Quasi-static Axial Crushing of E-Glass Fiber Reinforced Epoxy Composite by Different Number of Plies

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Abstract The purpose of this study is to analyze the effect of the crushing mechanism on e-glass under various loading. To do so, cylindrical composites tubes are required to be fabricated as the specimen. To test the various variable that might affect the energy absorption of the specimen, the hand's lay-up process had been selected. Glass fiber reinforced composites tubes were fabricated with a fiber content of 1 to 3 layers. To evaluate the effect of the crushing mechanism of the fabricated composite tubes, a compression test was conducted. The effect of fabrication method and thickness of specimen were studied. In addition, the response of crush load–displacement, peak load, total energy absorption, specific energy absorption, and crush force efficiency were determined. Furthermore, the microstructure of all the specimens was analyzed using the digital microscope. As a result, it indicates that energy absorption capabilities are highly dominated by a higher reinforcement layers. H3 has the highest specific energy absorption which is 9.3 kJ/kg.

Keywords Manufacturing process · Composite material · Mechanical properties

1 Introduction

Nowadays, structural crashworthiness is a crucial requirement in the design of the automobiles field. The crash-worthy structure is designed to absorb energy impact in a controlled manner in the event of a crash [1–3]. For instance, the side beams

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on the engine for an automobile had been well designed to absorb impact energy in a controlled condition. Generally, metals are the preferred material used in crash-worthy structural applications. But with the success story in the aerospace industry, it is proven that through plastic deformation the impact energy can be absorbed and polymer composites are the materials that stand out in this case [4–6].

Polymer composite materials had been accepted as it provides significant technical advantages over metals [7, 8]. However, there is a major challenge to use polymer composites as a controlled energy absorber. The reason that polymer composites behave better than metals is because of the characteristics of the polymer composites as it consists of plastic deformation which is helpful in energy absorption [9]. Besides that, several variables could affect the characteristics of the energy absorption of polymer composite materials that can be concluded to the main 4 part. The first is microstructural variables, followed by conditions of manufacture, the geometry of the tube, and conditions of testing [10]. Epoxy are one of the most regularly used polymer in structural applications.

Fibers occupy a largest volume fraction of composites and able to withstand a huge external load. Glass fiber is one of the most common fibers in the composites industry. The main reason is because of its relatively low costs and lightweight. However, glass fibers are weak in compressive strength. This raises the concern of the study on how to improve the compressive strength of glass fiber. A previous study showed that glass fiber can be successfully replaced metal as a car bumper [11]. Hence it is proved that glass fiber is eligible to serve as a crashworthy application.

Generally, manufacturing using composites involves the processing of two main ingredient materials to make a final product. The ingredients involve the matrix and fiber materials. There is various type of manufacturing process. The most common and simple one is the hand lay-up method. To cope with the problem mentioned above, the motivation of this study is to enhance the energy absorption capabilities of an e-glass fiber under various conditions.

2 Materials and Methods

2.1 Materials Preparation

The materials that had been selected to fabricate cylindrical composite tubes are epoxy and E-glass fiber supplied by Chemi-Bond from Selangor, Malaysia. The resin used in this project was Auto-Fix 1345 B hardener and Auto-Fix 1710 A epoxy. The epoxy and hardener are mixed by the ratio of 1:1 by weight as recommended by the supplier. Electric stirring was used in the mixing to reduced bubble formation. For E-glass fiber, it was cut in 200 mm in width and the length of the perimeter for the 50 mm inner diameter tube depending on the number of layers used. For the current study, composite with 1, 2, and 3 plies were investigated. The reason the plies or

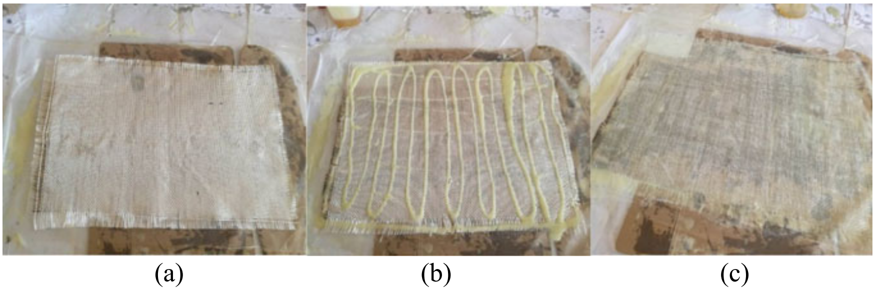

Fig. 1 E-glass fiber **a** before pouring resin **b** after pouring resin **c** the finished prepreg

stopped at 3 plies as, when it goes to 4 plies the fiber starts to undulating thus will result some gaps between the plies [12].

In the hand lay-up process, a 50 mm diameter steel mandrel was used. The mandrel was wrapped with PTFE plastic film and a release agent was applied. On the other hand, epoxy was applied to the E-glass fiber surface. The wetting of the glass fiber was rolled on the mandrel. At the same time, a steel roller was used to compress the fiber and it also helps to release bubbles form in between layers. After the fiber rolled on the mandrel, PTFE film again rolled on the mandrel against the fiber to produce a small compression force to hold the fiber in place. The composite was left to cure for 24 h at room temperature. After curing, the composite was separated from the mandrel and cut to 100 mm in length as testing specimens (Fig. 1).

2.2 Experiment Procedure

For the testing, quasi-static axial crushing was carried out. The test used Shimadzu AG-I Universal Testing Machine with a 100 kN load cell. It was carried out based on ASTM D7336M-16 standard with stroke length set to 50 mm. In the test, crushing of 10 mm/min was used [13]. The specimen was placed under the moving platen during crushing. During crushing, the static photograph was taken utilizing a camera with 48-megapixel resolution. The crushing pics were taken with every 2 mm moving platen to observed its deformation. From the test, the data history of force versus displacement was recorded automatically. For post-crushing, the crushed specimens were under a microscope to observe their crushing effect.

3 Results and Discussion

From the crushing history curve, it can be seen that the crushing peak load for all the specimens reaches their peak at about 5–6 mm after the moving platen as shown

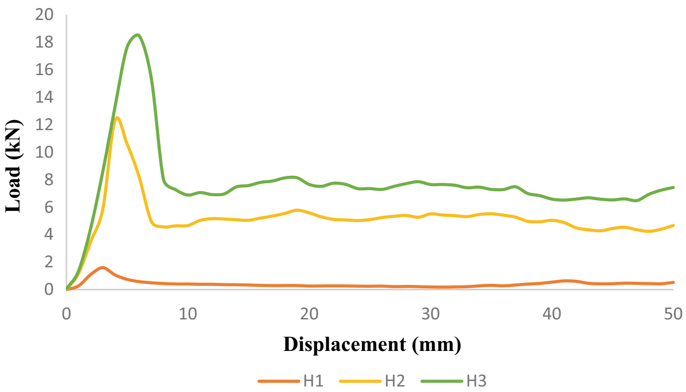

Fig. 2 Graph for Hand lay-up method with different layers of reinforcement; H1-1 layer, H2-2 layers, and H3-3 layers

in Fig. 2. Moreover, the crushing for the specimen was crushed progressively at the duration of 50 mm crushing length. However, from the test, the peak load was varied due to differences in the number of fiber plies used. As the plies number increases, the peak load increase. This is due to the more materials able to support a more compressive load. In a one-ply composite tube, the peak load of 1.6 kN was attained at a displacement of about 5 mm of moving platen. At that time, the structure began to have local buckling [14]. Subsequently, the top of the structure started to crack. The failure of the top part leads to progressive crushing in the test. This also happened to the test for structure with two plies. In the test, the two-ply structure reaches its peak load at 12.3 kN with a platen displacement of 5.3 mm. Moreover, the 3-ply cylindrical structure also behaves in the same manner. For the 3-ply structure, it achieved its peak load at 18.5 kN where the platen displacement at 6.9 mm. From the test, all the structures were having the same characteristic which is local buckling and cracks begin at the top part of the structures. Then, the structure's wall started to bend outwards till the end of the test. The results of the tests are listed in Table 1.

From the test, all specimen behaved in the same manner which crushed progressively. From the post-crushing, all the specimen begins to crack by bending outwards. During this moment, the wall began to splay which simulate the tension stress at the wall which is usually denoted as mode I failure [15–17] as shown in Fig. 3. Apart from that, the structures also experience bending at the wall. At this point, mode II

Table 1 Data was recorded for specimens made of 3 different reinforcement layers

Sample	Peak load (kN)	Mean load (kN)	Total Energy absorption (J)	Specific energy absorption (kJ/kg)
1	1.6	0.4	20.7	1.6
2	12.3	5.4	261.5	7.5
3	18.5	7.7	389.1	9.3

Fig. 3 **a** mode I failure and **b** mode II failure

can be observed. Mode II is referred to as interlaminar shear between the walls [18, 19]. From the failure mentioned, these have been contributed to energy absorption by the structures [20].

4 Conclusion

From this work, it can be concluded that the higher the number of plies used in the structures, the better its performance. It was observed the number of plies does not influence the crushing characteristics. Moreover, it increases the crushing performance of the tubes. Apart from that, specific energy absorption also does not affect the number of plies used. For the crushing characteristics, Mode I and Mode II are the main dominant in contributing the energy absorption for all the structures.

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