Hardness, Tensile and Microstructure Assessment of Carbon/Glass Hybrid Composite Laminate

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ABSTRACT

Hybrid composites are often made by combining the high and low modulus fibers. The high modulus fiber, such as Carbon fiber provides the stiffness and load bearing qualities, whereas the low modulus fiber, such as glass fiber makes the composite more durable and low in cost. Nevertheless, the optimum arrangement between these fibers is still under comprehensive investigation. This paper assesses the hardness, tensile and microstructure of Hybrid Composite Laminates by varying the arrangement of Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). Hardness and Tensile Tests were carried out on seven different layup arrangements of the Carbon-Glass Hybrid Composite Laminates. Hardness tests were performed using micro hardness tester and pyramid shape indenter. Tensile Tests were performed in accordance to ASTM D3039 to determine the Modulus of Elasticity, E and Tensile Strength, UTS. In addition, the failure modes of the laminates were also observed. Microstructural analyses were carried out using Scanning Electron Microscope (SEM). In general, the results show that the hybridization effect has improved proportionately the Modulus of Elasticity of the hybrid composite laminates compared to GFRP constituents. However, it is also interesting to observe that the hybridization effect does not necessarily improves the hybrid laminate Tensile Strength, UTS due to

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delamination and incompatibility at the interface between CFRP the GFRP bond.

Keywords: *hybrid composite, CFRP, GFRP, hardness, tensile test, microstructure*

Hybrid Composite

Hybrid composite is essentially the combination of different composite reinforcement of a common matrix by two or more types of fiber of lamina. They have better flexibility in comparison to other fiber reinforced composites. More often than not, it is a combination of high and low modulus fiber. The high modulus fiber provides the stiffness and load bearing qualities, whereas the low modulus fiber makes the composite more durable and low in cost. These class of composites is desirable as it could be tailor-made to suit different applications that require the combination of the aforesaid properties [1]. This paper attempts at investigating the mechanical and microstructural properties of CFRP/GFRP hybrid composite of seven unique arrangements.

Microhardness Testing Method: Vickers Microhardness

Hardness tester used in this research was the Vickers Micro Hardness tester located at the Materials Testing Lab, Faculty of Mechanical and Manufacturing, Universiti Tun Hussein Onn (UTHM), Johor with an indenter of pyramid shape at an angle of 136° as shown in Figure 1 and Figure 2. The specimens are cut into a 3 cm X 3 cm dimension and tested on the aforementioned hardness tester as illustrated in Figure 3. Seven (7) types of samples based on different composite have been prepared by using prepreg cured at 120º C and 0.6 MPa. The arrangement of hybrid composites is shown in Table 1. The test load used for the CFRP, GFRP and the different configurations of the Hybrid Composite was 2.942 N (HV 0.3). The Vickers hardness is a measure of the hardness of a material that could be computed from the size of the impression produced under load by a pyramid-shaped diamond indenter [2]. The pyramid shape indenter was exerted on the surface at three (3) selected points of all the specimens as depicted in Figure 4. Hardness value was identified after an impression of the pyramid shape was formed on the surface of the specimen using HMV AD software. The test was carried out in accordance with the ASTM E-384, and the measured values were converted to the hardness value [3].

Figure 1: Microhardness testing machine at UTHM

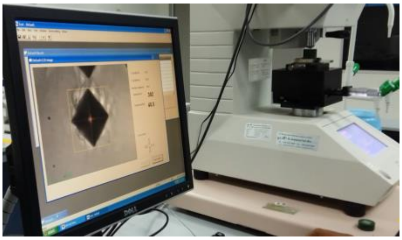


Figure 2: Microhardness testing which linked with inbuilt software

Figure 3: Sample undergoing microhardness testing

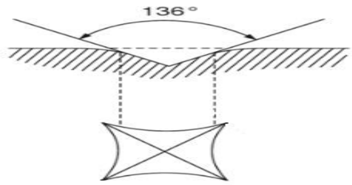


Figure 4: Pyramid shape indenter

Hardness Result for Hybrid Composite

Carbon Fiber Reinforced Polymer (CFRP)

The hardness test was conducted on two specimens, i.e., specimen one and specimen two. For each specimen, 3 measurement points were recorded two times for each point, and the values are averaged as suggested in [2].The results shows the value of all Vickers hardness (HV) is at range between 88.45 to 100.28.

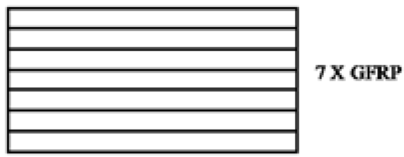
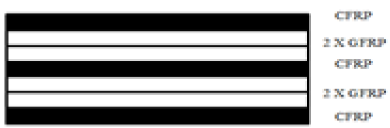
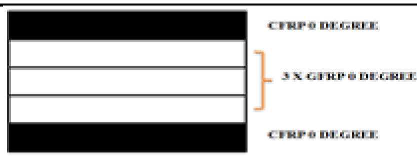
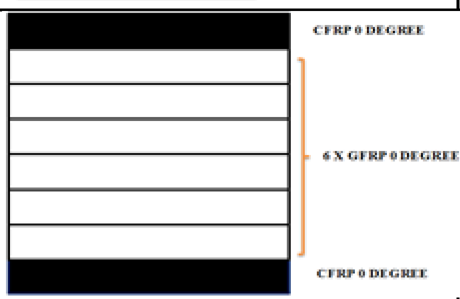
Glass Fiber Reinforced Polymer (GFRP)

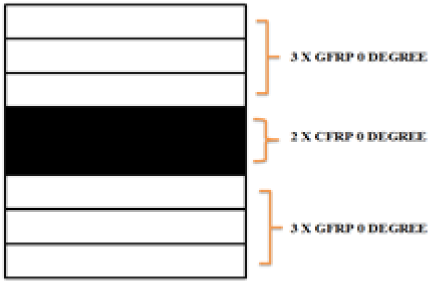
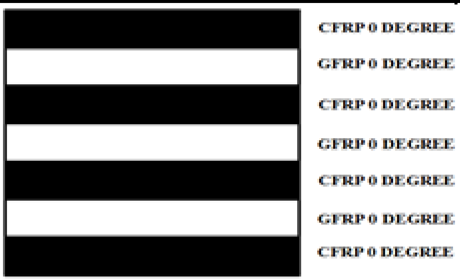
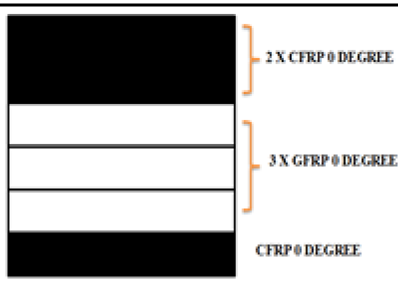
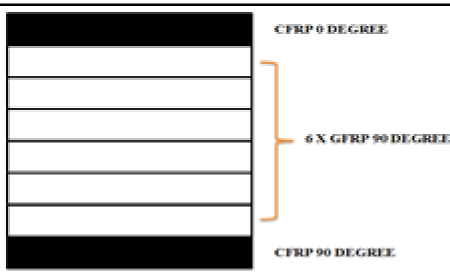
A similar approach as such as the CFRP for quantifying the hardness value of the GFRP was utilised. The number of layers used is shown in Table 1. It could be observed that the HV ranges between 62.49 to 74.67.

Hybrid Composite Hardness

The same identical method was also employed to attain the HV values of the hybrid composites, and the values are shown in Figure 6. The results indicate that the value Vickers hardness (HV) for Hybrid A ranges from 67.67 to 76.28. Hybrid B produces a HV value ranging from 71.03 to 75.67. The results for Hybrid C is between the range from 74.76 to 80.27. Whilst the HV results for Hybrid D, Hybrid E, Hybrid F and Hybrid G ranges from 57.41 to 62.91, 68.9 to 79.12, 70.32 to 76.92, and 71.42 to 76.29, respectively.

Table 1: Arrangement of composite material for Vickers micro-hardness test.

Composite	Arrangement of composite layup	Total Layer	Thickness (mm)
CFRP	 *Unidirectional 0 Degree*	3	1.2
GFRP	 *Unidirectional 0 Degree*	7	1.1375
Hybrid A		7	2.3
Hybrid B		5	1.2875
Hybrid C		8	1.85

Hybrid D		8	1.72
Hybrid E		7	2.39
Hybrid F		6	2.07
Hybrid G		8	1.81

Comparison of all Sample Hardness Results

Based on the result, it is apparent that the hardness value of carbon fiber reinforced polymer (CFRP) is highest that is 100.28 HV. Conversely, the glass fiber reinforced polymer (GFRP) has a value of 74.67 HV. This is anticipated due to the fact that the modulus of elasticity of CFRP (120-130GPa) is much higher than GFRP (45-65GPa) which in turn relates the resistance of the material to deform due to indentation[4]. Moreover, from the investigation, it could be observed that the HV values of the hybrid composites lie between the range of CFRP and GFRP as demonstrated in Figure 5 and Figure 6, respectively. It is worth noting that these observations are in agreement with the findings of [5], in which it was reported that the HV of CFRP is higher than both the hybrid composite (CFRP/GFRP) and pure GFRP composite, respectively. The Hardness Stress ranging from 0.25-0.35 GPa for 3~4 GPa modulus of elasticity of epoxy resin was reported [6] suggesting the rationale behind the lower values of HV at certain points. It could also be seen that the HV values between all the hybrid composite (C,E,F,G,A,B) are quite close to each other except for Hybrid D. A possible explanation for such behaviour is the layup arrangement for Hybrid D, in which the GFRP is the external layer where the indentation is applied. Conversion between Vickers Hardness into SI unit MPa and GPa could be made in order to represent the hardness in the form of stress value. Vickers hardness (HV) conversion to hardness stress in MPa unit is attained by multiplying it by 9.807. A constant strain value is used (d/D = 0.375). Stress unit used for the present study is in GPa [5]

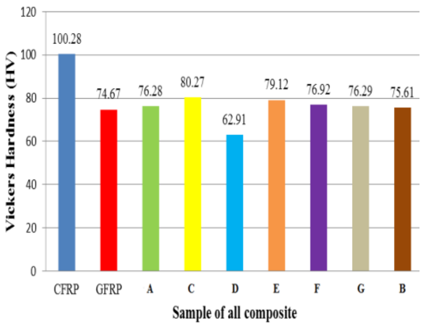


Figure 5: Vickers Hardness Value for all composite

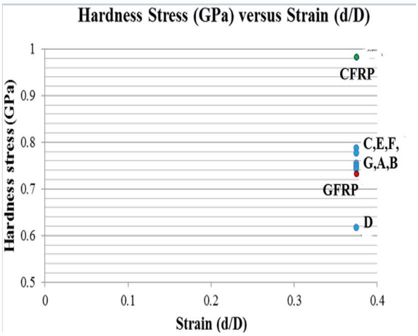


Figure 6: Plot of Hardness Stress(GPa) against Strain(d/D)

Tensile Behavior of Hybrid Composite

A number of literature have been reviewed to gain further understanding on the expected tensile behavior of the hybrid composite under static loading. A preliminary study on the performance and their comparison of hybrid and the non hybrid composite were reported in [7]. It was reported that the tensile properties of hybrid composite fall in between non-hybrid (baseline) composite properties. Among the hybrid composites tested, the filament wound composites demonstrated marginally better tensile strength and stiffness as compared to hybrid fabrics as shown in Figure 7. The authors opined that optimizing fibre architecture and its parameters are important for developing new hybrid fabrics for composite product developments[7].

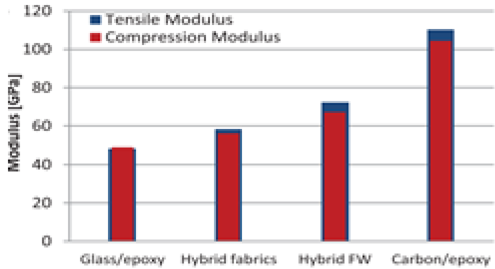


Figure 7: Bar graph demonstrating the comparisons of hybrid and non-hybrid stiffness[7]

In another work by [8], three types of hybrid arrangement of carbon and E-glass fiber were tested namely, $[CWW]_6$, $[BC]_6$, and $[CBBC]_3$, where C, W, and B denotes carbon fiber, E glass plain woven and E glass stitch biaxial (±45˚), respectively. Findings from the tensile test performed on those laminates show that the $[CWW]_6$ arrangement, which C and W formed by weaved carbon fiber and glass fiber provided the best mechanical properties. It was shown that the Carbon and woven glass fibers in $[CWW]_6$ arrangement was able to withstand loading in the direction of 0˚ fabrics. The summary of the tensile properties of the composites evaluated is shown in Figure 8.

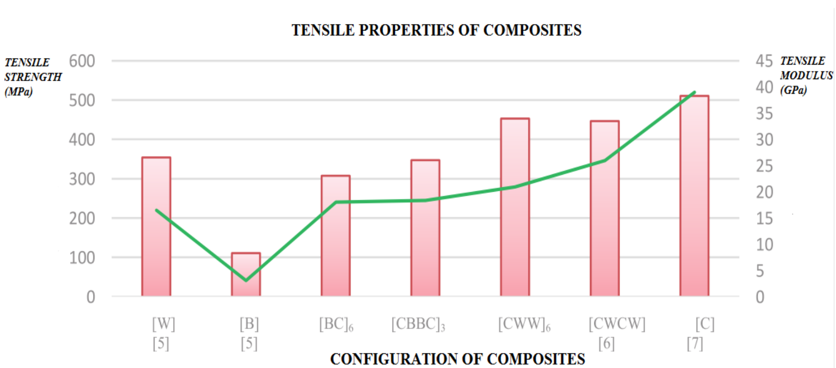


Figure 8: Tensile properties obtained from different arrangement of hybrid composite[8].

In another research on studying the effect of hybridisation of S-2 glass into T700S carbon fibers, it is found that tensile modulus decreases with the incremental hybrid ratio. Meanwhile, under tensile mode, the stress distribution is quantified by the difference in the tensile modulus of carbon/epoxy lamina and glass/epoxy lamina. If the offset is minimal, the tensile modulus versus the hybrid ratio shows a linear relationship; hence hybrid effects are insignificant. Meanwhile, if the difference is high, a nonlinear relationship is obtained, and significant hybrid effects transpire [9]. It was also reported that there is an improvement in failure strain of up to 20% for very thin plies UD hybrid composite (S-glass/epoxy and thin carbon/epoxy) whilst no significant improvement was observed for thicker laminates. It is then suggested that hybrid specimens with thick carbon plies could be used as a baseline for determining carbon/epoxy failure strain. The justification is that the strain recorded for hybrid composite is higher than the strain from full carbon specimens and is subjected to stress concentrations in the region of load introduction[10].

Tensile Test of Hybrid Composite CFRP/GFRP

To study the effect of hybrid composite on tensile behaviour of CFRP/GFRP composite, several arrangements of hybrid composite based CFRP/GFRP have been prepared and cut into ASTM D3039 dimension for the tensile testing purpose. The aim is to assess and evaluate the effect of hybridisation on the homogenized behaviour of hybrid composite. For the study of hybrid composite mechanical properties under tensile loading, there are three different layers, and orientation of composite for Hybrid A, Hybrid B, and Hybrid C were tested. From the tensile test, the average values of Tensile Modulus (E) for Hybrid A, Hybrid B, and Hybrid C are 101.052 GPa, 82.746 GPa, and 89.799 GPa, respectively. It is evident that the value of Tensile Modulus (E) for Hybrid A depicted highest, and Hybrid B recorded lowest. By referring to the layup/configuration of Hybrid A, it has the highest number of carbon fiber layers of three as compared to Hybrid B and Hybrid C which only possess two layers of carbon fiber. This shows that the quantity of carbon fiber contents in hybrid composite certainly affects the value of hybrid modulus of elasticity (E_{11}). Figure 9 shows the comparison of Tensile Modulus (E) between the single composite and the hybrid composites. It is shown that the value of Tensile Modulus (E) for the CFRP 0 degree depicted highest between the composites. Besides, the value of Tensile Modulus (E) for the hybrid composites located between the CFRP 0 degree and GFRP 0 degree. It demonstrates that the presence of the carbon fiber does to a certain extent influence the value of Young Modulus (E). For the 90 degrees orientation of fiber (CFRP 90 and GFRP 90), the value of Young Modulus (E) is almost similar. This is primarily due to matrix dominated region which accounts for similar behavior which CFRP recorded slightly higher.

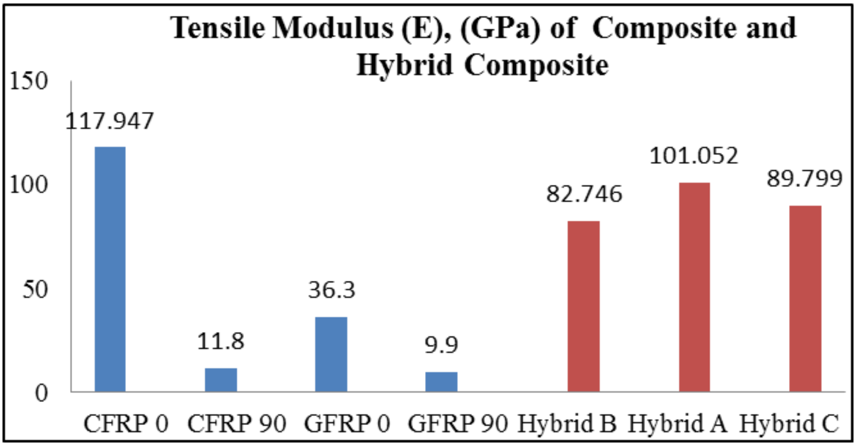


Figure 9: Comparison of the value of Young Modulus (E) between Single Composite and Hybrid Composite

Figure 10 shows the effect of reinforcement on Ultimate Tensile Strength (UTS) of the fiber reinforced composites. The UTS value of CFRP 0 degree is the highest in comparison to the other type of composites. The value of UTS for Hybrid B and Hybrid C is in between the CFRP and GFRP, and this is very much anticipated. Meanwhile, Hybrid A recorded a peculiar value of 733.8MPa which shows that it is lower than GFRP 0 degree. This is possibly due to the delamination behavior at the interface of CFRP/GFRP that occurs on the specimen during testing as shown by Hybrid B in Figure 11. These preliminary findings show that although modulus of elasticity is shown to bring positive hybridization effect, nonetheless, a similar conclusion could not be drawn for tensile strength. Amongst the factors that influence the failure mode of the composite are delamination, debonding and matrix cracking that are investigated in the subsequent section on the microstructural study of hybrid composite. It is apparent that the hybrid composite has a more favorable balance between the inherent advantages and disadvantages of the single composite, where it is positioned between modulus of elasticity of CFRP and GFRP. This observation is in agreement with the findings and conclusion of other researchers[7], [11]–[13].

Figure 12 depicts delamination phenomena experienced by Hybrid C during tensile loading, where the number of GFRP formed the hybrid is quite substantial amongst the three hybrids. Meanwhile, Figure 13 shows fiber bridging and fretting combined with matrix cracking of the GFRP that induced the start of the failure.

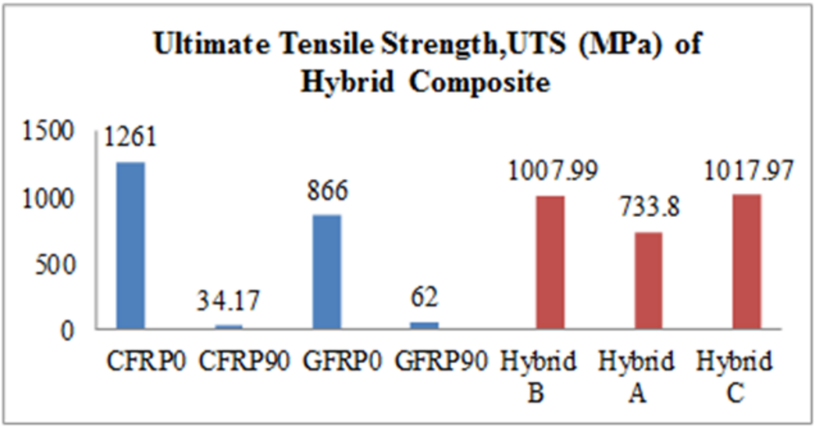


Figure 10: Comparison of the value of Ultimate Tensile Strength (UTS) between Single Composite and Hybrid Composite

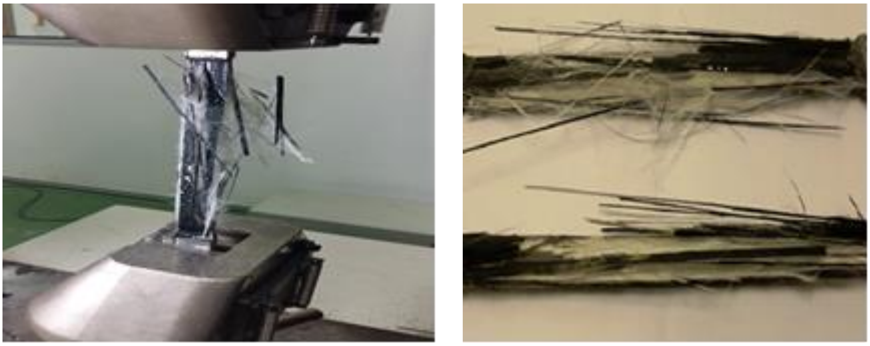


Figure 11: Failure mode of delamination experienced by Hybrid B

Microstructural Assessment of Hybrid Composite

A study on carbon fiber conducted by Srinivasa et al. (2010) suggests that a 1500x magnification (3μm) for the horizontal cross section while 500x magnification (10μm) for longitudinal distribution allows for a decent analysis of the microstructural condition[14]. For the purpose of volume fraction calculation at the cross-sectional position, the parameters used are 20kV voltages and 1500x magnification to attain a very small size of images as small as 3μm. For the analysis, the failure at cross-sectional for CFRP, the parameters used are 10kV voltages, with 2000x magnification to get 10μm image size. For the longitudinal view of composite (side view of through-thickness laminate) the same voltages will be used, 10kv but with 500x magnification[15]. Meanwhile, for the purpose of analysing the failure at the cross-sectional of GFRP, the parameters used are 5kV voltages and 1000x magnification to get a size of 50µm images. For analysis of hybrid composite, the voltages are ranging from 5kV to 20kV, the magnification and size will be used based on suitability. The microstructure view of hybrid is vital to identify the condition of the interface between two composites.

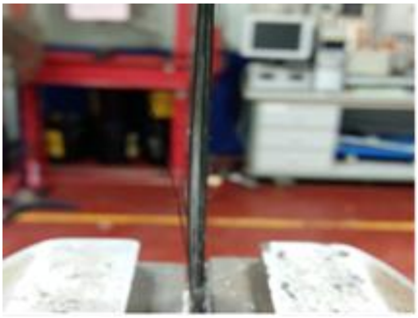


Figure 12: Hybrid C shows the delamination between CFRP and GFRP interface, while partial external layer of CFRP ruptured.

Figure 13: Hybrid A shows sign of fiber bridging (failure strain) combine with the start of delamination.

As mentioned previously, failure could happen based on different modes such as cracking between fiber and matrix when subjected to load (e.g., tensile, compression, shear). The study of microstructure on the hybrid composite material is essential in understanding the causes of failures and failure modes. It was observed that during service life, composite structures would experience high stresses resulting in crack propagation through fiber-matrix interfaces[16], [17]. The area where CFRP and GFRP composite placed together in the hybrid composite is the interface region. It was also reported that that weak point in hybrid composite materials is on the interface area[11] [18].Figure 14 shows the cross-sectional view of CFRP unidirectional prepreg after curing, as observed using Scanning Electron Microscope (SEM) at 500 times magnification at 50µm. The diameter of CFRP as observed is around 6.7µm to 7.5 µm observed at 5000 times magnification. Figure 15 depicts a longitudinal view of CFRP Unidirectional using SEM at 500 times magnification performed at the Material science Laboratory located at the Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka.

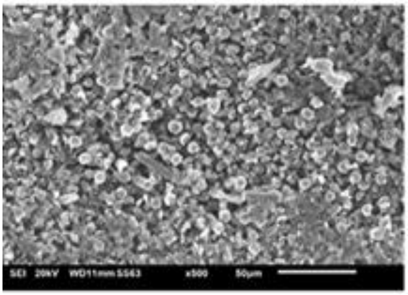


Figure 14: CFRP unidirectional microscopic cross-sectional view.

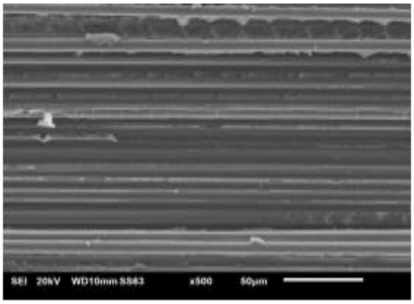


Figure 15: Microstructural longitudinal view of CFRP

Interlayer delamination and interlayer cracking are two most common failure modes. Fiber pullout is also one of the failure modes occurs for CFRP and GFRP. Figure 16 and Figure 17 (a magnified version of Figure 16 at interlayer section) indicated that failure mode of (Left) region is the delamination phenomena between CFRP and GFRP while (Right) hand side depicted matrix cracking. Different failure to strain during failure stage has induced the delamination at the interlayer zone for hybrid composite CFRP/GFRP.

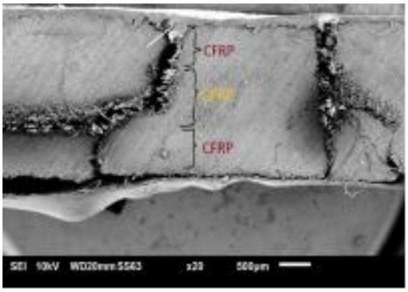


Figure 16: Cross-section view after rupture of sample Hybrid B

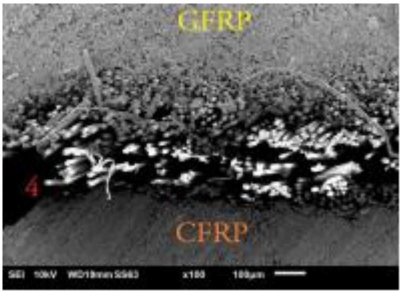


Figure 17: Interlayer delamination at Hybrid B.

The view of carbon fiber and glass fiber are obtained with the aim to measure the diameter, hence enable the computation of the predicted volume fraction. Figure 18 presents the measurement across through thickness of hybrid composite which encompasses different layers of the composite at the interface. The visualization is quite clear, and it is evident that the SEM is able to offer an interlayer view of hybrid composite. Figure 19 depicts the measurement of the interlayer distance and the fiber diameter of glass fiber and carbon fiber in a hybrid composite in the neighbouring region.

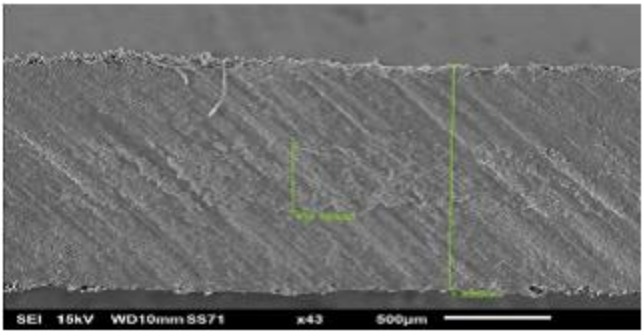


Figure 18: The macrostructure view of Sample Hybrid B

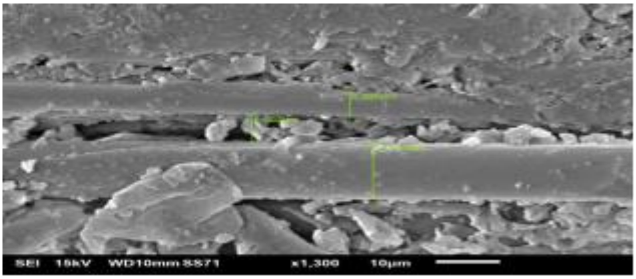


Figure 19: The measurement of the interlayer distance and the fiber diameter of glass fiber and carbon fiber in a hybrid composite

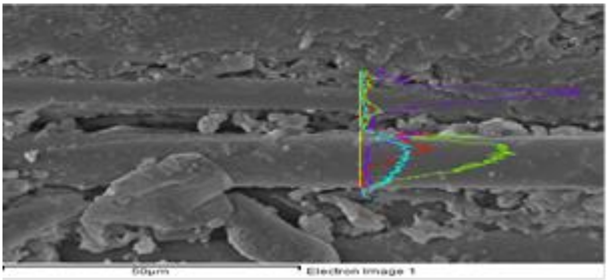


Figure 20: Sample hybrid composite EDS line scan.

The Energy Dispersive X-ray Spectrometry (EDS) line scan indicates that the upper fiber is CFRP, whilst the middle is an interlayer matrix and the lower fiber is GFRP. Based on Figure 20, the higher purple spectrum lies on the upper fiber is carbon element and explicitly coming from CFRP. The green spectrum was highest at the lower fiber, which accounts for silica element and fundamentally linked with GFRP. Meanwhile, the middle was believed to be interlayer matrix because of the existence of the purple and green spectrum at the location.

Conclusion

The hardness test on CFRP, GFRP and hybrid composite (CFRP/GFRP) attained by performing the Vickers Microhardness Test have been discussed. The value of CFRP hardness depicts the highest and hybrid composite computed values of between CFRP and GFRP which is in agreement with findings obtained in the literature. The influence of modulus of elasticity on indentation behaviour was demonstrated by the CFRP, which indicates that the highest hardness yields the highest modulus of elasticity. Small difference recorded for Vickers Hardness amongst all hybrid composite tested except for Hybrid D. The tensile properties of different compositions of the hybrid composite were also investigated. Moreover, different failure mode and behavior experienced by hybrid composite under tensile test was also scrutinized through the evaluation of the microstructural properties of the tested materials.

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