Tensile Behaviour of Hybrid Composites Between Glass and Short Carbon Fibres

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Article history
Received
13 November 2019
Revised
26 December 2019
Accepted
31 December 2019
Published
31 December 2019

ABSTRACT

This paper presents the tensile behaviours of the hybrid composites consisting of short carbon and synthetic fibres in the form of chopped strand mat glass (CSM) and woven glass. The short carbon fibre used in this study represents the discontinuous carbon fibre tows of the recycled carbon fibre with short fibre tows. All the specimens were fabricated using vacuum infusion process with epoxy resin as the matrix and the tensile test was carried out in accordance withthe ASTM D3039. In total, six different configurations of specimens have been examined comprising the non-hybrid, aligned hybrid and non-aligned hybrid specimens. From the tests, the aligned hybrid specimens show a significant improvement in the tensile properties such as tensile modulus (up to 99%), toughness modulus (more than 10%) and ultimate tensile stress (up to 59.9%) over the non-hybrid composites. The aligned hybrid composites also exhibit a non-linear pseudo-ductile response before failure compared to the catastrophic brittle failure of the non-hybrid and non-aligned hybrid composites.

Keywords: *Eco-hybrid, carbon fibre, tensile, hybrid, recyclefibre*

1.0 INTRODUCTION

The use of synthetic composite such as carbon fibre composite has been steadily on the increase,particularly in aerospace and wind energy industries due to its light weight and superiority in the mechanical properties. It is estimated that the global demand for carbon fibre will double from 70,000 tonnes in 2015 to 140,000 tonnes by 2020 [1]. It is also estimated that 12,000 aircraft will be retiring in the next two decades [2]. *Boeing 787*, for example, carries approximately 18,000 kg of salvageable carbon fibre, while a jumbo jet like *Airbus A380* carries about 25,000 kg of composites per plane [3].

In addition, manufacturing these carbon composite components cancreate up to 40% scrap materials [4]. Due to ecological reasons, landfill cannot cope with such a large volume of non-biodegradable composite waste.Environmental awareness and depletion of the petroleum resources are among vital factors that motivate a number of researchers to explore the potential of reusing natural fibre as an alternative composite material in industries such as packaging, automotive and building constructions. However, their applications are still limited due to several factors like moisture absorption, poor wettability and large scattering in mechanical properties [5-8]. Among the main challenges of natural fibres reinforced matrices composite is their inclination to entangle and form fibres agglomerates during processing because of the interaction between the fibres. Hence, the research on natural fibre is being done by mercerization treatment on mechanical properties enhancement of natural fibre reinforced composite or so-called bio composite. Mercerization treatment is the process of subjecting a vegetable fibre to an interaction with a fairly concentrated aqueous solution of strong base, to produce great swelling with resultant changes in the fine structure, dimension, morphology and mechanical properties [9].

Thus, there is another option to replace or control the usage of synthetic composite which is by reducing the production of the synthetic composite. The solution to reduce the production is by recycled it and perform hybridisation with other synthetic or natural fibres to create eco-hybrid type composite. Apart frombeing environmentally friendly, recycling the synthetic fibre can also enhance and improve the mechanical properties of the synthetic fibre itself. The hybrid composites are expected to have animprovement in toughness so that it could have the damage propagation behaviours instead of sudden failurethat commonlyoccursin synthetic composites.

Nevertheless, there are limited studies regarding the eco-hybrid composite that typically consists of recycle carbon either hybridised with natural or synthetic fibres in the open literature. Hence, the mechanical behaviours of the eco-hybrid systems are still questionable as it depends on the design of the laminates, including the stacking sequence, material used as well as the fabrication technique. Therefore, this study focuses on the design of the eco-hybrid composite and its mechanical properties in order to consider the effect of the stacking sequence and material used.

2.0 EXPERIMENTAL SET-UP

In this research, the tensile test was carried out on several types of the eco-hybrid composites consisting of recycle carbon either hybridized with natural or synthetic fibres to study and analyze the mechanical properties of these composites. Six different configurations of specimens were designed and fabricated. Short carbon fibre was used in this study to represent the arrangement of the recycled carbon fibre that is normally available in the form of short carbon fibre strands. The mechanical properties are expected to be similar with the recycle short carbon fibre. The length of each strand of short carbon fibres is approximately 12mm as shown in Figure 1.

Figure 1: Short carbon fibres [10]

These short carbon fibre tows were hybridised with woven glass and chopped strand mat glass (CSM). Two kinds of orientation were used in the fabrication of specimen which are unidirectional discontinuous oriented and random oriented discontinuous. Five samples were prepared for each specimen configuration. The details of the specimen configuration areshown in Table 1.

Table 1: Specimen configurations

No	Specimen configurations	Number ofsamples
1	CSM (glass) + alignedcarbon fibre	4
2	CSM (glass) + random carbon fibre	4
3	CSM (glass) pure	4
4	Woven (glass) + alignedcarbon fibre	4
5	Woven (glass) + random carbon fibre	4
6	Woven (glass) pure	4
	Totalspecimens	24

All the specimens were fabricated viavacuum infusion process (VIP) based on three different configurations; three layers of pure synthetic composites (Figure 2), synthetic composites hybrids with aligned short carbon fibre tows (Figure 3) and composites hybrid with random short carbon fibre tows (Figure 4). All the specimens were bonded using *epoxy resin 1006*.

CSM Pure	Woven Glass Pure
CSM Pure	Woven Glass Pure
CSM Pure	Woven Glass Pure

Figure 2: Stacking sequences for pure synthetic composites

CSM Pure	Woven Glass Pure
=================	=================
CSM Pure	Woven Glass Pure
=================	=================
CSM Pure	Woven Glass Pure

Figure 3: Stacking sequences for synthetic fibres intercalation with aligned short carbon fibres (0°angle of aligned fibres)

CSM Pure	Woven Glass Pure
xxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxxxxx
CSM Pure	Woven Glass Pure
xxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxxxxx
CSM Pure	Woven Glass Pure

Figure 4: Stacking sequence for synthetic fibres intercalation with random short carbon fibres (random angle of aligned fibres)

The tensile test was carried out in accordance to *ASTM D3039* (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials) [11]. The machine used was *Instron 8801* Universal Testing Machine and the experimental set-up is shown in Figure 5. The extensometer was used and attached to the specimen to measure the elongation. Tensile load was applied, and the specimen was pulled at a rate of 1mm/min.

It is necessary to ensure the sample to be positioned vertically 90º in the grip of the testing machine as shown in Figure 5.

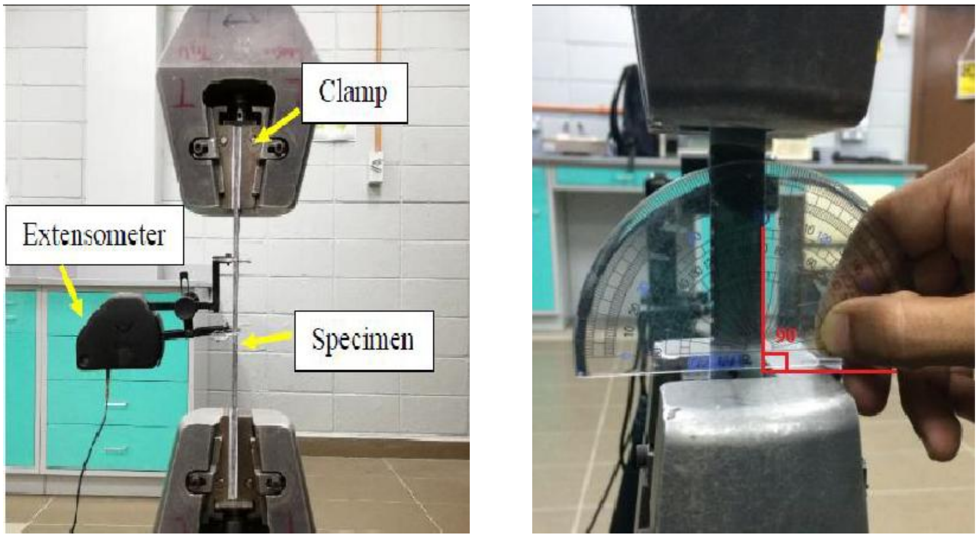

Figure 5: Experimental set-up

The stress-strain curves were converted from the main product of a tensile test, load versus elongation curve. The stress can also be determined from equation:

$$\sigma = F/A \tag{1}$$

Where, σ is stress in MPa, F is force in N and A is an area of the sample in mm².

According to *Hooke's* Law in the linear or plastic region, the line obeys the relationship where the ratio of the stress to strain is constant. E is the slope of the line in this region where stress is proportional to strain and is called the modulus of elasticitywhile the modulus of toughness was obtained by integrating the area under the stress-strain curve.

3.0 RESULTS AND DISCUSSION

The analysesof the results were carried out and presented according to each base material, namely, the CSM and woven glass. The effects of the hybridisation between the based materials and the short carbon fibre tows (aligned and random) were analyzed with the stress-strain curves.

Figure 6 shows the tensile stress-strain curves for all CSM configurations. Samples for each of the configuration shows similar response with small variation of the curves.As shown in Figure 6, the hybrid specimen with aligned carbon fibre (CCA) exhibits higher tensile strength and better ductility in comparison to the pure CSM laminate (C) and random hybrid specimen (CCR). The summary of the results based on average values of the modulus of elasticity, modulus of toughness and ultimate tensile stress are presented in Table 2. The results show that the CCA specimen has increased the ultimate tensile stressby 59.6%, tensile modulus 99.1% and toughness modulus 11.5% compared to the pure CSM (C)laminate. The inclusion of short carbon fibre tows as filler in aligned mode configuration (CCA) contributes to the improvement of the tensile propertiesand produced a fairly non-linear pseudo-ductility response due to subcritical progressive damage [10]. Thus, it increases the area under the stress-strain curves which related the toughness properties.

In contrary, the inclusion of the short carbon fibre in random mode configuration (CCR) shows insignificant improvement in the tensile properties compared to pure laminate (C). Although it is able to improve to about 40% of the tensile modulus, but in terms of modulus of toughness and ultimate tensile stress, it shows a reduction in both properties for about 26.5% and 23.6%, respectively.

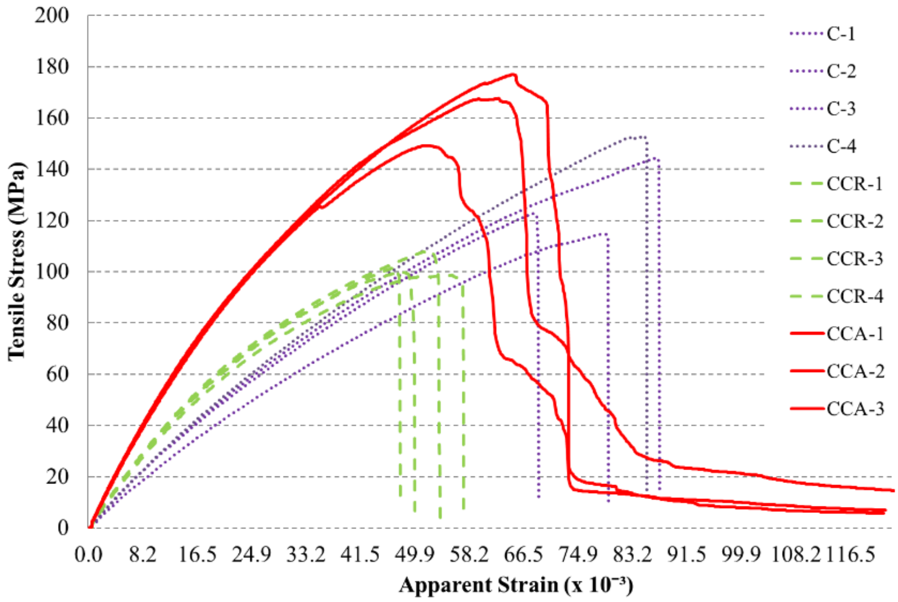

Figure 6: Tensile stress-strain curves comparison for CSM configurations

Table 2: Comparison of tensile properties of CSM glass-based material specimens

Tensile properties	Pure (C)	Random carbon fibre (CCR)	Alignedcarbon fibre (CCA) [10]
Tensile modulus of elasticity (GPa)	10.07	14.09	20.05
Modulus of toughness (MPa)	1.6215	1.1911	1.808
Ultimate tensile stress (MPa)	133.69	102.19	163.08

Figure 7 on the other hand shows the tensile stress-strain curves for all woven glass configurations. Correspondingly, each of the configuration shows similar pattern of the curves with small dispersion. As shown in Figure 7, the pure woven glass laminate (W), exhibit higher ultimate tensile stress compare to hybrid specimen with aligned carbon fibre (WCA) and random hybrid specimen (WCR). The average values of the modulus of elasticity, modulus of toughness and ultimate tensile stress are listed in Table 3. The results show that the WCA specimen has increased the tensile modulus to 75.7% and toughness modulus 12.1% compared to the pure woven glass laminate (W). However, it shows a decreasing trend by about 14% in terms of ultimate tensile stress.

The inclusion of short carbon fibres as filler in aligned mode configuration (WCA) contributes to the improvement of tensile properties andat the same time, it produces a large non-linear pseudo-ductility response that can be clearly seen in Figure 7 due to a subcritical progressive damage [10]. The presence of this response in other words demonstrates this specimen has better toughness properties that is able to avoid a sudden breakage of specimen when experiencing the tensile loads. Thus, it could delay the catastrophic failure of specimen.

Like the CCR specimen, the hybridisation between the short carbon fibre tows and woven glass in random mode configuration (WCR) has also shown insignificant improvement in the tensile properties. From the results obtained, the WCR specimen is not only able to improve the tensile modulus of elasticity for about 52.1% but at the same time manages to reduce the toughness modulus to 42% and ultimate tensile stress to 42.7% as compared to the pure woven glass specimen (W).

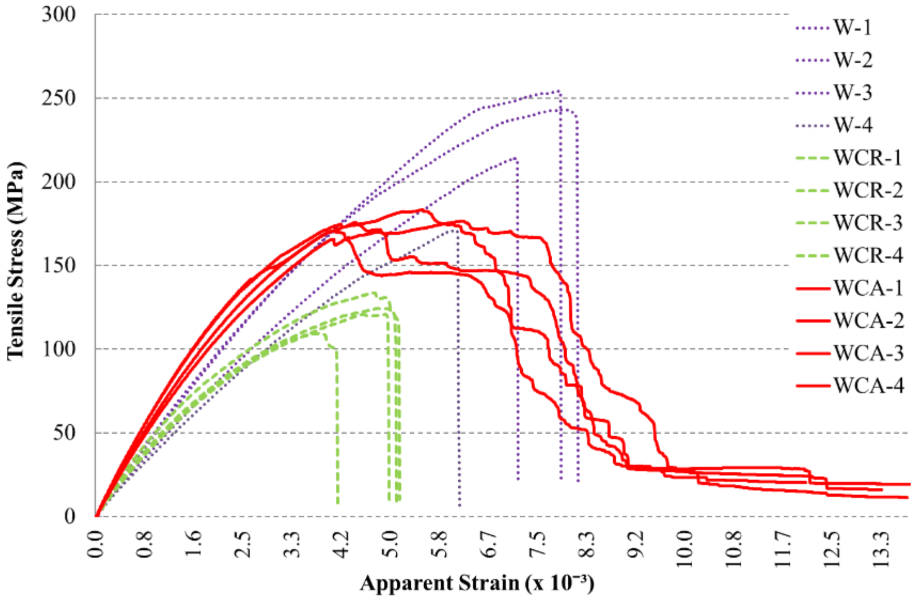

Figure 7: Tensile stress-strain curves comparison for woven configurations

Table 3: Comparison of the tensile properties of woven glass-based material specimens

Tensile properties	Pure (W)	Random carbon fibre (WCR)	Alignedcarbon fibre (WCA)[10]
Tensile modulus of elasticity (GPa)	15.69	23.87	27.57
Modulus of toughness (MPa)	2.5345	1.469	2.842
Ultimate tensile stress (MPa)	220.54	126.36	189.61

The decreasing in tensile properties of the CCR and WCR specimens could be due to the presence of void between the layers in the laminates. The variation in thickness resulted inevitably from the gap and overlap defects in the discontinuous random carbon fibres [12]. This creates the available empty spaces as residue in the composite laminate and allows void to form.

4.0 CONCLUSION

The hybridisation between the synthetic fibres (CSM and woven glass) and aligned short carbon fibre tows in this study contributes a noteworthy improvement of the tensile properties as compared to the non-hybrid specimens. It can be seen that, the CCA and WCA are able to improve more than 75% of the tensile modulus of elasticity in comparison to the non-hybrid specimens. Although WCA has a small drop of about 14% in the ultimate tensile stress, it produces better modulus of toughness by more than 10%. for both CCA and WCA compared to the non-hybrid specimens.

Nevertheless, the hybridisation between the synthetic fibres and random short carbon fibre tows seems insignificant in this study as it shows improvement only in the tensile modulus but decreasing in other two tensile properties for about 40% as compared to non-hybrid specimens. As discussed earlier, this may be due to the presence of void between the layers in the specimens.

Moreover, the eco-hybrid laminate with aligned short carbon fibre tows is able to produce a pseudo-ductility response that could delay the failure of the composite laminate. In other words, these specimens still display some degree of integrity after the major load drop without breaking and show the damage propagation in the stress-strain curves. On the other hand, the sudden stress drops in the stress-strain curves indicate the non-hybrid and non-aligned composites experienced the catastrophic brittle fracture.

ACKNOWLEDGMENTS

The authors acknowledge the financial support through the UTM-TDR Grant (05G22) and FRGS (5F040) as well as the Royal Malaysian Air Force (RMAF) for providing the scholarship. The authors also appreciate the University of Southampton Malaysia Campus for providing the fabrication facilities.

REFERENCES

1. Onishi M., 2012. *Toray's Business Strategy for Carbon Fibre Composite Materials*. Retrieved from: http://www.toray.com/ir/pdf/lib/lib_a136.pdf.
[Accessed: 1 September 2019].
2 AFRA., 2015. *Aircraft Fleet Recycling Association*. Retrieved from: www.afraassociation.org.
[Accessed: 15 August 2019].
2. Wood K., 2010. *Carbon Fibre Reclamation: Going Commercial, High-Performance Composites*. Retrieved from: http://www.compositesworld.com/articles/carbon-fibre-reclamation-going-commercial.
[Accessed: 1 September 2019].
3. Recycled Carbon Fibre Ltd., *Converting Composite Waste into High Quality Re-usable Carbon Fibre*. Retrieved from:http:///www.recycledcarbonfibre.com.
[Accessed: 15 August 2019].
5. Yap C.T.M., Israr H.A. Wong K.J. and Yahya M.Y., 2016. Compressive Properties of Hawaiian Gold Timber Bamboo under Different Conditions, *Journal of Advanced Research in Applied Mechanics*, 25: 10-18.
6. Yap C.T.M., Wong K.J. and Israr H.A., 2017. Mechanical Properties of Bamboo and Bamboo Composites: A Review, *Journal of Advanced Research in Material Science*, 35: 7-26.
7. Faruk O., Bledzki A.K., Fink H.-P. and Sain M., 2012. Biocomposites Reinforced with Natural Fibers: 2000–2010, *Prog. Polym. Sci*., 37(11): 1552–1596.

8. Hill C. and Hughes M., 2010. Natural Fiber Reinforced Composites Opportunities and Challenges, *Journal of Biobased Materials and Bioenergy*, 4(2): 148-158.
9. Campbell F.C., 2010. *Structural Composites Materials*. ASM International.
10. Gan K.W., Ho Y.W., Ow Z.Y., Israr H.A., Wong K.J., 2019. A Vibration-assisted Dry Alignment Method for Discontinuous Fibre Tows in Hybrid Composites and Their Tensile Performance, *Journal of Composite Materials*, 53(26–27): 3893–3907
11. ASTM D3039/ D3039m, 2010. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, *Annual Book of ASTM Standards*, 1–16.
12. Fu S., Lauke B., 1996. Effects of Fiber Length and Fiber Orientation Distributions on the Tensile Strength of Short-fiber-reinforced Polymers, *Compos Sci and Technol*., 56 (10): 1179–1190.