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Original Article

Experimental investigation of span length for flexural test of fiber reinforced polymer composite laminates

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ABSTRACT

Testing and evaluation of mechanical properties for FRP (Fiber Reinforced Polymer) composite parts play a significant role to qualify it for the end use. Among the mechanical properties, the flexural strength is significant and vital as it may vary with specimen depth, temperature and the test span length. The flexural strength varies for different materials with varying the test span length hence the current work aims to find an optimum span length to test flexural strength for the specimens made of Glass (7781, EC9756) and Carbon (HTA7, G801) prepreg materials. Experiments are conducted as per the ASTM Standard D 790 for flexural test by varying the span lengths to understand the behavior of the flexural strength and flexural modulus. The experimental data were compared with those obtained from the finite element program software Altair Hyper works 14.0. The results indicate that flexural modulus increases with the span length to a point and then it decreases. Thereby, an optimum span length can be obtained for testing flexural strength, which will be useful to the designers and the composite manufacturers to accomplish better standard testing procedures.

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1. Introduction

Flexural or bending test can be used to get a semi qualitative idea of the fiber/matrix interfacial strength of a composite. The flexural tests are conducted to determine the mechanical properties of resin and laminated fiber composite materials. These test methods are generally applicable to both rigid and

semi rigid materials. However, flexural strength cannot be determined for those materials that do not break or that do not fail in the outer surface of the test specimen within the 5.0% strain limit. These test methods utilize either a three-point or four-point loading system to a simply supported beam. Park et al. [1] have carried few studies on the changes in flexural strength with the change in stacking sequence of aramid fiber composite laminates. They found that the flexural failure mechanism, which had an effect on the flexural strength, depends on the stacking sequence. Christiansen et al. [2] have investigated the effect of testing variables and the volume

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fraction of fibers on the three-point bend testing of glass fiber-reinforced composite laminates. They found that the flexural strength obeys a simple law of mixture relationship with fiber loading but the shear strengths were independent of fiber loading. Variation in the amount of overhang had no effect on the shear strength of the composites, but they have not evaluated the effect of variation in span length on flexural strength. Nunes et al. [3] have carried studies on polymeric matrix composite discs supported on three points subjected to a bending test to study their behavior in complex flexural loading situations. These authors [3] noticed that the flexural behavior of the composites varies on fiber orientation, laminate stacking and surface waviness. Grande et al. [4] have carried studies to evaluate whether the span/diameter ratio (L/D) would affect the mechanical properties of fiber reinforced composite posts. They noticed that the span diameter ratio is an important parameter for the interpretation of flexural strength and flexural modulus. Valarinho et al. [5] conducted experiments to study the flexural behavior of multi span composite beams made of annealed glass panes reinforced with GFRP. They mentioned that the ultimate load and the post-cracking performance of the multi span composite beams are affected by the type of the adhesive used to bond the GRFP to glass panes. Studies on the flexural fatigue behavior and enhancement of residual strength in 2D cross-ply carbon fiber reinforced carbon composites were done to show that the three-point bending fracture in both unfatigued and fatigued specimens is of delamination mode [6]. Few research has been done on short fiber reinforced composites to study the effect of flexural strength with different span lengths. It was found that as the span length reduces the flexural properties showed linear reduction [7]. Few studies have been reported earlier to analyze the effects of the specimen thickness and width on the flexural modulus in general for a composite laminate using Ansys [8]. However, the effect of the testing span length was not considered and the testing span length set for one class of material will not be the same for other types of laminates. Kumar et al. [9] conducted experiments to study the impact of the UTM testing speed on the inter-laminar shear stress and the flexural strength on fiber composites. Singh et al. [10] have carried experiments and found that with increasing in weight fraction of reinforcement, the tensile strength and flexural strength increased by 14.5% and 123.65% for 20% glass reinforced composites over pure epoxy. Haldar et al. [11] investigated the behavior of curved sandwich composite structures by performing flexural test for two different radii of curvature. Stiffness, strength and failure initiation were predicted using Finite Element Analysis (FEA) and the numerical simulations were verified with the experimental measurements. Alander et al. [12] have carried experiments to find flexural strength and flexural modulus of fiber-reinforced composite (FRC) specimens of rectangular and circular cross-sections with varying span length (L) to diameter (D) ratio. On the basis of their results, it was concluded that by increasing L/D ratio, the flexural strength and flexural modulus increased for shorter span length up to 20 mm. Hence the testing method, specimen dimensions and the process parameters play a significant role in the evaluation of flexural strength of any composite laminate. So, it is necessary to determine the effect of the testing span length on the flexural properties to find an optimum

span length for a particular type of composite material. This paper solicits to find the optimum testing span length for flexural strength of four commercially used BD Carbon fiber G801, BD Glass fiber-7781, UD carbon fiber-HTA7 and UD Glass fiber-EC9756 materials. Bending moment in a three-point bending test increases from the support points of the beam to a maximum value at mid-point, i.e., maximum stress is reached along a line at the center of the beam, where the bending moment and the flexural stress is given by the following equations.

$$\text{Bending moment, } M = \frac{P}{2} \times \frac{L}{2} = \frac{PL}{4} \quad (1)$$

$$\text{Flexural stress, } \sigma_f = \frac{3PL}{2bd^2} \quad (2)$$

where P is the load, L is the length of support span, b is the width of test specimen and t is the thickness/depth of test specimen.

If support span-to-depth ratio greater than 16/1 are used such that deflections in excess of 10% of the support span occur, the stress in the outer surface of the specimen for a simple beam can be reasonably approximated with the following equation [13].

$$\sigma_f = \frac{3PS}{2bd^2} \left[1 + 6 \left(\frac{D}{L} \right)^2 - 4 \left(\frac{d}{L} \right) \left(\frac{D}{L} \right) \right] \quad (3)$$

where D is the deflection of the center line of the specimen at the middle of the support span.

When large support span-to-depth ratios are used, significant end forces are developed at the support noses which will affect the moment in a simply supported beam. Eq. (3) includes additional terms that are an approximate correction factor for the influence of these end forces in large support span-to-depth ratio beams where relatively large deflections exist. Flexural modulus is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and is given by Eq. (4).

$$E_f = \frac{L^3 m}{4bd^3} \quad (4)$$

where m is the slope of the tangent to the initial straight-line portion of the load-deflection curve.

2. Materials and method

Prepreg materials of Carbon UD (Hexply 913/35%/132/HTA7), Carbon BD (Hexply 913/40%/G 801), Glass UD (Hexply 913/28%/192/EC 9756) and Glass BD (Hexply 913/37%/7781) were used to manufacture the laminates. Hand-lay-up method was used to manufacture the laminates of size (150 mm × 150 mm) with $[0/90]_s$ layer stacking sequence and were cured in autoclave. The cured laminates are tested for NDT tests like Ultrasonic C scan test to check the internal defects like voids and the compaction of the cured laminates and the C scan images of the four laminates were tested as shown in Figs. 1–4. The C scan profile indicates the absence of the voids and internal defects in the cured laminates. All four

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