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Characterization of Carbon Fibre Reinforced Polyphenylene Sulfide Composite Under Interlaminar Shear Strength

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ABSTRACT

Aerospace industry is seeking thermoplastic composites materials due to several advantages over thermoset material and one of them is mechanical properties. Mechanical properties of thermoplastic composite materials are found to be superior compared to thermoset materials. High strength fibre composites parts are made of several plies with different fibre orientation with a designed balanced of lay-up sequence. Interlaminar Shear Strength (ILSS) is an essential consideration when designing laminated structures exposed to transverse stresses. It is to predict quality and strength of laminate levels of composite due to, composite failure cannot be observed directly to the propagation of single macroscopic crack when subjected to cyclic loading. This test is employed to evaluate both the interfacial adhesion of the matrix and the influence of the reinforcement on the mechanical characteristics of the composite. This study provides the understanding of ILSS test of 2 different thickness for 6 and 8 plies Carbon Fibre Reinforced Polyphenylene Sulfide (CF/PPS) according to the testing standard EN 2563. The results show that 8 plies have higher ILSS properties compared to 6 plies. The fractography of the CF/PPS composite under Scanning Electron Microscope (SEM) shows good agreement with the experimental values which was recorded 8 plies can withstand to shear strength of 79 MPa with maximum load applied was 2.738kN while, 6 plies recorded 75 MPa on shear strength with load of 1.971kN. More damage/cracks on 6 plies specimen compared to 8 plies.

1. Introduction

Global production for aircraft is increasing dramatically because composite production combines product versatility and quick processing to maximise manufacturing productivity improvements with the ability to simplify the design while lowering operating costs by decreasing its weight [1]. Previous researchers, agreed that composites contributed 50 percent of the entire of the compositional body weight for both the Airbus A350 XWB and the Boeing 787 [2].

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When heated, thermoplastic polymers become soft or molten and pliable and thus revert back to a solid cooling state without altering their intrinsic structures; this process allows thermoplastic composites to be recycled [3]. Whereas, according to Li and Englund [4], to recycle thermoplastics is very straightforward process unlike thermosets which create a large crosslinked network. Therefore, create many problems in recycling process of certain products [5].

Thermoplastics composites can be used at higher operating temperatures for good thermal stability, and the market is seeing the introduction of new thermoplastic matrices, so it has been used in advanced airframes such as the horizontal tail plane of the AW 169, the weapon bay doors of the F-22, the rudder of the Boeing Phantom Eye, and also the rudder and elevators of the G650 [6]. From the previous reference, some aircraft experienced critical gust load on wing structural, which can actually happen due to the turbulent situation, and this can be upgraded by implementing composite in modern aircraft structures due to their lightweight characteristics [7].

Carbon fibre reinforced polymeric composites are used in the aerospace industry to make a variety of components such as aileron, flaps, and so on [8]. This is due to the exceptional mechanical strength and toughness capabilities, as well as great chemical resistance and outstanding electrical properties, making it appealing to the aerospace sectors [9].

Over the last 40 years, thermosetting resin-based composite materials have seen widespread application. However, they have clear limitations, such as the necessity for low-temperature storage, a difficult-to-control reticulation process, a very long curing process, and handmade draping, which produces the majority of the manufacturing process's irreversible problems [10]. Therefore, according to Hamdan *et al.,* [11] the process to fabricate aerostructure part can be performed by using integrated hot pressed machine in which, it is one of the process Out Of Autoclave (OOA) method.

According to Vieille and Taleb [10], high degree of chemical resistance, excellent damage and impact resistance, and ability to be used over a wide temperature range, high-performance thermoplastic resins such as Polyether ether ketone (PEEK) and Polyphenylene sulfide (PPS) offer a promising alternative to thermoset resins. Unlike thermoset resins, thermoplastic resins may be melted down once they are produced, allowing for recycling. It also has several types of fabrication, with one of the processes used to fabricate thermoplastic components from a flat laminate is thermoforming [9].

Polymeric composites are prone to mechanical degradation when exposed to compression, tension, and flexural loads, which can result in interlayer delamination. In any situation, increasing the external load promotes delamination propagation across the interlayer, resulting in catastrophic component failure [8]. The Interlaminar Shear Strength (ILSS) is a vital destructive test carried on the test laminates as per the testing standards, so that, the data based on the test results are qualified for final part of assembly [12]. Hence there is a need to find an accurate ILSS value of the actual part to predict its quality and strength. As a result, ILSS is an essential material attribute to consider when designing laminated structures exposed to transverse stresses [13].

Short-beam shear testing is a popular method for determining the interlaminar failure resistance of fibre-reinforced composites. This test method involves loading a beam with dimensions under three-point bending (a short-beam) [14]. Unlike metals, the failure can be occurring after propagation of a single macroscopic crack but, this is not applied to the composite due to the accumulation of multiple modes such as debonding of matrix and fibres, fracture of fibre, cracking of transverse-ply, delamination as well as crazing and cracking of the matrix when subjected to cyclic loadings [15].

This test is employed to evaluate both the interfacial adhesion of the matrix and the influence of the binder on the mechanical characteristics of the composite, such as fracture toughness and interlaminar shear strength [8]. The "apparent" interlaminar shear strength of composite materials is measured using this approach. Thus, the interlaminar shear strength offers information regarding the quality of adhesion at the fibre/matrix interface [14].

2. Materials and Methods

The composite materials studied in this work is carbon fibre reinforced PPS. It is woven-ply consists of 5-harness satin weave carbon fibre fabrics with 2 different thicknesses of CF/PPS 6 plies and 8 plies of 1.90 mm and 2.52 mm respectively. For the orientation, 6 plies were [(0,90)/ (±45)/ (0,90)] s while 8 plies were [[(0,90)/ (±45)]2] s. The composites were cut by using waterjet cutting machine into the respective dimensions according to the standard required. The surface and lateral view of the CF/PPS composite are shown as in Figure 1 and Figure 2 [16].

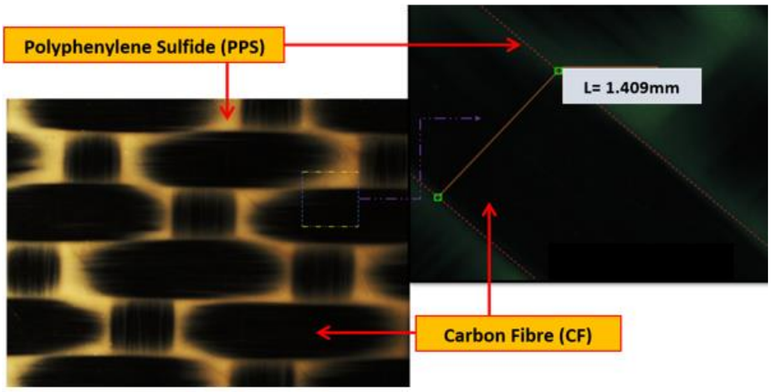
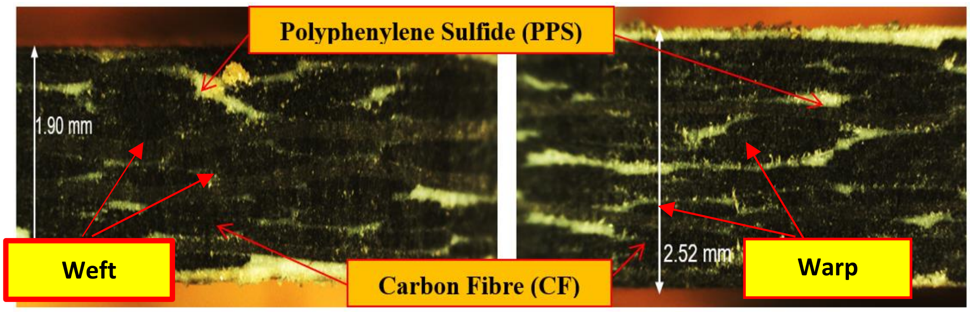


Fig. 1. Surface view of CF/PPS [16]

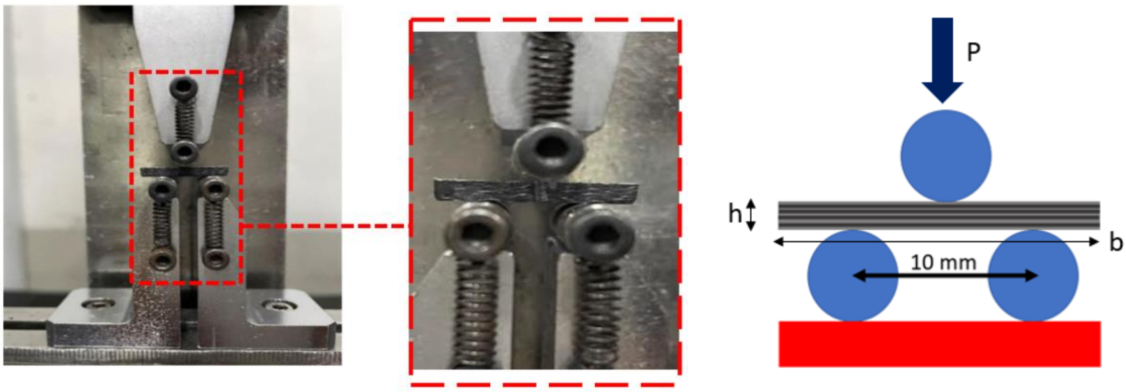


(a) (b)

Fig. 2. Lateral view of CF/PPS for (a) 6 plies and (b) 8 plies [16]

2.1 Shear Test

This method provides information about the quality of the adhesion at the fibre/matrix interface. The ILSS test was determined by using a Universal Testing Machine 5 (UTM5)/Instron 5967 according to the EN 2563 standard with the dimension of 20 mm x 10 mm with 10 mm span length and 1 mm/min speed. The loading nose radius and support radius is 3 mm as in Figure 3.



(a) (b)

Fig. 3. (a) Experimental setup of ILSS test (b) Geometry of specimens ILSS

The interlaminar shear strength were carried out at least 5 specimens/test coupons for both plies. To determine ILSS value, the formula is given as in Eq. (1) which provides the information on mechanical behavior of resin or fibre resin liaison.

$$ILSS = \frac{3P}{4bh} \quad (1)$$

where,
ILSS = Interlaminar shear strength
P = maximum load recorded
b = width specimen
h = thickness of specimen

2.2 Morphological Analysis

For morphological observation, SEM machine type JEOL6010PLUS with elemental analysis EDS is used as shown Figure 4. The specimens were coated by using platinum at 3nm thickness.

Fig. 4. SEM machine JEOL6010PLUS

3. Results and Discussions

ILSS is an important destructive test carried on composite to test the laminates level to predict its quality and strength. It is very essential attribute to consider when designing the laminated structures. In this research, the 2 different thickness of 6 and 8 plies CF/PPS were test to observe the ILSS properties. Table 1 shows the data for ILSS.

Table 1
ILSS data for 6 plies and 8 plies CF/PPS [16]

Sample	Width (mm)	Thickness (mm)	Maximum Load (N)	Interlaminar Shear Strength (MPa)
6 Plies	10.22	1.90	1970.79	75
8 Plies	10.23	2.52	2738.00	79

Figure 5 shows the results of the ILSS test. According to Azam *et al.,* [17], ILSS is used to evaluate the influence of fibre matrix bonding on the interlaminar shear strength (ILSS) at a laminate level. In this research, it can be seen that the 8 plies of CF/PPS show relatively high ILSS properties which was recorded 79 MPa compared to 6 plies which was 75 MPa. Similarly, according to Hamdan *et al.,* [16], it was found that, the interlaminar shear strength increased as the material is tended to be more elastic in the thick material. For all specimens it is observed a typical failure mode by shear, with the interlaminar cracking in the middle part of the transverse region of the specimen and this shows good agreement with Paiva *et al.,* [8] that the test should be revealed the shearing part that occurred at the centre of the specimen.

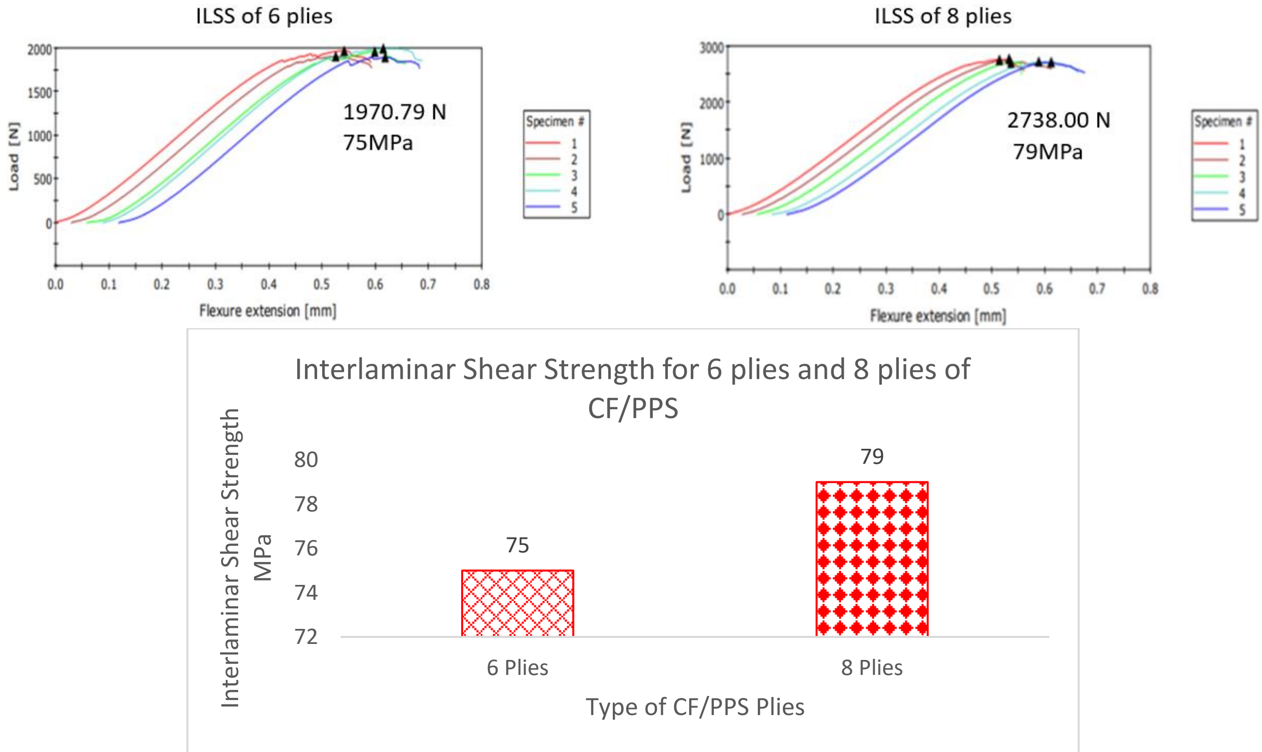


Fig. 5. Comparison between ILSS for 6 plies and 8 plies CF/PPS [16]

In this research on microscopic observation, both specimens recorded intralaminar, interlaminar, and delamination as shows in Figure 6 to Figure 9. There was significant difference in both specimens in terms of number of cracks that can be seen on 6 plies which recorded more deformation on the intralaminar shear cracks, an interlaminar and a small delamination as in Figure 6. While, 8 plies recorded one observation on the interlaminar shear cracks, intralaminar and a long delamination as in Figure 8. Also, it can be observed that the cracks were happened on the warp fibre region and not on the weft fibre region of both specimens as in Figure 7 and Figure 9. Therefore, the results of interlaminar shear test confirms that the adhesion between plies and fibre/matrix bonding of 6 plies were lower compared to 8 plies as recorded in Table 1.

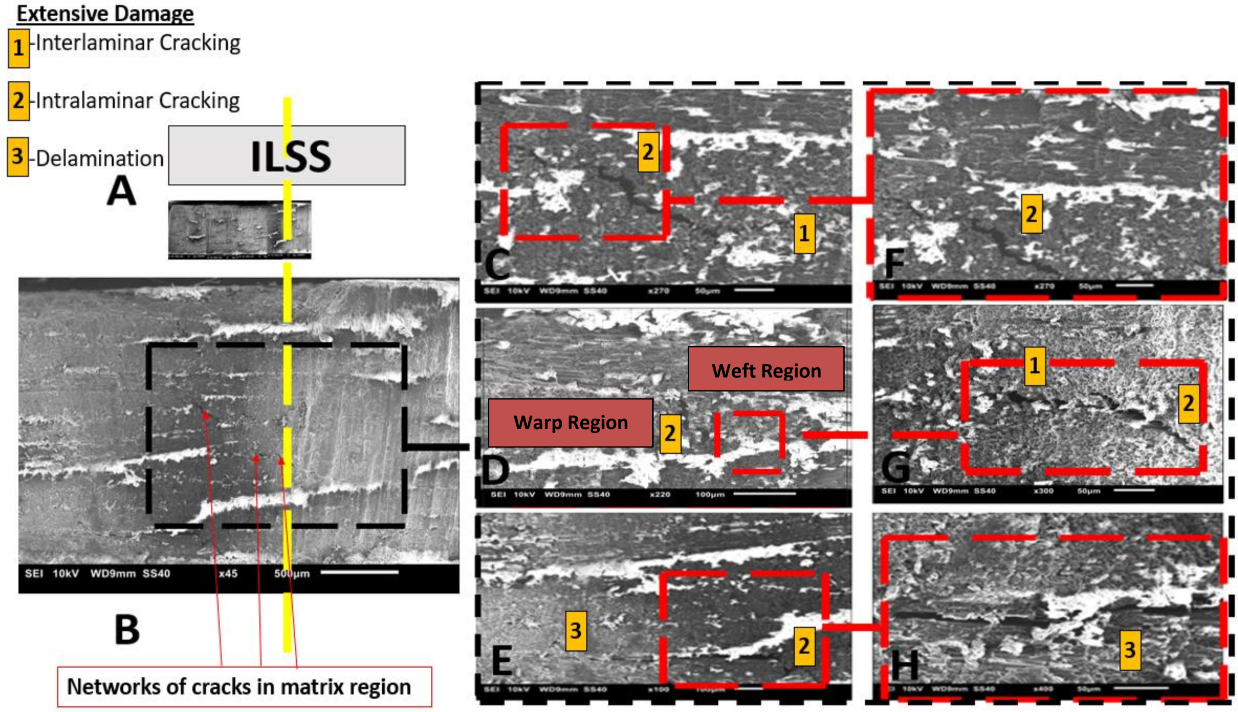


Fig. 6. 6 Plies CF/PPS under SEM for ILSS test magnification (A) x40, (B) x45, (C) x270, (D) x220, (E) x100, (F) x270, (G) x300, and (H) x400

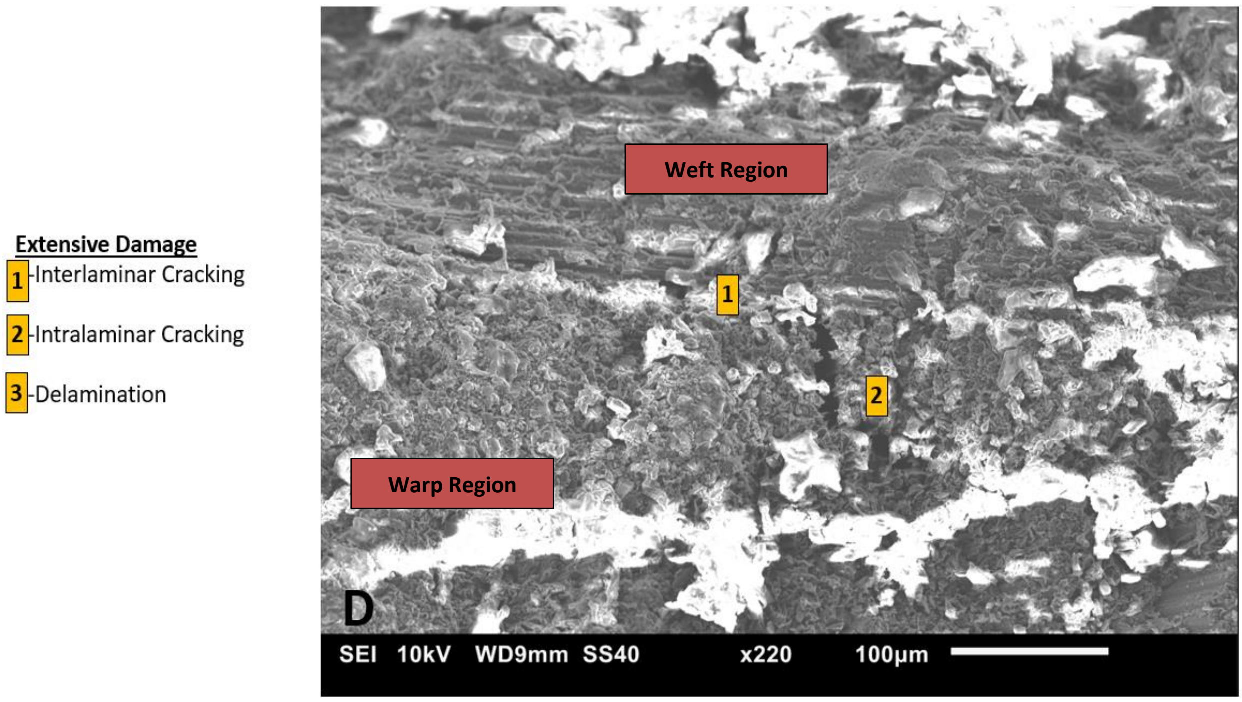


Fig. 7. 6 Plies CF/PPS under SEM for ILSS test magnification (D) x 220

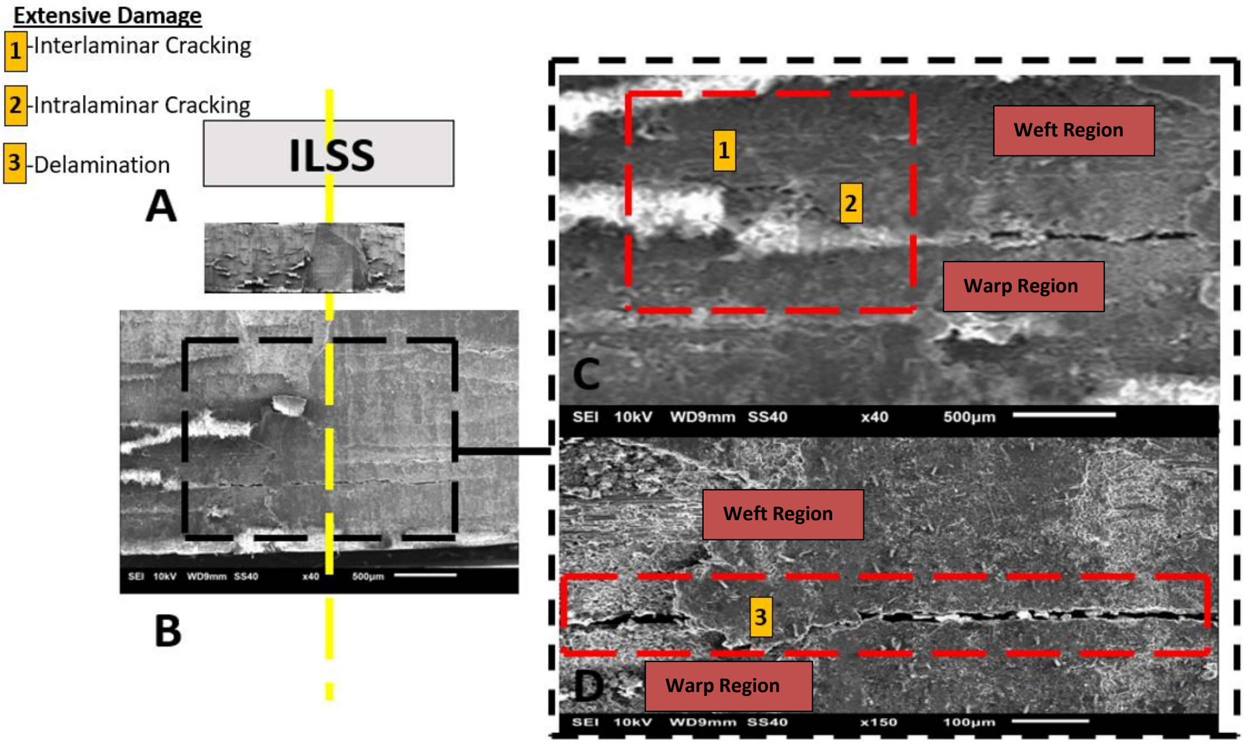


Fig. 8. 8 Plies CF/PPS under SEM for ILSS test magnification (A) x30, (B) x40, and (C) x40 and (D) x150

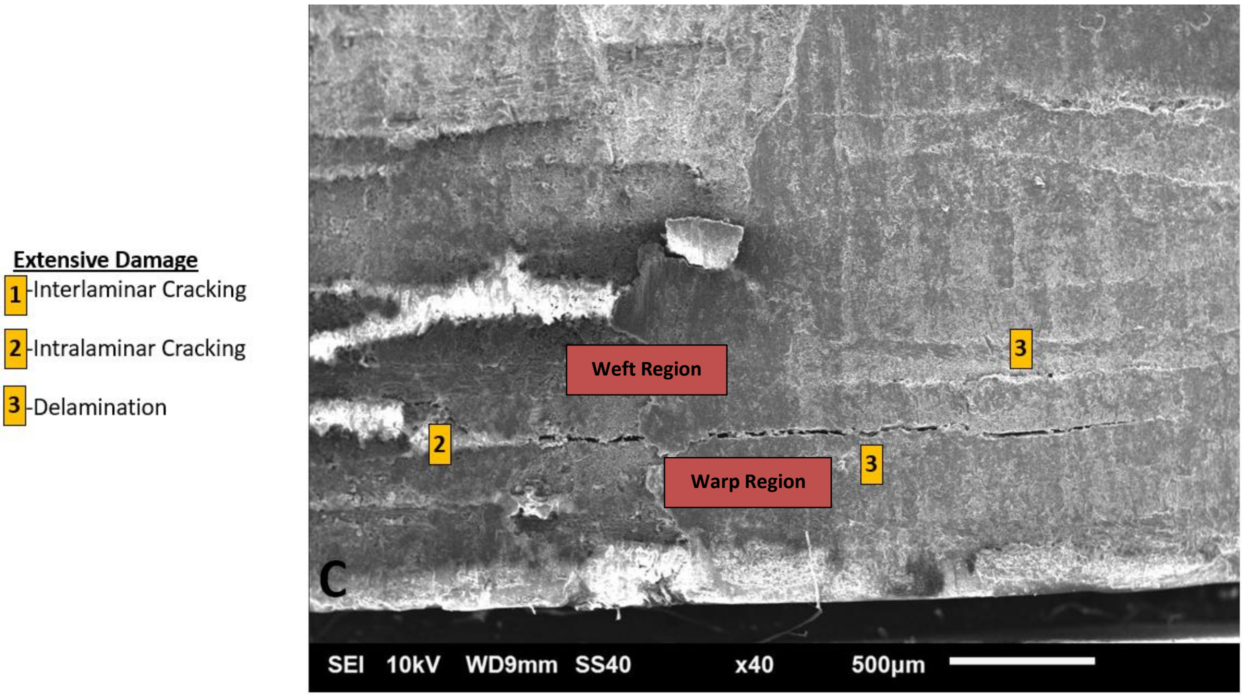


Fig. 9. 8 Plies CF/PPS under SEM for ILSS test magnification (C) x 40

Throughout the ILSS experiment with the validation from SEM analysis, it can be observed that 6 plies recorded lowest ILSS value as the number of failures recorded more compared to the 8 plies. In Figure 10, it can be concluded that the crack happened across the warp fibre. It starts to crack and then propagate. Thus, break the fibre from the warp and it continues to propagate again and the trend is, the failure didn't across the weft fibre. These weft regions might not prone to the damage initiations and cracks. It is due to, cracks and damage initiation appeared in transverse fibres bundles and then propagate across the matrix rich regions or at the interface between warp and weft (overlapping areas) in the case of on axis loadings.

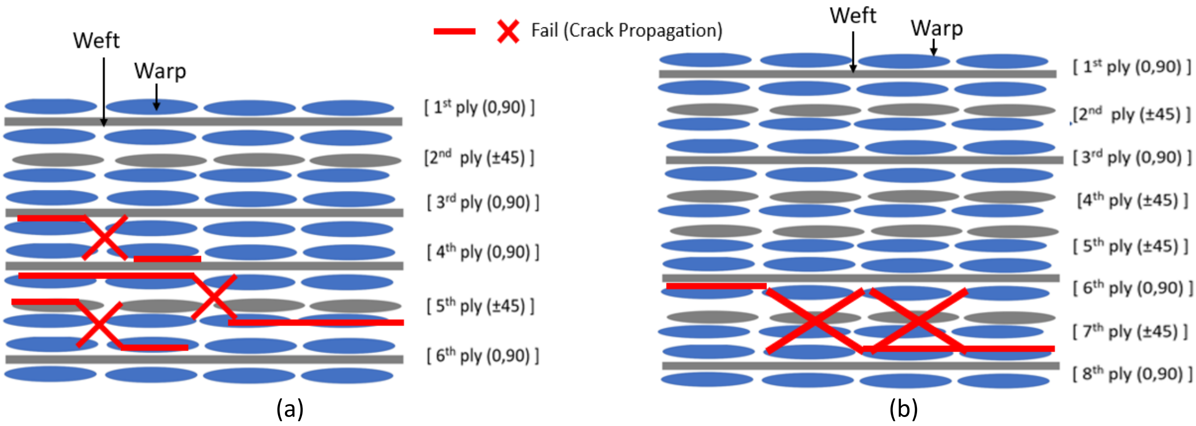


Fig. 10. Illustration of damage on (a) 6 ply and (b) 8 plies of CF/PPS under ILSS test

The observation shows the good agreement with Albouy *et al.,* [15]. Not only that, SEM results proved that according to Hamdan *et al.,* [16] of CF/PPS for both 6 plies and 8 plies after Impact Tests. It was observed that 6 plies shows greater on fibre pull out. In definitions, the bonding between the matrix of resin and fibre for 8 plies is higher compared to 6 plies. In terms of fibre crash, it is obviously shown that more crush was observed in 6 plies of CF/PPS compared to 8 plies. In addition, it proved that 8 plies absorbed more energy compared to 6 plies CF/PPS which recorded 3070.87 J/m and 2308.07 J/m respectively [16].

4. Conclusion

Interlaminar shear strength test is a commonly used method in characterizing the interlaminar failure resistance of fiber-reinforced composites. In this research, ILSS values of CF/PSS were determined for both 6 plies and 8 plies. ILSS properties for 8 plies of CF/PPS recorded higher value which was 79MPa whereas 6 plies recorded 75Mpa. The fractography of the CF/PPS composite under Scanning Electron Microscope (SEM) shows good agreement with the experimental values. It can be observed that 6 plies specimen had more cracks compared to 8 plies specimen. Thus, provides the information that 8 plies had strong quality of bonding between matrix and fibre compared to 6 plies.

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