Mechanical and Fracture Toughness Analysis of Woven Carbon Fibre Reinforced Epoxy Composites

Nikita Agarwal[1], Prof. (Dr.) Manish Bhargava[2]
[1]M.Tech Scholar, Maharishi Arvind Institute of Engineering and Technology, Jaipur, Rajasthan, India
[2]Professor and Principal, Maharishi Arvind Institute of Engineering and Technology, Jaipur, Rajasthan, India

ABSTRACT

In the present work, a set of carbon fibre reinforced epoxy composites is fabricated by varying fibre content from 20 to 50 wt% in an interval of 10 wt%. The research begins with the preparation of composite and then studies the mechanical properties and the Mode-1 fracture toughness using three-point bending test of the composite. It was found that critical stress intensity factor is constant for all considered notch-to-depth ratios.

Keywords-*carbon fibre, composite, epoxy, fracture toughness, mechanical properties*

1. INTRODUCTION

The development in the science and technology is taking place at a rapid pace and this advancement in the technology demands such material which is superior in their physical/chemical properties than the existing conventional materials and also the material should be lighter in weight. Fibre-reinforced polymer (FRP) matrix composites are the material which meets the above criterion. Fibre-reinforced composites are basically fabricated with two or more materials with precisely different physical or chemical characteristics [1]. Fibre reinforced composites are mostly used in load bearing applications due to exceptional bonding between the matrix materials which imparts excellent mechanical properties and this is the sole reason of being the first option in engineering applications [2].

Carbon fibre-reinforced epoxy matrix composites, which are extensively used in various fields such as aircraft, sports accessories, automobile, marine etc [3, 4, 5, 6]. Polymers are extensively used because of its high strength, stiffness, light weight, low coefficient of friction, excellent thermal conductivity, exceptional fracture resistance and low electrical resistivity composites are accomplishing its significance as a dynamic material in the field of space, satellites, ships, infrastructure etc [7, 8, 9]. In comparison with uni-directional fibre, bi-directional woven fibre offers better shock and impact resistance as well as ease of handling and stable characteristics are responsible for its popularity [10, 11]. It was concluded that with increase in fibre content, tensile strength, flexural strength, tensile modulus, flexural modulus, inter-laminar shear strength and impact strength increases considerably [12]. Fracture toughness of a material is evaluated with the help of following parameter viz; crack-tip opening angle (CTOA), J-integral method, stress intensity factor: K, elastic energy release rate: G, and the crack-tip opening displacement [13]. The ability of a material to resist fracture increases with increase in critical stress intensity factor (K_{IC}) as the glass fibre loading increases and also with the particulate filled glass epoxy composites [14]. Avci et al and Arkan et al. conclude that K_{IC} do not rely upon the notch-to-depth ratio by using three point and notch bending configuration experimentally [15, 16].

This paper investigates fabrication of the carbon fibre reinforced epoxy composites and to study their mechanical and fracture toughness performance as per ASTM standards.

2. MATERIALS AND METHODS

2.1 PREPARATION OF COMPOSITES

Carbon fibres are embedded in epoxy resin in four different weight proportions (20 wt%, 30 wt%, 40 wt% and 50 wt%) to prepare the composites EC-20 (Epoxy + 20 wt% carbon fibre), EC-30 (Epoxy + 30 wt% carbon fibre), EC-40 (Epoxy + 40 wt% carbon fibre), EC-50 (Epoxy + 50 wt% carbon fibre) respectively. Every individual ply of carbon fibre is of dimension 200x200 mm^2. Conventional hand-layup technique in combination with light compression moulding technique is used to make composite slabs. The castings are place under load (25 kg) for about 24h for proper curing at room temperature. After curing, the specimens of suitable dimensions are cut mechanical and fracture toughness testing. The details of composite designation and composition are given in Table 1.

Table. 1 Designation of Composites

Composites	Compositions
EC-20	Epoxy + Carbon Fibre (20 wt %)
EC-30	Epoxy + Carbon Fibre (30 wt %)
EC-40	Epoxy + Carbon Fibre (40 wt %)
EC-50	Epoxy + Carbon Fibre (50 wt %)

2.2 MECHANICAL ANALYSIS

Hardness measurement is done using Rockwell hardness tester. A diamond indenter, in the form of cone and an angle 120˚ between opposite faces, is forced into the material under a minor load of 10 kgf and major load is 150 kgf. The tensile test is done in the Universal Testing Machine Instron 1195 as per ASTM D3039-76 test standards and the dimensions of the specimen are 200 x 10 mm at a crosshead speed of 10 mm/min. The flexural test is done in the Universal Testing Machine Instron 1195 as per ASTM D2344 test standards and the dimensions of the specimen are 100 x 10 mm at a cross head speed of 10 mm/min and a span of 60 mm was maintained. Though, impact strength is evaluated confirming to ASTM D256.

2.3 FRACTURE TOUGHNESS ANALYSIS

The composites are tested for fracture toughness (K_{IC}) by measuring the stress intensity factor in crack opening mode (Mode-I). This is measured by the help of the same UTM (Instron) in single end notch bend (SENB) configuration confirming to ASTM D5045. The ratios of crack length to width of specimen in the above configuration are 0.2, 0.3 and 0.4 respectively

3. RESULTS AND DISCUSSION

3.1 HARDNESS

The erosion of the composites depends primarily on the surface hardness of the composites. The variations in hardness of the composites are shown in Figure 1. This result shows that with an increase in carbon fibre loading from 20 to 50 wt%, there is an increase in the surface hardness of composites. The reason behind the improvement of the hardness is due to better stress transfer and indentation resistance of the matrix produced due to the application of the force needed to bring the matrix and reinforcement closer to each other.

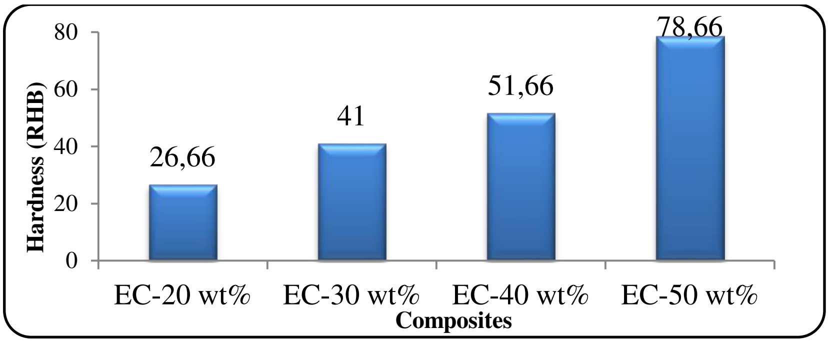

Fig.1 Effect of fibre loading on hardness of composites

3.2 TENSILE STRENGTH

As we know fibre content and fibre strength are the criteria by which the strength of the composite are determined. With the enhancement in fibre loading the tensile load carrying capacity increased and deformation at break reduces which ultimately leads to better tensile strength of carbon fibre reinforced epoxy composites. It is ‘fibre surface’ and not the ‘fibre content’ which determines the level of adhesion [12]. Lower percentage of fibre loading results in lower tensile strength as the interface adhesion is satisfactory but the area under interface is less.

Beyond certain limit (40 wt%), by increasing the fibre loading tensile strength decreases as complete adhesion is impossible at the entire surface because of fibre- fibre interaction and improper wetting of fibre. The variations in tensile strength of the composites are shown in Figure 2.

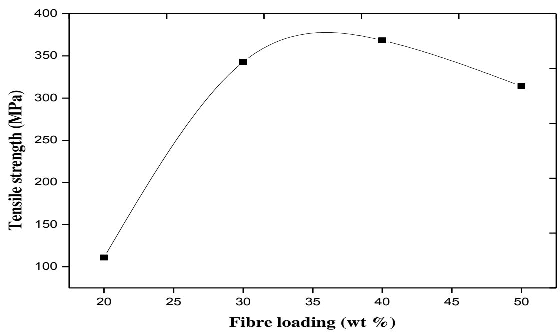

Fig.2 Effect of fibre loading on tensile strength of composites

3.3 FLEXURAL STRENGTH

Carbon fibre has a tendency to bend as the ratio of lateral dimension to thickness is high. Therefore flexural strength is one of the significant properties of fibre reinforced polymer composites. It is observed that with the increase in carbon fibre loading from 20 to 40 wt%, there is an increment in the flexural strength of composites Fibre loading to 50 wt% results in no improvement in flexural strength as shown in Figure 3.

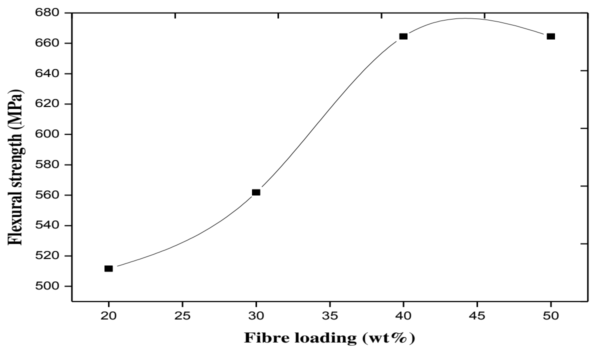

Fig.3 Effect of fibre loading on flexural strength of composites

3.4 IMPACT STRENGTH

The energy absorbed by the unit area under high strain loading before the fracture is termed as impact strength. The ability of fibre to absorb ample amount of energy before fracture results in providing higher impact strength. Polymer composites are mainly used in structural application and are subjected to sudden applied load. Under the action of this sudden load and poor impact resistance the material eventually fail. Therefore, it is important to study the impact behaviour of the polymer composites. The impact strength of carbon reinforced epoxy composites increases with the increase in fibre loading from 20 wt%, to 50wt% as shown in Figure 4.

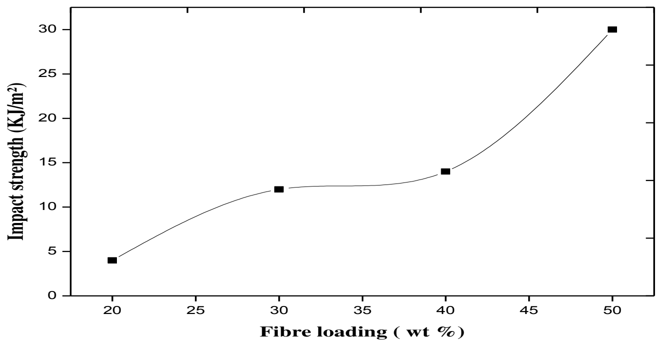

Fig.4 Effect of fibre loading on impact strength of composite

3.5 FRACTURE TOUGHNESS

The increase in the value of K_{IC} is rapid for initial reinforcement of carbon fibre up to 30 wt% and beyond this addition of carbon fibre results in marginal increase in values as shown in Figure 5. It is clearly noticeable that the effect of a/W ratio on K_{IC} value is small. For the a/W ratio of 0.4 the K_{IC} increased to 8.9, 9.8 and 10.6 MPa.m$^{1/2}$for the reinforcement of 30, 40 and 50 wt% of carbon fibre, respectively as compared to 6.59 MPa.m$^{1/2}$ for reinforcement of 20 wt% carbon fibre. The increase in stress intensity factor is in the order of 1.35, 1.49 and 1.61 times respectively.

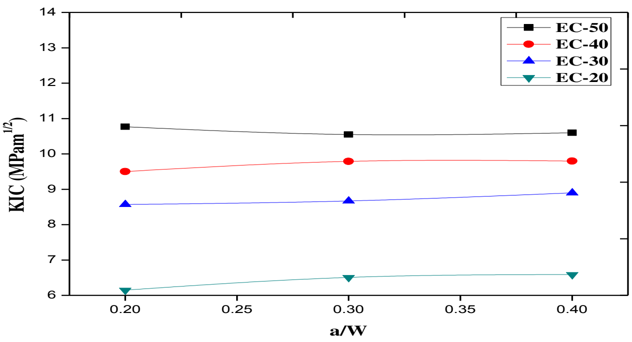

Fig.5 Variation of stress intensity factor of carbon fibre reinforced composites

4. CONCLUSIONS

In this study series of carbon fibre reinforced epoxy matrix composite are fabricated. Response of these composites for mechanical and fracture toughness behaviour are evaluated experimentally. Based on experimental results following conclusions can be drawn:

Both tensile strength and flexural strength increase with increase in fibre loading. Beyond certain limit (40 wt%), by increasing the fibre loading tensile strength decreases. The 40 wt% of carbon epoxy composites has tensile strength of 368.47 MPa as compared to 110.95 MPa for 20 wt % carbon epoxy composite. Hardness and impact strength increase with the increase in fiber loading and impact strength is maximum for 50 wt % of carbon fibre. The critical stress intensity factors K_{IC} of the unfilled carbon fibre reinforced epoxy composites are increased with the increase in carbon fibre loading from 20 to 50 wt% respectively.

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