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Research Paper Engineering

Effect of Notch Orientation, Temperature and Filler Material on Impact Toughness of GFRP Composites

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ABSTRACT

The effect of notch orientation, service temperature and filler material on the impact durability of glass fabric composite have been experimentally investigated. The results of the experimental analysis carried out on the impact toughness of these laminates have been reported. Impact tests were conducted on the specimens with two notch configurations. Results have shown that the notch along the laminate is highly prone to the catastrophic failure and the notch across the laminates will sustain the impact loads to a considerable extent. The results have revealed that there is a particular level of service temperature within which these components will yield maximum strength. The durability of laminates with 60% of glass and 40% of epoxy was found to be very high compared to the other two types. With respect to addition of filler material higher the percentage of filler material greater the toughness values and TiO2 filler material has shown greater toughness than graphite filler material.

Keywords : Polymer composites, impact strength, service temperature

I. Introduction

Impact resistance is one of the major concerns for laminated fiber-reinforced polymer composites [1-4]. The fiber reinforcement provides non-isotropic in-plane strength but produces weak interlaminar resin-rich regions, where under impact loading, extensive damage is generated, especially between plies of different fiber orientation. Impact damage in fiber composites is known to consist of intralaminar matrix cracking, delamination in the interlaminar resin-rich regions, indentation at the contact surface, and fiber breakage. With delamination being the major mode of damage that may cause a significant loss in structural stiffness and lead to catastrophic failure. Therefore, enhancing impact resistance of fiber composite has long been a major task for materials scientists and engineers.

Composite laminates are used in many engineering applications which expose them to low-velocity impact by foreign object. A typical example is that of an air craft structure subjected to the impact of a dropped tool or the collision with run way debris. The relatively weak behavior of composite materials under localized impact has been one of the major weakness limiting their use. Unlike metals, polymeric matrix composite do not have the ability to deform plastically to absorb the kinetic energy of the impactor. The energy absorption mechanism of these materials consists in the creation of large fracture area, especially at the weaker interfaces between the composite layers, in a process referred to as impact-induced delamination. In view of the extensive delamination of fiber composites under impact, much work has been dedicated to the area. Many studies [5-7] have suggested that the delamination under impact is initiated by matrix cracking in a local opening mode. For subsequent growth of a delamination crack, Chang and coworkers [6, 7, and 11] and Springer and co-workers [10] suggested that both the opening mode (mode I) and the in-plane shear mode (mode II) were involved.

The extensive amount of experimental work on impact induced delamination of composites, recently reviewed by Abrate [12, 13] and Cantwell [14], as allowed the scientific community to achieve a relatively sound understanding of the phenomena leading to the impact-induced failure of composite laminates. Several failure models have been developed for the prediction of notched strength of composite laminates. An extensive review of these models can be found in the literature [15]. Failure behavior of notched composite laminates depends on a variety of factors, the most important being laminate configuration and specimen geometry.

A review of the literature reveals that many studies have already been done in the impact response of laminate composite structures and it still remains an important area of research. Based on this review of the literature it was found that less work has been carried out on the effect of notch orientation, post-heat treatment on the impact toughness of the glass fabric composites (Figure 1) In view of this an attempt has been made to investigate the impact-toughness of the composites.

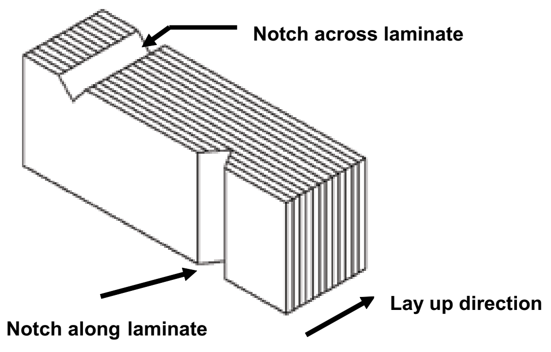

Figure 1. Notch orientations on the impact specimen.

II. Specimen Preparation

The laminated composite specimens consists of general purpose room temperature curing polymer epoxy resin, plain weave E-glass fabric three types, Mat – I (600 GSM), Mat – II (330 GSM), Mat – III (210 GSM) were selected. The laminates were fabricated by using hand lay-up technique with a stacking sequence of [0/90]s. The percentage volume of glass fabric varied from 15 to 45% in steps of 15%. The test matrix of impact specimen is as shown in Table 1.

Table 1. Test matrix of impact specimens

Composition	Types	Samples on each composition		
		65-35	60-40	55-45
G -E	GE-Mat I	10	10	10
	GE-Mat II	10	10	10
	GE-Mat III	10	10	10
Total		30	30	30

III. Experimental Procedure

After curing of the specimen they were cut to size as per ASTM standards and notch across and along the laminates were made. Specimens were kept in freezer and electric oven to maintain different temperatures as shown in Figure 2. Specimens were tested on a pendulum type impact testing machine, under different temperatures, 0^0C, room temperature (34^0C) and 60^0C. The amount of energy absorbed by the specimens before it breaks is directly obtained from a graduated scale provided in the impact testing machine. Impact strength is calculated on the basis of energy absorbed. The experimentations were carried out according to the ASTM standards D259.

Figure 2. Notching and heating of specimen to different temperatures

IV. Results and Discussion

A. Effect of the fabric content, notch orientation and temperature on the impact toughness

In order to determine the effect of fabric content on the impact toughness, the test coupons were prepared with three different volume fractions. Also, to identify the effect of service temperature on the impact toughness, the specimens were impact tested under three different temperatures. Figure 3 shows the results of the impact testing carried out on these test coupons.

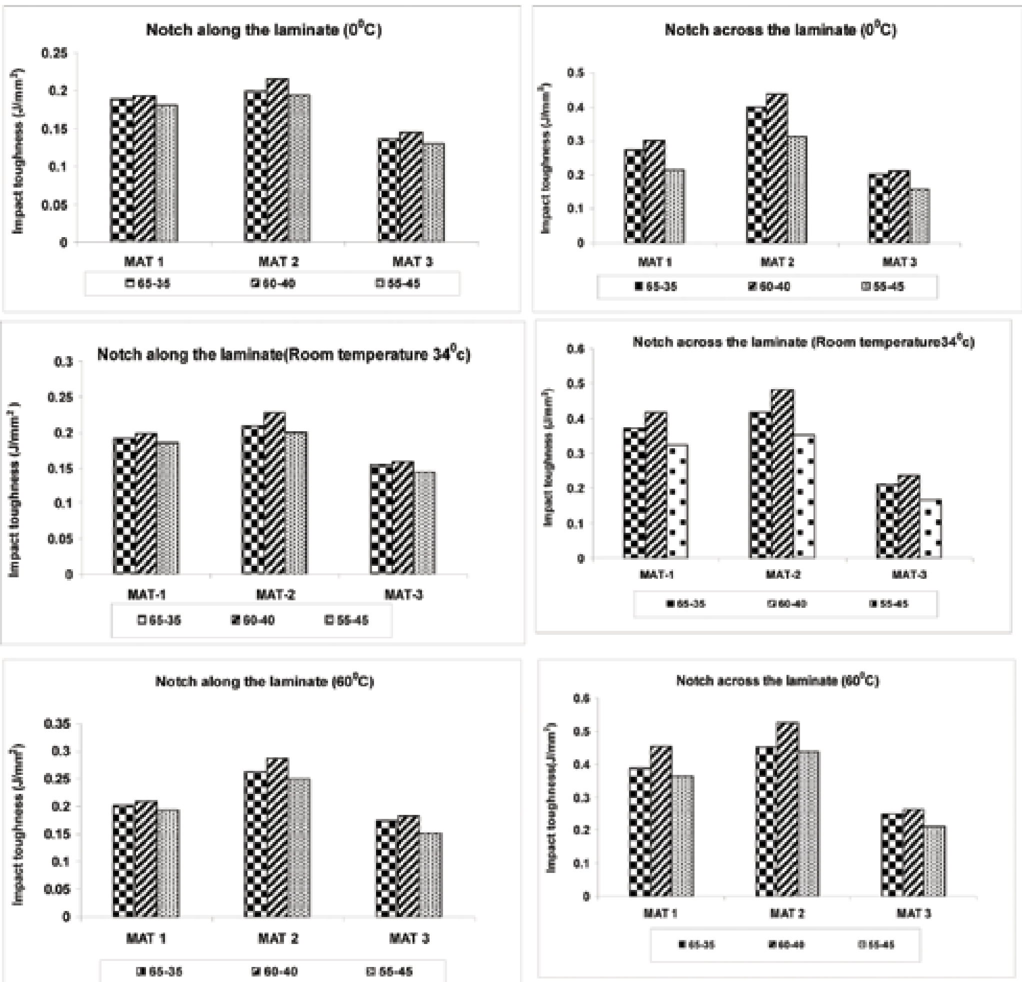

Figure 3. Effect of fabric volume, Notch orientation and temperature on the impact toughness.

As can be seen from the figure 3, it is very much clear that the impact toughness of the test coupons with the notch grooved across the laminates is higher than that of the coupons with the notch along the laminates, irrespective of the volume fraction. We can also observe that impact toughness is increasing as volume fraction of GF increases but has decreased for 65%. The three main mechanisms identified to be responsible for the increase or decrease in the impact toughness in these composites are: (a) fracture and failure of fabrics; (b) fractional sliding that takes place in the fiber matrix interface as fiber pull out during failure and (c) matrix cracking or deformation of matrix in shear and transverse tension/compression. In the case of notch along the laminates the failure is mainly because of the debonding of the laminates at the interface. A shear failure is observed in the glass fibers.

In order to determine susceptibility of these composites to the service temperatures, the test coupons were impact tested under different temperatures at 00C and 600C. Figure 3 shows the variation of impact energy with reference to these temperatures. It can be very clearly seen from Figure 3 that there is change in the impact toughness with service temperature. It can also be seen from the figure, that the increased volume of glass has increased the impact toughness of this composite, irrespective of service temperature. The increase in the impact toughness for all three types of specimens is achieved with increased service temperature. The same behavior is observed in the specimens with both the types of notch orientation.

The increase in the impact toughness with increase in service temperature is mainly because of the increase in the bonding strength with increased temperatures. But at higher temperature the brittle polymer epoxy matrix will get fused, leading to the debonding of the laminate. Because of this debonding the impact toughness of these test coupons at elevated temperatures is found to be less.

B. Effect of Heat Treatment on the Impact Toughness

In the case of the present composite, room temperature curing has been carried out. When the composite is kept in elevated temperatures such as 900, which is higher than that of the curing temperature, the resin will become very soft. When the resin becomes soft the laminate will become unstable. After a specified time when the laminate is removed from the furnace and when it cools down, the resin will try to shrink, but the reinforcement (GF) with which it has been set, will not allow the resin to shrink. This phenomenon will cause the internal residual stresses solely due to these thermal effects. It is also identified that the outgassing of water vapor and organic volatiles may result in the formation of micro-and macro-cracks in the resin. This phenomenon is magnified with increased time-at-temperature. The high residual stresses at the fiber/matrix interface, at elevated temperature heat treatment has reduced the impact toughness. Because of these delaminations the energy absorbed before failure and in turn the impact toughness is found to be less.

C. Effect of addition of filler material on Impact Toughness

From the above result we could conclude that out of three mats Mat I, Mat II and Mat III. Mat II (330 GSM) has shown greater value of sustainability over the other two mats. Further out of three volume fractions, 60-40 (60% Glass Fiber – 40% Epoxy resin) combination showed optimum result. Two filler materials TiO2 and Graphite were added to Mat II 60-40 combination, by keeping epoxy percentage constant (40%). Based on literature survey the amount of filler added for Graphite was 3, 6 and 9 % and for TiO2 it was 1, 2 and 3 %. The details are as shown in Table 2. After the preparation of the specimen, they were tested in impact testing machine to obtain impact toughness values.

Table 2. Details of specimen with filler material

Mat II (330GSM)			
	Glass Fiber Content %	Epoxy Resin %	TiO_2 %
1	59	40	1
2	58	40	2
3	57	40	3

Mat II (330GSM)			
	Glass Fiber Content %	Epoxy Resin %	Graphite %
1	57	40	3
2	54	40	6
3	51	40	9

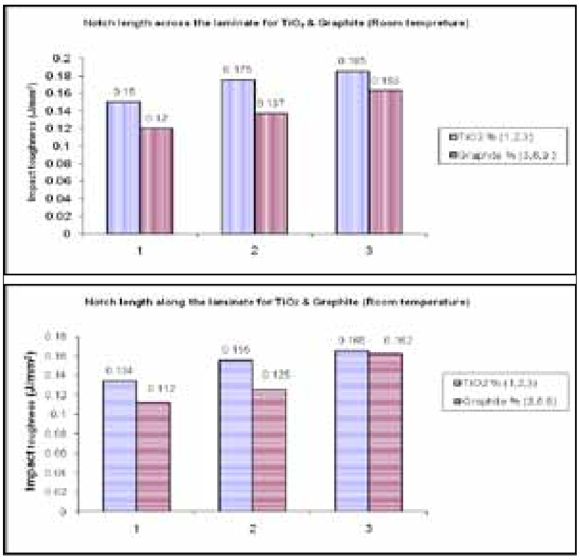

Figure 4. Effect of fiber volume, notch orientation and filler material on the impact toughness.

By the addition of filler material like TiO2 and Graphite an observation could be made from the figure 4 that notch grooved across the laminates is higher than that of the specimens with the notch along the laminates holds good, also second observation was, as the percentage of filler material increases, the impact toughness values also increases which shows that the filler material has bonded itself into the matrix of fiber and thereby toughness sustainability has increased, lesser the percentage has decreased the toughness value because of the gap in fabric matrix. When compared, specimens with TiO2 as filler showed tougher value than that of graphite filled specimens. This is due to grain size and bondability aspect of the filler material.

V. Conclusions

The behavior of the glass fabric composites under impact loads, with varied notch configurations and service temperatures has been evaluated experimentally. The analysis indicates that the composite with 60-40 combination for Mat II (330 GSM) has shown maximum strength. It was also found that the notch along the laminate is highly prone to the catastrophic failure and the notch across the laminates will sustain the impact loads to a considerable extent. These composites posses a transition temperature (600C), beyond which the strength has decreased to a maximum extent. The post-heat treatment has also shown significant influence on the strength of these laminates. Effect of addition of filler material has been evaluated experimentally. The analysis indicates that the composite with higher percentage of filler material have given greater toughness value both for TiO2 and Graphite. The composite specimen having TiO2 as filler materials has shown greater toughness than that of specimens having graphite as filler material.

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