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EFFECT OF HYBRIDIZATION ON COMPRESSIVE PROPERTIES OF WOVEN CARBON, GLASS AND KEVLAR HYBRID COMPOSITES

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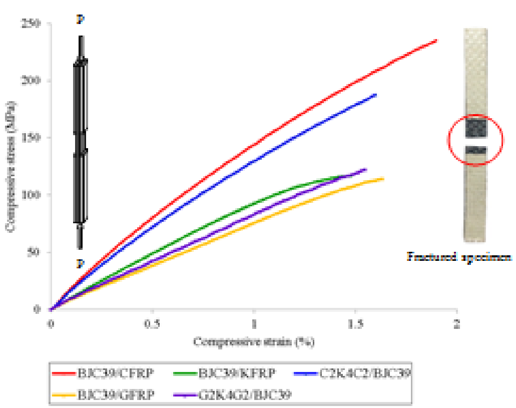
Graphical abstract



Abstract

The growing use of high-performance materials, which are made of hybrid composite systems, has increased rapidly in engineering applications. Hybridization of woven carbon, glass and Kevlar fibre offers better mechanical properties of composite materials. This is also an effective way to reduce the cost of advanced composites. At the moment information on compressive properties of hybrid composites is very limited. It is well known that the compressive strength of composite materials is lower than the tensile strength. Therefore, compressive strength becomes one of the most important criteria in designing composite structures. Therefore, this research is aimed to evaluate the compressive properties of hybrid composites and compare to the properties of neat systems. Hybrid composite samples were fabricated using a vacuum bagging system. The compressive properties of Kevlar hybrid with carbon and glass composites were studied using an INSTRON 3382 universal machine with a constant crosshead speed of 1 mm/min. The compressive properties were determined based on the stress-strain diagram. It was observed that for hybrid composites, placing carbon woven cloth layers in the exterior and Kevlar woven cloth in the interior showed higher compressive strength than placing glass woven cloth layers in the exterior and Kevlar woven cloth in the interior. The modes of failure of the hybrid composite laminates were observed and evaluated using optical microscope and scanning electron microscopy (SEM).

Keywords: Hybrid composites, fibre reinforced polymer composites, compression test, compressive properties, compressive strength

1.0 INTRODUCTION

Nowadays, woven type fibre reinforced polymer (FRP) composites are increasingly been used in various high technology as well as conventional applications. The woven type FRP composites has a better strength to crack propagation due to the warp produces greater shear strength to the crack opening in the matrix when compared to continuous fibre or chopped fibre composites [1,2]. Thus, woven type FRP composites have the advantage of interlocking between fibres and also showed the possibility of a significant anisotropy reduction. Currently, the designer is looking for the high strength to weight ratios materials and also those that allow for cost savings [3-9] to undergo different loading conditions during service life. Hybrid composites are the best material solution for such applications.

Hybrid composites are materials made by combining two or more different types of fibres in a same resin matrix [1-9]. The main reason of developing the hybrid systems is to improve toughness or stiffness of the material while reducing the cost of materials. Some fibres such as glass fibres are relatively cheap and available in the market; additionally when hybridized with other fibres such as carbon fibres which are high cost and relatively low in compressive strength can get the advantages of both fibres and reduce the weaknesses of each of them. Hybrid fabrics, which consist of combination of woven glass, carbon and Kevlar fibres, produce unique properties of composites due to combination properties of these pristine materials.

It is known that compression tests have been a challenge due to several factors such as Euler buckling, specimens' geometric imperfection and misalignment of the specimen in the test fixture, fibre misalignment in the specimen and bending/stretching coupling in the laminate [10-13]. There are several studies on hybrid composites under compressive loads. The compressive behavior of hybrid composites made of carbon/glass woven fabrics was investigated by Pandya *et al.* in [6]. Haery *et al.* [7] studied hybrid composites materials made of 12 plain weave plies glass/carbon fibres using hand lay-up method and Wang *et al.* [8] investigated the mechanical properties of glass/Kevlar woven fabrics reinforced composites. Based on these researches [6-8] they concluded that for Kevlar composites, the compressive moduli are much lower compared to tensile moduli and compressive strength of hybrid composite was higher than the pure composite. There were also typical studied on hybrid composites under flexural, fatigue, impact loading and CAI. The impact, flexure and fatigue properties of hybrid composites were better than the pristine FRP composites.

Therefore, the objective of this present work is to investigate the behaviour of hybrid composites made of carbon, glass and Kevlar cloth with epoxy resin under compressive loads. The results were then compared to the pure FRP systems.

2.0 EXPERIMENTAL

2.1 Materials

Eight plies of woven cloth types carbon, glass and Kevlar fibre which were supplied by Vistec Technology Services (VTS) were used in this studies. The polymer matrix used was Morcrete BJC 39 epoxy resin with hardener supplied by Morstrong Industries Sdn. Bhd.

2.2 Sample Preparation

Hybrid composite laminates for carbon/Kevlar/carbon (C2K4C2/BJC39) layers and glass/Kevlar/glass (G2K4G2/BJC39) layers were fabricated using vacuum bagging system. The arrangement is shown in Figure 1. Eight layers of plain weave carbon, glass and Kevlar cloth were used to produce the panels with approximate thickness of 2-2.5 mm, which complied with CRAG test method and ASTM D-3410. The Morcrete BJC39 epoxy resin and hardener were uniformly mixed with proportion ratio of 3:1 (as recommended in manufacturing datasheet) at room temperature. Then, the mixture of Morcrete BJC39 epoxy resin was poured onto a fibre layer by layer. The specimens were covered with plastic film to ensure the smooth surface finish and easy to remove. Next, the system was degassed for 1 hour in the vacuum bag section to eliminate any air bubbles existing in the composite. The composite system was then cured at room temperature and a load of 10 kN was applied for 24 hours in order to ensure uniform laminate thickness.

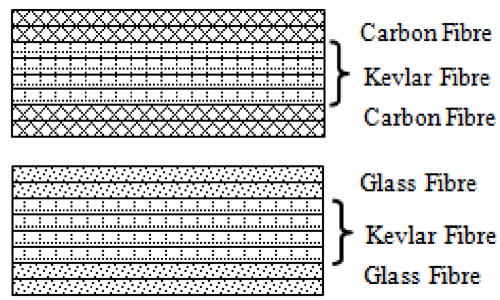
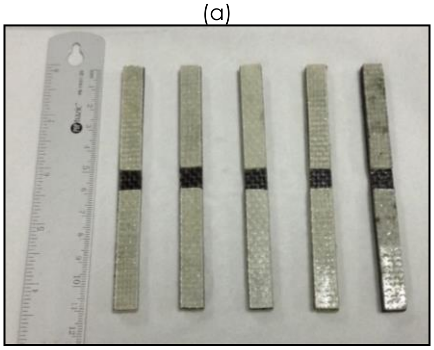


Figure1 Stacking configurations layer of fibre

2.3 Compression Tests

The compression tests were performed in accordance to the ASTM D-3410 and CRAG Test Method. The specimens with dimensions and gauge length of 110 mm x 10 mm and 10 mm were prepared. At least five specimens were tested for each system using a 100 kN INSTRON servo-hydraulic machine model 3382 with UiTM Dual guide compression test fixture as shown in Figure 2. The cross head speed of 1 mm/min was applied to the specimens until failure was observed. All the data were recorded by the computer via data acquisition system under compression loading. Several tests were stopped before the final failure occurred in order to examine the initial failure mode. The fractured specimen was prepared using the standard metallographic technique and observed under the optical microscope and Scanning electron microscopy (SEM) to identify the failure mechanisms involved during compression tests.

(a)



(b)

Figure 2 (a) A 100 kN compression servo-hydraulic machine with UiTM dual guide test fixture set-up for compression test (b) The example of hybrid $C_2K_4C_2$/BJC39 compression test specimens

3.0 RESULTS AND DISCUSSION

3.1 Compressive Properties

The compressive stress-strain responses of a typical hybrid composites system $C_2K_4C_2$/BJC39 and $G_2K_4G_2$/BJC39 under uniaxial static compression loading are shown in Figure 3. The figure presents the comparison between hybrid and non-hybrid (pure system of CFRP, GFRP and KFRP) composites systems performances after compression loads.

In general, the compressive stress-strain graphs were linear up to a strain of 1.5% for $C_2K_4C_2$, 1.5% for $G_2K_4G_2$, 1.9% for CFRP, 1.6 for GFRP and 1.4% for KFRP. Based on the observation during the experiments, all specimens failed suddenly at the middle of the gauge section. It was accompanied by a spontaneous release of sound during fracture event. The elastic modulus of 14.70 GPa, 11.05 GPa, 21.19 GPa, 13.52 GPa and 10.24 GPa was calculated at 0.3% applied strain for $C_2K_4C_2$, $G_2K_4G_2$, CFRP, KFRP and GFRP composites, respectively. Catastrophic failure occurred at the average failure stress of 186.45 Mpa, 122.11MPa, 239.82 MPa, 116.76 MPa and 114.14 MPa for $C_2K_4C_2$, $G_2K_4G_2$, CFRP, KFRP and GFRP composites, respectively. Table 1 shows the summary of compressive properties of these two hybrid composite systems compared with pure systems.

Table 1 Effects of hybridization on compressive properties of FRP composite laminates

Compressive properties	$C_2K_4C_2$/BJC39	FRP			$G_2K_4G_2$/BJC39
		CFRP	GFRP	KFRP	
Compressive modulus, E (GPa)	14.70±0.30	21.19± 0.59	10.24± 0.28	13.52± 0.13	11.05± 0.37
Compressive strength, σ_U (MPa)	186.45± 0.22	239.82± 0.13	114.14± 0.25	116.76± 0.30	122.11± 0.58
Compressive strain at break, ε_f (%)	1.59	1.91	1.63	1.48	1.54
Compressive load (kN)	0.12	1.59	0.72	0.85	0.73

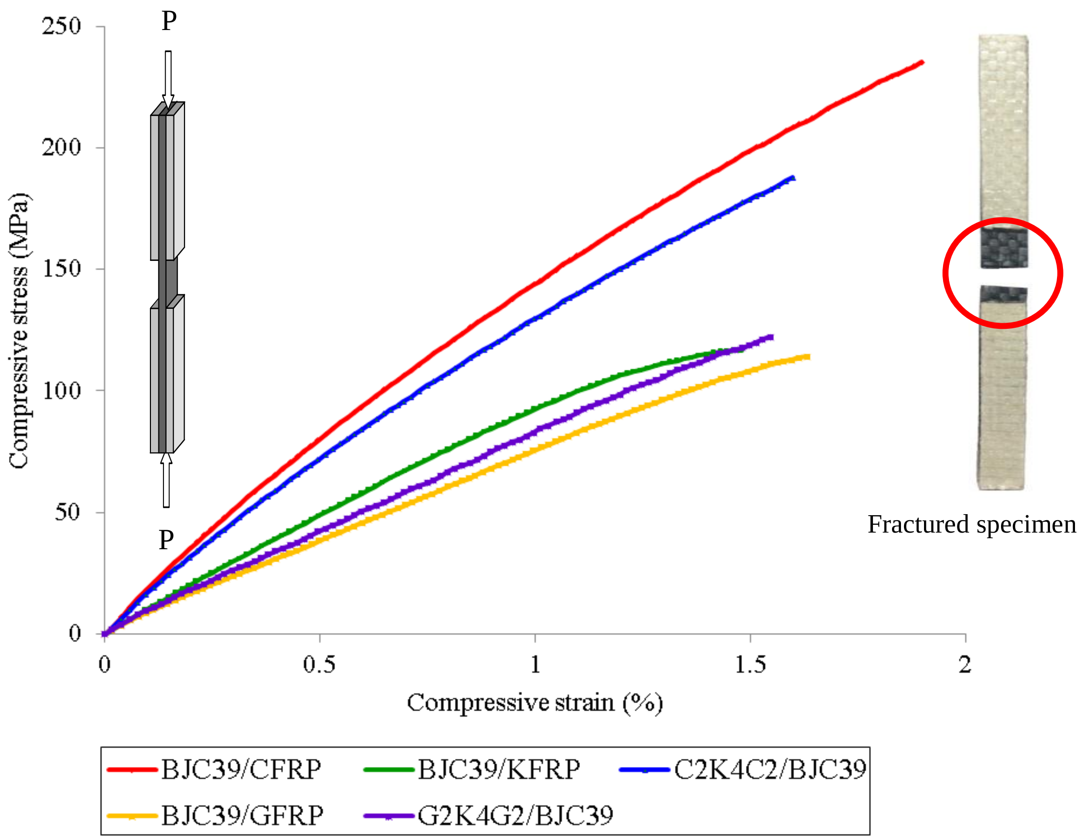


Figure 3 Typical stress-strain curves of hybrid and non-hybrid (pure) composites specimens loaded in static uniaxial compression loads

3.2 Hybridization Effects

The hybridization effects of carbon/Kevlar/carbon ($C_2K_4C_2$/BJC39) layers and glass/Kevlar/glass ($G_2K_4G_2$/BJC39) layers on compressive stress-strain are summarized in Table 1. As expected, the CFRP composite laminates had the highest compression strength and GFRP had the lowest compressive strength. This observation is similar to Zhang *et al.* [9] which reported that the average compressive strength of pure glass fibre account almost 50% less than the pure carbon. For hybrid systems, it was observed that the compressive strength of $G_2K_4G_2$/BJC39(116.76 MPa) system showed slightly higher compared to GFRP (114.15 MPa) composites. It was also observed that, the hybridazation of glass/Kevlar not much contribute to the improvement of Compressive Modulus (11.05 GPa) when compared to pure GFRP (10.24 GPa). The results showed that carbon fibre composites have better properties compared to those of glass fibre and Kevlar fibre composites. This is due to the fact that, the elastic modulus of carbon fibre is higher than glass fibre and Kevlar fibre.

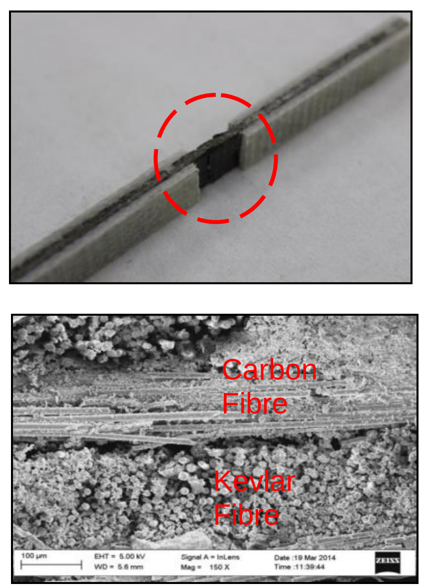
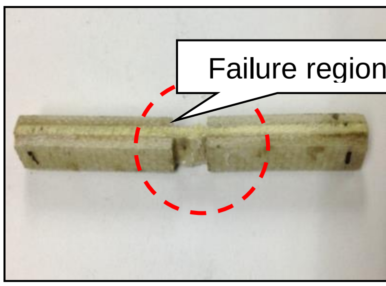


Figure 4 SEM fractography of $C_2K_4C_2$/BJC39 showing the fracture surface

The presence of Kevlar fibre in the inner layers makes the specimens not to failure by brittle cracking, as shown in Figures 4 and 5. The specimens of pure CFRP and GFRP composites failed in brittle manner where these specimens cracked and broken into two sections after they were loaded under compression. Figures 4 and 5 showed that the hybrid systems of $C_2K_4C_2$/BJC39 and $G_2K_4G_2$/BJC39 failed into two regions without separation. The SEM micrographs showed that these two regions still intact to each other due to the presence of Kevlar fibres. The compressive strength of $C_2K_4C_2$/BJC39 hybrid system showed second higher value when compared to the other composites. The enhanced compressive strength for the carbon fibre in the outer layers may be caused by the properties of the carbon fibres itself.



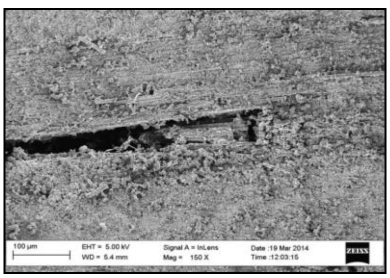


Figure 5 SEM fractography of G2K4G2/BJC39 showing the fracture surface

4.0 CONCLUSION

Studies on hybridization effect of woven fabric composites under compressive loading are very limited. In this research, woven hybrid composite systems which were made of carbon/Kevlar and glass/Kevlar were successfully fabricated. The compressive properties of hybrid composites were determined based on the compressive stress-strain graphs. It can be concluded that the presence of Kevlar fibre enhanced the properties of glass fibre composites. Glass/Kevlar Hybrid composites have better properties such as stiffness, ductility and strength that cannot be achieved by single fibre reinforced composites alone. It was also observed that placing carbon layers in the exterior and Kevlar layers in the interior gave higher compressive strength compared to placing glass layers in the exterior and Kevlar layers in the interior. In general, Kevlar are high in strength but has very low stiffness. The presence of carbon and glass fibres at the exterior layers results in enhancement of compressive properties of Kevlar composites. In addition, the presence of Kevlar fibre in the inner layers resulted in a better failure mode of the hybrid composites when compared to their pure systems. Hybrid composites did not failed in brittle manner. Therefore, the results obtained could contribute to the new knowledge on the compressive properties of woven fibre hybrid FRP composites.

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