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Energy Absorption of Basalt Filament Wound Rectangular Tubes: Experimental Study

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ABSTRACT. The objective of this study was to determine the energy absorption of basalt filament wound rectangular tubes under crushing test. Basalt fibre gained a lot of potential in various application due to low cost of this material together with its capability to breaking the domination of e-glass as a reinforcement material. Coupon tensile and axial compression (crushing) test were performed to investigate the strength and energy absorption performance of basalt filament wound rectangular tubes. Both test have been conducted using $[\pm 70^0]_3$ winding angle of sample configuration and comparison have been made in coupon test in which the basalt sample shows 8.7% higher than e-glass while produced opposite results in modulus of elasticity. Crushing test was performed in 25mm displacement with different loading rate which are 5, 10 and 15mm/min. The results obtained from three different conditions were compared showing a higher energy absorbed in the lower loading rate. The comparable crashworthiness of basalt suggest possible applications such as automotive industry which is requires a good energy absorb materials in some particular components.

INTRODUCTION

Structural crashworthiness is an essential design requirement in automotive, rail cars, aircraft and rotorcraft. For automotive industries, crashworthy structure is designed according to the event of a crash, it absorbs the impact energy in a controlled manner before the energy gets transmitted into the passenger compartment. Cylindrical components performed well in absorbing energy due to the stability of the geometry. For other geometry with involving edge characteristics in the component design, energy absorption is important structural function which is need to be investigate to prevent catastrophic failure occur. Capability of composite energy absorber devices is mainly depending on its materials and properties, fabrication conditions, geometry and dimensions of the structural components, and test conditions [1]. Mahdi et al. performed an optimization of fiber orientation of collapsible composite tubular energy absorber device in order to improve its energy absorption capability [2]. They recommended fiber orientation $15^0/-75^0$ and $75^0/-15^0$ to be use for the crushed composite collapsible tubular for better load capacity and energy absorption. Many researchers investigated the crushing behavior of composite with different cross-section geometrical properties in different loading conditions. Eshkoor et al. conducted in experimentally to identify the damage mechanisms of silk/epoxy composite rectangular tubes [3]. They highlighted that cross-sectional geometry and loading conditions significantly influenced the energy absorption capabilities. Palanivelu et al. conducted crushing and energy absorption study of different geometrical shapes of small-scale glass/polyester composite tubes under quasi-static loading conditions [4]. They concluded that higher t/W and t/D ratio (0.083) of the square and the hexagonal cross sectional composite tubes generated uniform and progressive crushing failure modes. It was revealed that the t/D or t/W ratio of a composite tube plays a major role for uniform and progressive crushing and also were reported by Mamalis and his co-workers in their similar results [5,6]. Jimenez et al. performed a study on open section such as ‘‘I” sectional tubes [7]. The results concluded that 15%

smaller energy absorption capability of the ‘‘I” section profile than the square cross sectional composite tube. Many data have been published on the energy absorption of composite tubes using the circular and square cross sections [8-10]. In addition, they all agreed to mention that the geometrical shape is an important parameter which is significantly affects the energy absorption performance. In this study, basalt filament wound rectangular tubes is characterize in term of crashworthiness performance in order to determine the performance under crushing test.

EXPERIMENTAL

Material and Method

Basalt roving 2400 TEX was purchased from Incotelogy GmbH Company located in Pulheim Germany and e-glass roving fibre were supplying from Universal Star Group Limited Company in Ningbo China. Epoxy resin was purchased from S&N Chemical Company located in Johor Malaysia. Dry filament winding process with angle $[\pm 70^0]_3$ was used in this study for basalt rectangular tubes roving prior to subsequent process. Vacuum infusion technique was used to impregnating the fibre using epoxy 1006 resin as well as to control the quality of all sample fabrication.

Mechanical Testing

Axial compression and coupon tensile tests were performed using the universal testing machine which is 600DX model that was supplied by Instron Company, Singapore branch. A crosshead speed of 5, 10 and 15mm/min was used towards rectangular tubes sample (length 50 mm (L), width 56 mm (W), breadth 31 mm (B), 3.0 mm wall thickness) and the test was performed at room temperature. The tensile stress, elastic modulus, energy absorption, peak and average crushing load were calculated from load-displacement graph. Results that were collected represent the values of the load resisting performance of the material. The results of the total energy absorption were divided with cross-sectional area to obtain the specific energy absorption (SEA) of each samples.

RESULT AND DISCUSSION

Tensile Properties

The results tensile test results shows basalt rectangular tubes has higher tensile stress as compared to e-glass tubes. Basalt generated 8.7% more tensile stress which is gave the valuable contribution of basalt fiber in composite system.The correlation of these results emphasizes the importance of an adequate combination of matrix and reinforcement material. Fig. 2(a) shows the maximum stress of basalt and e-glass tubes. From the graph, it can be observed that the tensile stress for basalt sample is higher, 7.52 MPa, followed by e-glass sample, 6.92 Mpa. Elastic modulus for both samples are significantly different than tensile stress results. E-glass rectangular tubes recorded 38.96% higher than basalt sample as shown in figure 2(b). These results are good platform to highlighted that the comparable properties of basalt have been identified.

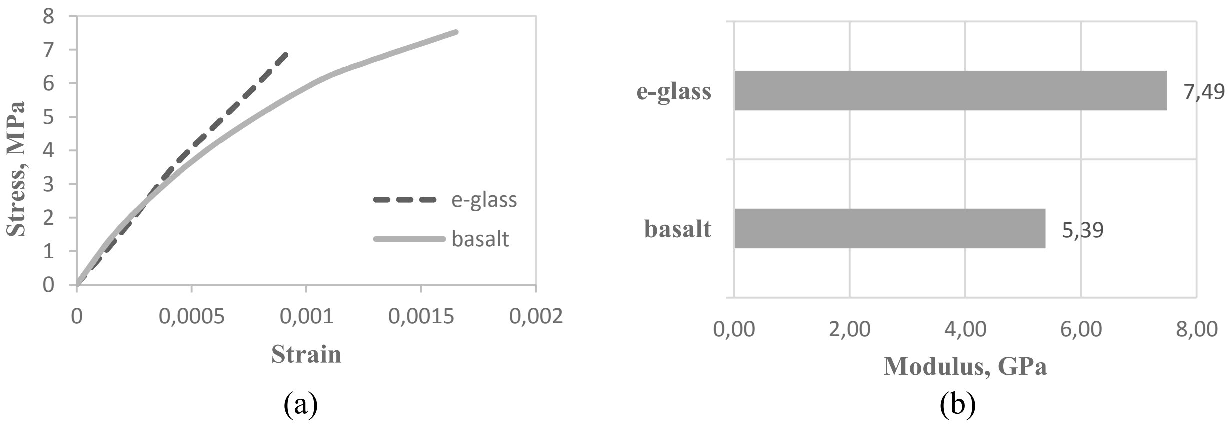

Fig. 2 Results comparison (a) Tensile Stress (b) Elastic modulus

Energy Absorption

The peak load variations seen in the load vs. Extension graph traces varied. Overall, basalt in 15mm/min of loading rate showed the lowest peak load variations in the crushing load. Refer to Fig. 3, basalt in 15mm/min having constant load after peak load while basalt sample in 5 and 10mm/min loading rate tends to increase after peak load. Average total energy absorbed for basalt in 5mm/min is 277.99 kJ, 10mm/min was 17.8% lower and 15mm/min only recorded 183.940 kJ. The peak crush load for basalt sample in 5mm/min was higher than for other specimens which is 20.09 kN while 10mm/min and 15mm/min were 42.7% and 69% lower respectively. In overall result, basalt sample in 5mm/min of loading rate produces higher than 10 and 15mm/min of loading rate as shown in Table 1.

Table 1: Basalt tubes crushing test results

Specimen	5 mm/min	10 mm/min	15 mm/min
Peak Load Average (kN)	20.09	14.08	11.08
Average crush load (kN)	11.12	9.44	7.36
Total Energy Absorption (kJ)	277.99	235.96	183.94
Crushing Efficiency ɳc (%)	55.4	67.02	66.4

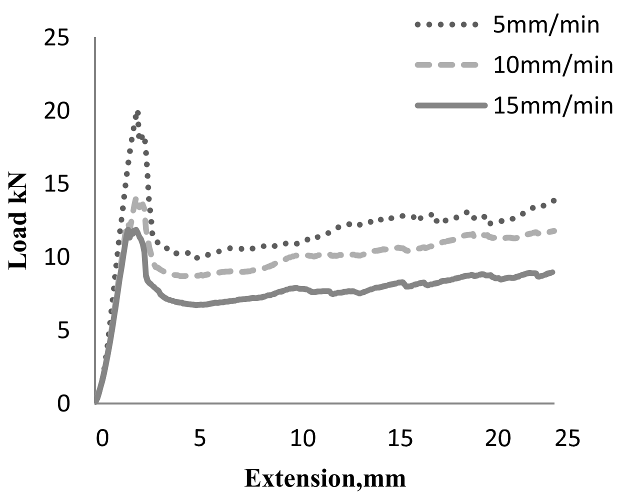

Fig. 3: Progressive failure of basalt tubes

Scenario performance for e-glass tubes sample represented in Fig. 4. It can be observed that there is significant difference in their general characteristic. E-glass tubes in 5 mm/min shows better peak load which is 43% and 61% higher than 10mm/min and 15mm/min respectively. All the curves from experiment show a large initial peak load corresponding to the initial collapse followed by rapid decrease in load due to instability of the tube during crushing test. After this stage the load reduced gradually. After stage of peak load, the load increase gradually and the curves become almost flat. In total energy absorption, e-glass rectangular tubes in 5mm/min of loading rate produced 363.07 kJ which is more than 19% and 49% higher than sample with 10mm/min and 15mm/min respectively. In overall result, e-glass sample in 5mm/min of loading rate produced higher than 10 and 15mm/min as shown in Table 2.

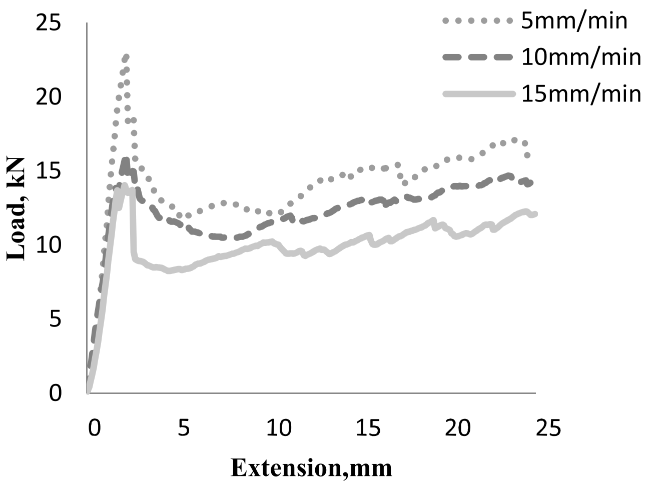

Fig. 4 Progressive failure of e-glass tubes

Table 2: E-glass tubes crushing test results

Specimen	5 mm/min	10 mm/min	15 mm/min
Peak Load Average (kN)	22.56	15.76	14.04
Average crush load (kN)	15.93	14.63	12.64
Total Energy Absorption (kJ)	363.07	306.16	243.45
Crushing Efficiency ŋc (%)	70.6	92.8	90

Specific Energy Absorption (SEA)

The lowest of SEA from experiment is basalt rectangular tubes that having 15mm/min of loading rate which is 9.43 kJ/kg. The predicted SEA rectangular tube with loading rate 15 mm/min (e-glass tube) capabilities are about 35.12% higher than basalt rectangular tube . The highest of SEA of basalt tubes from experiment is 14.95 kJ/kg. The predicted specific energy absorption for e-glass rectangular tube with loading rate 5 mm/min capabilities was 19.5% higher than basalt sample . Basalt sample in 10mm/min loading rate generated 12.22 kJ/kg while SEA for e-glass rectangular tube produces about 27.76% higher than basalt as shown in Fig. 4.

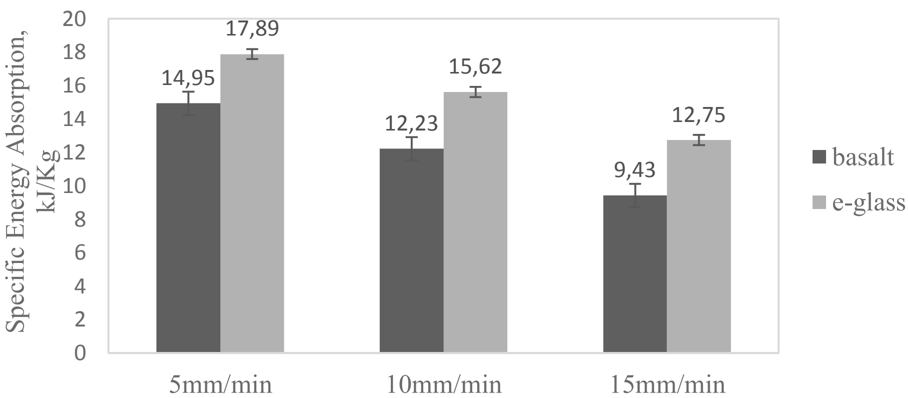

Fig. 4 SEA comparison

CONCLUSION

The strength performance of basalt filament wound composites rectangular tubes have been identified. Tensile stress of basalt sample is slightly higher than e-glass rectangular tubes and not directly proportional with elastic modulus results. Even though with better tensile stress, the basalt filament wound rectangular tubes had a significantly lower results when compares to e-glass in term of energy absorption. The basalt rectangular tubes exhibited most significant reduction when increasing the loading rate when compared to the e-glass rectangular tubes. Basalt rectangular tubes were tested to identify the crashworthiness potential in rectangular shape for possible use in automotive applications. Instead of e-glass product that is practically well-known compatible to combine with thermosetting resin, basalt rectangular tubes shows the comparable crashworthiness performance which are created a lot of ideas to extending their usage especially in automotive component product where the application require an adequate performance of energy absorption material to reduce the catastrophic damage phenomenon.

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