So by observing delamination Phenomenon life of the structure can be predicted. Flexural rigidity (EI) and shear stiffness (KGA) value were determined for given composite beam.

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