Experimental Investigation of Tensile Properties of Eco-composite Laminates

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ABSTRACT

Natural fiber composites are green composites that are renewable and sustainable towards the environment. It has low density which results in a good specific strength. With the current trending to lower the dependency on petroleum-based products, it leads to investigation on the environmental friendly materials to replace the conventional fibers. Therefore, natural fibers are hybridized with conventional fibers to form eco-composite laminates. Eco-composites have ecological and environmental advantages compared to synthetic composites while its strengths are comparable to the synthetic composites. However, not many studies have been done on the mechanical properties of this type of eco-composites. This paper presents the tensile properties of eco-composites consisting of flax-carbon/epoxy laminates in sandwich-like and intercalation configurations. From the tensile tests, the eco-composites strengths are comparable to the synthetic composite laminates. For eco-composite laminates, sandwich-like configurations are found to have better properties compared to the intercalation counterpart.

Keywords: *Composite, eco-hybrid, eco-composite, natural fiber, tensile test*

1.0 INTRODUCTION

Synthetic fibers such as carbon, glass and *Kevlar* based fibers have been widely used to replace the heavy metallic structures. It has many advantages and applications in daily usage mainly due to its technical properties such as high strength, low density and durability. Nevertheless, the usage of synthetic fibers has given rise to pollution problem since most of the synthetic fibers are non-recyclable [1]. With the current emphasis on the environmental-friendliness and sustainability, natural fibers have gained more attention to be used as alternative materials. Natural fibers are material that originate from the surrounding environment. It is composed of natural fibers embedded in matrix. Although natural fibers are not as strong as the synthetic fibers, they are abundant in our surrounding environment and the fact that they are recyclable [2]. Furthermore, it can be replanted again at a lower cost and the extraction process of the natural fibers causes minimal pollution to the environment compared to the synthetic fibers.

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In term of technical advantages, natural fibers have low density which gives them high specific strength [3]. Therefore, it has high potential to substitute the synthetic fibers reinforced plastics at lower cost and better sustainability [1, 3]. However, its mechanical properties are still considered slightly inferior compared to the synthetic counterpart [2, 4-6].

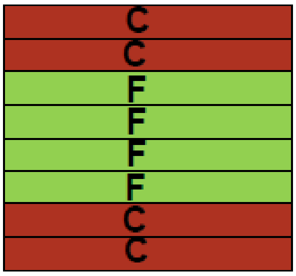
One of the ideas to improve the mechanical properties of the natural fiber laminates is by hybridizing it with the synthetic fiber laminates together with the polymer matrix to develop new type of eco-composite laminates [7-8]. Shahirul *et al*. has reported that these new type of eco-composite laminates are capable to compensate the disadvantages of the synthetic fibers such as ductility behavior as well as the disadvantages of natural fibers related to their mechanical properties [8]. Most of the studies found in the open literature regarding the bio-composites laminates were developed by reinforcing the natural fiber laminates with the polymer matrix [9-10].

Literary wise, there are very limited studies on the mechanical behaviors of eco-composite laminates (hybridization between the natural and synthetic fiber laminates). Therefore, this paper presents the investigation of the tensile properties of flax/carbon eco-composite laminates.

2.0 MATERIALS AND METHODS

The natural fiber and synthetic fiber used in this study is biotex flax fiber (290 gsm) and unidirectional carbon T300 fiber (250 gsm). In this study, four types configuration of specimens has been used which are the pure flax laminate (PF-8), pure carbon laminate (PC-8), sandwich-like (SC/F-8) and intercalation (IC/F-8) eco-composite laminates configurations. For each type of specimen, it consists of eight plies either natural or synthetic plies and all the specimens have been reinforced with epoxy resin 1006.

For sandwich-like configuration, the flax layers are located in between the carbon laminates as shown in Figure 1 (a). For intercalation configuration, the flax and carbon are arranged alternately to each other as shown in Figure 1 (b). (*Note: The designation of specimens was based on the code [SM/M-n] where; S: Stacking sequence, M: Material, n: number of plies)*.



(a)

(b)

Figure 1: Eco-composite laminates; (a) sandwich-like laminates (b) Intercalation laminates

The tensile test was carried out in accordance to the ASTM D3039 [11] (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials). The dimensions for the specimens are 250 mm (L) × 25 mm (W) and 2.5 mm (T) as shown in Figure 2. The aluminum tabs were glued at the clamping areas of the specimens to prevent the specimens being damaged by the clamps. Three samples were prepared for each specimen configuration.

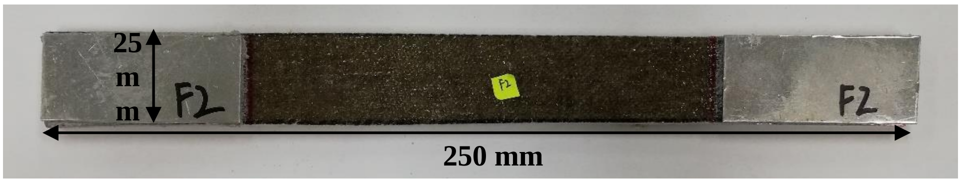


Figure 2: An example tensile specimen (PF-8-n2) with dimension

The machine used was *Instron* 5982 Universal Testing Machine and the test set-up is shown in Figure 3. The extensometer was used and attached to the specimens to measure the elongation. The tensile load was applied at a uniform rate of 2.0 mm/min.

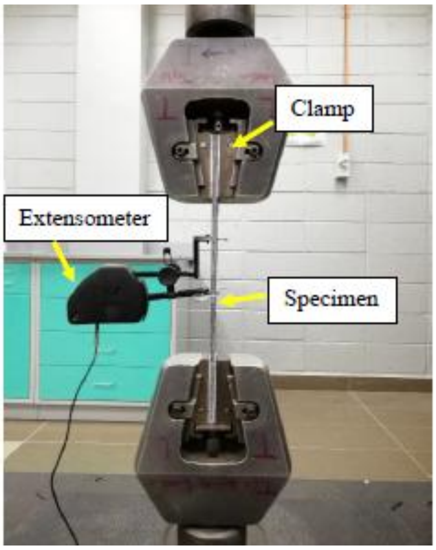


Figure 3: Tensile test set-up

3.0 RESULTS AND DISCUSSION

Figure 4 shows the tensile stress-strain curves for all types of specimens. The three samples of each specimen configuration show similar trending of the curves. The black dots indicate the maximum tensile strength of the specimens. As expected, pure carbon specimens (PC-8) delivered the highest tensile strength (436.3-552 MPa), while the lowest tensile strength is produced by the pure flax specimens, PF-8 (67-77 MPa). For the eco-composite specimens, Figure 4 shows that SC/F-8 (sandwich-like) specimens deliver better tensile strength (340-435 MPa) compared to IC/F-8 (intercalation) specimens (297-310 MPa).

The tensile modulus of elasticity for each type of specimens is calculated from the gradient of the elastic region of the stress-strain curves. Similarly, PC-8 specimens produce the highest tensile modulus (79.5-90.4 GPa) followed by IC/F-8 specimens (32.9-38.1 GPa), SC/F-8 specimens (27.1-30 GPa) and PF-8 specimens (11.7-12.5 GPa).

Table 1 shows the summary of average data for all specimens in terms of tensile modulus of elasticity, tensile strength and tensile strain for comparison purpose. Pure carbon specimens (PC-8) clearly have a better tensile properties as they have better mechanical strength and stiffer [12] compared to the other types of specimens. While, pure flax specimens (PF-8) have the highest tensile strain among all specimens as they have better ductility behavior [13] than the other types of specimens.

For the eco-composite specimens, the applied load was uniformly distributed on the cross-sectional area. Even though the stacking sequences are different, the eco-hybrid laminates were constructed to maintain an equal percentage of fiber loading between the synthetic and natural fibers. Nevertheless, due to a higher number of interfaces in the intercalation (IC/F-8) sequence, it may cause a detrimental effect on the final properties of the laminates, especially on their stiffness. This finding partially agrees with the previous studies on the effect of lay-up architecture on the plain-weave flax laminates which suggested that the effect of the amount of fibers oriented in the load direction is absolutely predominant and exclusive [14], as well as in the hybrid composite laminates of E-glass/carbon with different sequences [15].

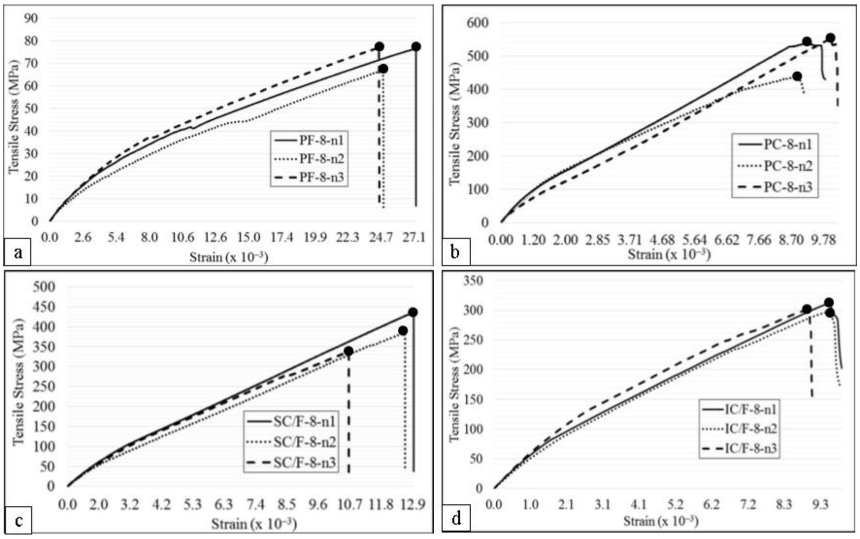


Figure 4: Tensile stress-strain graphs for (a) Pure flax, PF-8 (b) Pure carbon, PC-8 laminate (c) Flax/carbon (sandwich-like), SC/F-8 (d) Flax/carbon (intercalation), IC/F-8

Table 1: Average data of the tensile properties of the tested specimens

Specimens	Max Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Tensile Strain
PF-8	73.4	12.12	0.02524
PC-8	506.4	85.85	0.00945
SC/F-8	382.7	28.43	0.01207
IC/F-8	302.2	35.67	0.00929

Table 1 also shows that the SC/F-8 exhibits 421% higher tensile strength and 134.5% higher tensile modulus compared to PF-8 laminate. On the other hand, IC/F-8 laminate exhibits 311.7% and 194.3% higher than PF-8 laminate of tensile strength and tensile modulus respectively. Thus, it shows that the presence of carbon fiber in carbon/flax hybrid laminates have significantly improved the tensile properties of the pure flax laminate.

In terms of the damage mechanism, almost all the tested specimens in this loading configuration failed due to fiber breakage. It is believed that, the eco-composite laminates (SC/F-8 and IC/F-8) exhibit the dominant fibers failure caused by the weakness of the flax fibers as it exhibits the lowest tensile strength. This result agrees with the fiber bundle theory as previously found by Asim *et.al* in the study of pineapple leaf/kenaf phenolic hybrid composite, whereas at higher load, the weaker fiber breaks first, then followed by the stronger fibers [16].

4.0 CONCLUSION

The tensile properties of the eco-composite carbon/flax with sandwich and intercalation stacking configurations have been obtained. The effect of hybridization was remarkable for flax with the increase of about 421% of tensile strength when carbon was embedded into a sandwich-like configuration. In terms of the failure modes, almost all the tested structures failed due to fiber breakage. It can be concluded that with proper treatment and manufacturing process, the eco-composite can be commercialized in many engineering structures as it has many advantages including lightweight, abundant, ecology friendly, and comparable strength in comparison to the conventional materials.

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