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Axial impact crushing behaviour of thin-walled braided composite tubes: experimental comparison on basalt fibre and glass fibre reinforcement

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Axial impact crushing behaviour of thin-walled braided composite tubes: experimental comparison on basalt fibre and glass fibre reinforcement

M N Roslan[1,2], M Y Yahya[2], Z Ahmad[2] and A H A Rashid[1]

[1]Advanced Technology Centre, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia
[2]Centre for Composite, Universiti Teknologi Malaysia, Johor, Malaysia

Abstract. The collapse performance and energy absorption of thin-walled tube of basalt/ epoxy and glass/epoxy subjected to axial quasi-static and dynamic impact crushing were investigated. The effects of braid orientation, fibre materials, and loading rate focusing on crushing behaviour were discussed. The braid orientation could be found to have significant influences on energy absorption performance and crushing mechanism. Based on results, thin-walled basalt composite tube has greater energy absorption capacity than thin-walled glass composite tube. The energy absorption capability in impact crushing tests could be found approximately 30% to be higher than that in quasi-static crushing tests. Thin-walled basalt/epoxy tubes have lower crush rate dependency as compared with thin-walled glass/epoxy tube.

1. Introduction

Fibre reinforced polymer (FRP) composite offers excellent specific strength and stiffness for engineering structures. Due to their great mechanical properties, over the years studies, researchers and scientist has reporting FRP composite materials are highly potential in replacing conventional metals [1,2]. The advanced capability for energy absorption capacity also has gain interest for light-weighting crashworthy structures[3]. Most studies have reported on energy absorption characteristics of FRP composite materials influence by many factors, such as fibre and matrix property, fibre orientation, hybridization, geometry dimension and shape, trigger mechanism, and filler. Among those factors, fibre orientation is the most basic design parameters in FRP composite materials. In particular, braided composite offers many advantages such as excellent impact resistance and high interlaminar shear strength due to their locking mechanism and continuously oriented to any kind of shapes. Owing to their good impact resistance and interlaminar shear properties, braided composites extinsively explored by researchers as one of the good potential candidate for energy absorber units. Specifically, the crushing performance of energy absorber made with braided composite significantly depends on its fibre/matrix material properties, fabrication conditions, braid angle and dimensions of the structural components[4,5].

To date, considerable interest in environmental issues has promoted the amount of literature has been published on the employment of natural fibres in polymer reinforcing[6,7]. Most kind of plant fibres like, flax, sisal, and, kenaf have been studied and applied. Unfortunate, those fibres are very delicate to thermal and hygroscopic load. Moreover, it shows limited mechanical properties due to the fibre removal system, the difficulty in fibre arrangement, interfacial strength and the fibre dimensional homogenous. Fortunately, continuous improvement on production technology, one type of mineral natural fibre called basalt has been successful made with continuous filament type yarn and finally has available in market nowadays. The basalt fibre has many advantages such as high modulus and strength, high temperature resistance, good chemical resistance, non-toxic, eco-friendly and inexpensive. The density of the basalt fibre is the same as that of the glass fibre, but the specific modulus and strength of the basalt fibre are higher than general glass fibre[8]. Basalt fibre composite had been applied on high performance end uses because of their heat insulation has three times than asbestos material promoted basalt uses on the electromagnetic shielding structures, automobile, aircraft, ship and household appliance components[8]. Therefore, to fabricate cost-effective and eco-friendly composite structures for crashworthiness, the basalt reinforced polymer composite is the alternative choice. In this study, a series of thin-walled composite tubes with different braid angles and fibre materials were fabricated using braided basalt reinforced epoxy matrix and braided glass reinforced epoxy matrix. The axial crushing tests of the thin-walled tubes under quasi-static and impact loads were carried out. The effects of the braid angle, the fibre material parameters and the different load rate conditions on the energy absorption capability, and failure modes of the thin-walled tubes were investigated.

2. Experimental procedure

2.1 Materials and fabrication

The Two type of fibre materials used in present study called basalt braided and glass braided as received from Siltex Co., Germany. Epoxy resin (#1006) supplied by S&N Chemical, Malaysia was used as matrix resin ingredient in making thin-walled tube composite. At initial step, the dry braided sleeves of three layers were stacked on a mandrel with diameter 36 mm. Then, the mandrel wrapped with dry braided sleeves was set up on a lathe machine, and the mixed epoxy resin with the weight ratio10:6 of resin and hardener were impregnated into the braided sleeves wrapped on the rotating mandrel by hand lay-up method with the help of a brush and a roller. Next, a thermo-shrink tube was wrapped over the wetted braided preform and heated by a hot gun through the mandrel to remove the excess resin and any air trapped. The mandrel continuously rotated for 8 hours and post-cured for 24 hours in room temperature. A 45° chamfer was made at one end of the composite tubes to initiate crushing. Total six types of specimens were fabricated for the quasi-static and impact crushing tests, as listed in table 1. *Fij* denote six types of thin-walled composite tubes which *F* (*B* = basalt, and *G* = glass) denote for fibre type. The fibre volume fraction of thin-walled composite tubes was approximately 60%.

Table 1. Thin-walled composite tube physical properties.

Designation name	Braid angle (θ˚) Outer wall	D_o mm	D_i mm	Thickness mm	Weight g
B30	30	39.80	36.00	1.90	29.83
B45	45	40.16	36.00	2.08	30.00
B60	60	40.20	36.00	2.10	36.80
G30	30	40.28	36.00	2.14	28.67
G45	45	38.47	36.00	1.24	17.67
G60	60	38.67	36.00	1.34	19.00

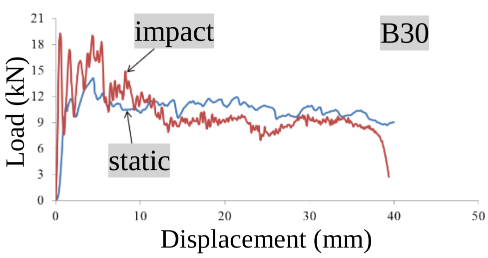
2.2 Quasi static and dynamic impact crushing test

The axial quasi-static crushing tests were carried out using a standard 100 kN Testometric servo-hydraulic testing machine. The specimens were compressed at a crosshead speed of 10 mm/min for displacement of 40 mm. While, the dynamic crush impact tests were conducted using Instron drop impact machine. The impact speed of the impactor was set at 4.5 m/s, and the impact energy 600J. The crushing displacement was measured using a photocell sensor placed near to the tube specimen.

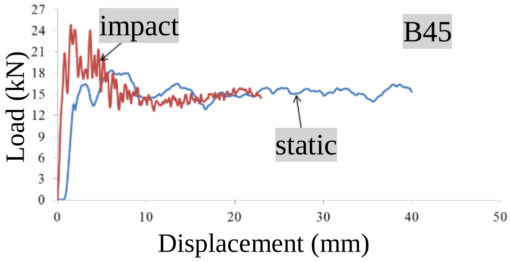
3. Experimental result and discussion

Typical load-displacement curve and corresponding photographs taken from the axial crushing tests for thin-walled basalt composite tubes are shown in figure 1 and 2 respectively. It was observed that the whole crushing process could involve with two class of collapsible modes subsequently named as Mode I and Mode II. The Mode I denoted for tube local buckling failure which associated to crushing load oscillating in more stable manner near constantly load, while Mode II referred to global buckling failure on tube's wall which regard to sudden drop of the initial load curve. Figure 1(a) and (b) show typical load curve at Mode I failure for basalt composite tube of B30 and B45 respectively. The load was oscillating in control and stable through the whole crushing process nearly average load of 10kN and 14kN respectively. Those two crushing photo morphologies observed in figure 2(a) and (b) predicted similar crushing mechanism which the crushed failure was initiated near chamfer portion. However, the specimen B30 was observed with obvious interlaminar cracks, broken fibre tows and extensive splaying on their tube wall. Meanwhile, the tube of B45 exhibited progressive diamond local buckling and relatively limited folding of braided tube wall were observed. Figure 1(c) displays the Mode II of typical load curve and crushing morphologies for specimen B60. At near 10kN of the peak static load, a global buckling occurred near the middle region of the tube of B60 caused low axial stiffness, resulting sudden and deeply dropping of crushing load. Then, the tube was crushed from the buckling location toward the upper and lower parts of B60 around 8kN. The progressive jamming of braided fibre tows was observed in figure 2(c). Subjected to different loading rate, the impact crushing load exhibited approximate 35% higher oscillating wave at beginning of crushing stage followed by smaller load waves indicated that kinetic energy being absorbed by the tubes during impact process. Basalt composite tube of B30, B45 and B60 had impact crushed at near 40mm, 25mm and 35mm of tube length respectively. Comparative load curve between quasi-static and impact crushing were demonstrated similar trends for all types of basalt composite tubes. However, the tube of B60 exhibited slightly farther curve from the quasi-static load curve. Compared with failure tubes on quasi-static crushing (figure 2), the impact crushed tubes were observed similar crushing modes but slightly severe crushing damage. It seen that larger axial crack and wall splaying occurred on tube B30 with interlaminar crack cause tube's wall splitting outward and inward. For tube of B45, it was observed that a little number of diamond shape edges and tube's wall crumping from upper to lower part of the tube. On the other hand, B60 tube was observed that the failure tube was crushed originated from middle part of tube as well at chamfered area.

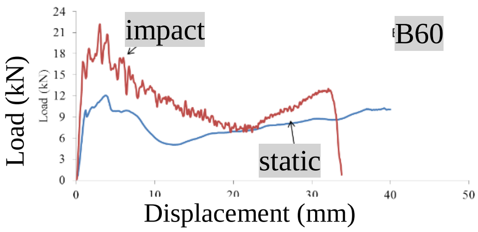
Figure 3(a)-(c) present typical load-displacement curve for glass composite tubes of G30, G45, and G60. Compared with basalt composite tubes load curves, glass tube of G45 and G60 demonstrate similar oscillating load wave with B45 and B60 respectively. However, glass tube of G30 exhibited larger load wave at around 40% of initial post-crushing stage denoted Mode II failure mechanism followed by Mode I for the rest of crushing process. It was observed that tube of G30 was occurred global buckling at middle of the tube that might cause by high axial stiffness resulting load concentration on the tube's wall. As it crushing process continues on the shorter tube height, the load distributed evenly in circumferential G30 tube caused axial interlaminar crack and wall splaying on braided tube. While specimen G45 was observed with diamond buckling and tube's wall folding similarly with basalt tube B45 (Mode I), but the buckling was observed occurred at upper and lower part of the tube. Meanwhile, glass tube of G60 was observed similar crushing mechanism (Mode II) with basalt tube of B60. Unlike basalt composite tubes, the whole glass tubes were impact crushed at 40mm length of tube indicated that glass tube has lower energy absorption capacity. The load waves presented significance 40% higher oscillating throughout impact crushing process as compared on static loads. Comparing with quasi-static loading, the tube of G30 and G60 were observed similar oscillating load trends under impact loading. However, G45 tube was observed slightly different on collapsible mode (mode II) depicted at beginning of post-crushing stage followed by sudden drop and continues with mode I failure. From the morphologies photo figure 4, it was observed that impact crushing gave much higher energy dissipation to the specimen tubes. Overall glass tubes demonstrated similar crushing failure as in quasi-static loading. But, tube of G30 wall splaying was larger than in impact loading with interlaminar crack resulted wall splaying outward and inward. On the other hand, G60 tube was seems like it had been crushed from middle to lower part of tube after pre-crushing stage happened at chamfer area.



(a) Basalt tube of B30

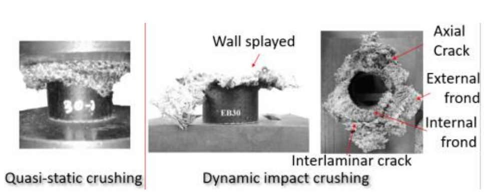


(b) Basalt tube of B45

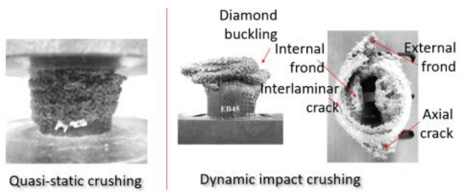


(c) Basalt tube of B60

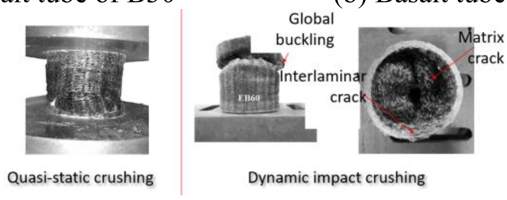
Figure 1. Comparative load-curve for basalt tube under different crush loading.



(a) Basalt tube of B30

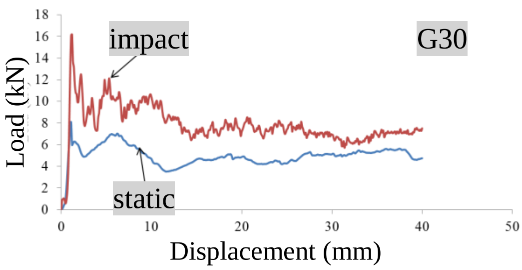


(b) Basalt tube of B45

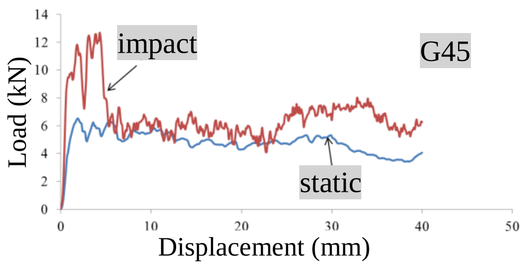


(c) Basalt tube of B60

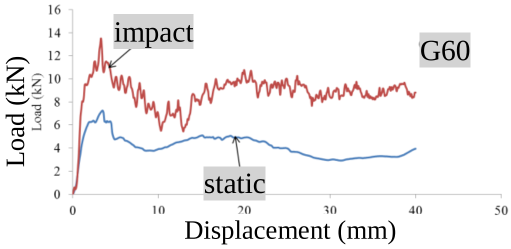
Figure 2. Impact crushing failure morphologies for basalt composite tube.



(a) Glass tube of G30

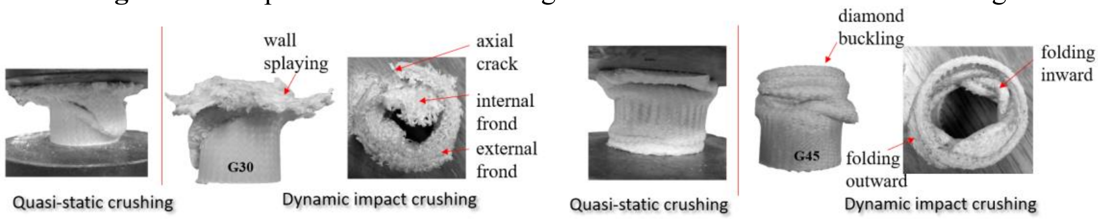


(b) Glass tube G45

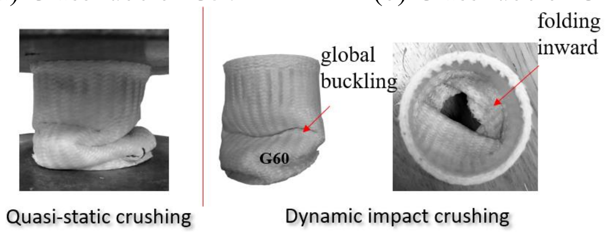


(c) Glass tube of G60

Figure 3. Comparative load-curve for glass tube under different crush loading.



(a) Glass tube of G30 (b) Glass tube of G45



(c) Glass tube of G60

Figure 4. Impact crushing failure morphologies for glass composite tube.

4. Conclusions

In this study, the effect of braid angle on the energy absorption behavior under axial quasi–static and impact crushing for composite tubes of basalt and glass braided were investigated. All specimens exhibited progressive failure process. Experimental results showed that the effect of braid angle was proved to have a great influence on the energy absorption performance. Basalt composite tube at ±45° braid angle has greater energy absorption capacity than glass composite tube at ±60° braid angle. Basalt reinforcement predicted lower crush rate dependency as compared with glass fibre reinforcement.

5. References

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6. Acknowledgementsfi

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