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Research paper

Uniaxial Tensile Stress-Strain Response on the 3D Angle Interlock Woven Fabric Composite

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Abstract

An experimental study have been performed to investigate the uniaxial tensile stress-strain response on the 3D angle interlock (3DAI) woven fabric composite. The tensile analysis were examined based on different woven fabric set-up parameter of draw-in plan ; pointed (DRW 1), broken (DRW 2), broken mirror (DRW 3), and straight (DRW 4). Meanwhile, the woven fabric composite were produced based on 22 and 25 pick.cm^{-1} of weft densities. The outcomes produced shown that woven composite sample with 25 pick.cm^{-1} on DRW 4 projected the highest stress response, 113 MPa. Extensive review indicated that DRW 1 and 4 gave better tensile stress-strain response than the other counterpart.

Keywords: *Angle interlock woven fabric: woven fabric composite: stress-strain: weft density: draw-in plan*

1. Introduction

Textile fabric is one of the textile material which can be manufactured either by using weaving, knitting or non-woven techniques. Studies have shown woven fabric have a prominent strength-to-weight ratio factor which important for the composite application [1 - 5]. 3D woven can be categorized into several types of structures; layer-to-layer, multilayer, angle-interlock, and orthogonal. Among these structures, the 3D angle interlock (3DAI) woven fabric has enticed attention from numerous researchers to explore the potential of mechanical behavior towards certain end-use application requirements. NASA and Airbus done experimental mechanical behavior studies on 3D angle interlock to explore suitable replacement of steel for aerospace applications [6 - 11].
Researchers have suggested that physical properties such as fabric weft density and type of weave structure plays a significant contribution towards the tensile strength outcomes [8, 10, 12, 13-15] of textile woven fabric. A variety of textile weave structure resulted to different yarn interlacement point. S. Dai *et. al* [8] and J.S Jones *et. al* [10] on the studies of the weave architectural factor towards the mechanical performance revealed that different type of weave structure produced variation sets of yarn interlacement. The dissimilarity of yarn interlacement positively will influence the yarn crimp presence and thus affect the tensile strength of woven fabric.
A comparative between conventional 2D and 3D woven fabric displayed that 3D woven fabric exhibited better tensile strength than certain conventional 2D. An investigation study [12] on 2D plain weave and 3D orthogonal woven fabric composite by using E-glass fibre. It was found that single ply 3D orthogonal exceed the tensile strength by 4 % than four layers of 2D plain weave. This outcomes portrayed that 2D plain weave consists of higher yarn interlacement that 3D orthogonal which resulted to low tensile strength. Hence, this paper intended to investigate the uniaxial tensile stress-strain response on the 3D angle interlock woven fabric composite based on different set of draw-in plan variables.

2. Experimental

The 3DAI woven fabric samples was manufactured by using a Sulzer Rapier Loom. A set of fabric weft density were set during the weaving sample production; 22 and 25 pick.cm^{-1}. The fabric weft density arrangement were control through a computerized system during weaving.
On the other hand, the fabric warp density were constantly fixed at 16 end.cm^{-1} throughout weaving production. The 3DAI woven fabric samples were constructed based on two different sets of polyester yarns. The warp (vertical) direction, 90^{o} were assembled based on spun polyester yarn while the weft (horizontal) direction, 0^{o} were made by plied multifilament polyester yarn. Figure 1 shows the rapier loom used to manufacture the woven fabric samples.

Fig 1: Sulzer Rapier loom located in Textile Weaving Workshop, UiTM Shah Alam.

Figure 2 displayed the draw-in structures used in the woven fabric production. The draw-in plan structures were marked as DRW 1 (pointed), DRW 2 (broken), DRW 3 (broken mirror), and DRW 4 (straight).

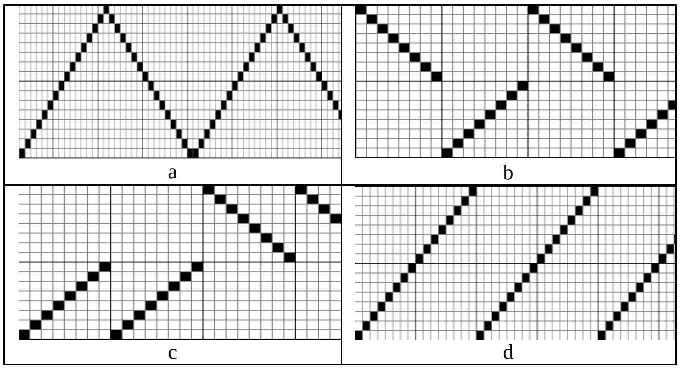


Fig. 2: Four different types of draw-in plan used on weaving production a) DRW 1 b) DRW 2 c) DRW 3 d) DRW 4.

Later, the 3D Angle Interlock woven fabric samples was fabricated into a polymer composite by using a hand lay-up technique. The woven fabric sample was placed into a custom mold plate, an epoxy BJC-39 resin mixed with hardener with the mixture ratio 3.7 : 1.7 (epoxy : hardener) was poured on the woven fabric samples. The mixture was dispersed evenly on the woven composite sample.

2.1. Tensile Stress-Strain Response Analysis

The mechanical uniaxial tensile strength properties of woven fabric composite were analysed according to the standard ASTM D3039. Three composite samples were tested to calculate the average breaking strength of woven fabric composite for each warp and weft directions. The woven composite tensile strength samples were cut and prepared by using bandsaw cutter with length of 200 mm, width of 25 mm, and thickness of 1 mm. Five samples were prepared for the tensile analysis to get the average results. The test was performed at 50 kN load cell and 100 m/min crosshead speed.

$$\sigma = F / A \qquad (1)$$

$$\varepsilon = \frac{\Delta L}{L} \qquad (2)$$

Equations 1 and 2 were used to determine the stress and strain of woven composite samples respectively. In equation 1, the stress value was determined by measuring the maximum force (N) at peak exerted and the cross sectional area of woven composite (mm). The stress value was measured in megapascal (MPa). Besides, in Equation 2, the strain rate of woven composite was derived based on the comparison between the extended length and the original length of sample (mm). The strain value was measured in percentage (%).

3. Results and Discussion

In this section, the outcomes of tensile stress-strain response on the 3D Angle Interlock woven composite based on two different weft densities parameters: 22 and 25 pick.cm^{-1} were discussed.

3.1 Stress – Strain Response on 22 pick.cm^{-1}

Figure 3 and 4 display the stress-strain curve behavior of 22 pick cm^{-1} woven composite in warp and weft direction. Figure 3 exhibits the stress-strain curve behavior in warp direction. In general, it can be seen that the curve was categorized into two significant phases. In first phase, all draw-in plan in the work showed close curve pattern within 0.25 % strain range. In the second phase, DRW 1 and 4 were emerged on top of DRW 2 and 3 in the range of 0.5 to 4% strain. In general, DRW 1 give the highest stress at 37 MPa and strain at 4%. Though, DRW 2 result lowest stress value at 35 MPa and strain value at 4%.

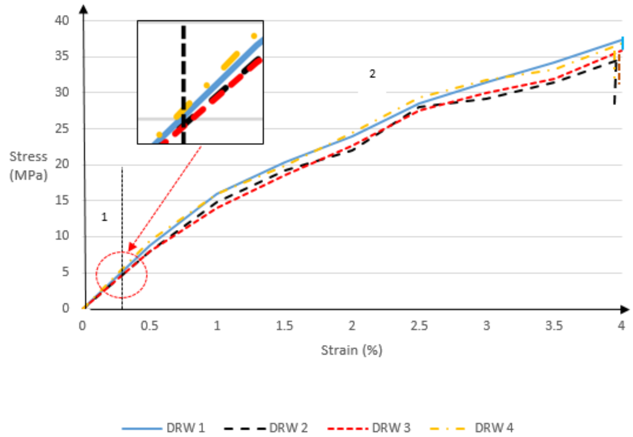


Fig 3: Stress-strain behavior of 22 pick.cm^{-1} woven composite in warp direction

Figure 4 exhibits the stress-strain curve behaviour in weft direction. The curve behaviour was characterized into three significant phases. In the first phase, it can be seen that all draw-in plan present close stress curve line within 0.6% strain range. In the second phase, DRW 1 recorded the lowest curve line in the range of 1 to 6.5% strain as compared to the other counterpart DRW 2, 3 and 4. However in the third phase, all draw-in plan showed high stress-strain curve line fluctuation in 6.5 to 7% strain ranges.
In general, DRW 1 give the highest stress value at 112 MPa and strain at 9% respectively. In contrast, DRW 2 give the lowest stress value at 103.2 MPa and strain at 7%.

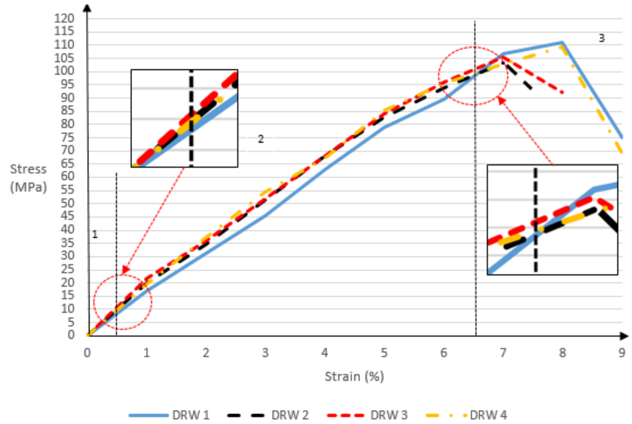


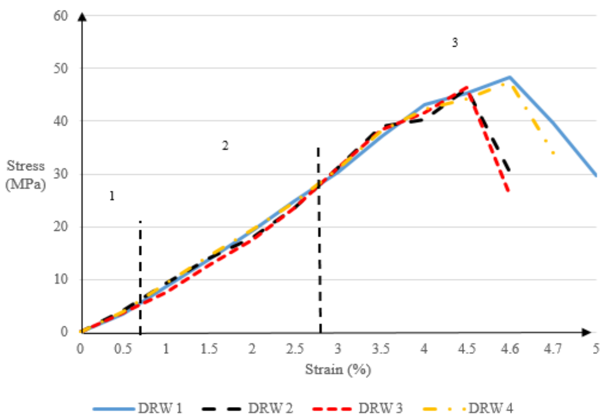
Fig 4: Stress-strain behavior of 22 pick.cm^{-1} woven composite in weft direction.

The stress-strain pattern behaviours of 22 pick.cm^{-1} woven composite was displayed on Figure 3 and 4. In Figure 3, a variation of stress-strain curve line along all draw-in plans within two different regions was presented. Within the first phase, the initial tensile load projected a close stress requirement along all draw-in plans. In the second region, there are two different stress-strain curve pattern behaviours. DRW 1 and 4 indicated an increment of stress resistance of warp loaded yarn during woven composite straightening compared to the other counterparts, DRW 2 and 3. However, all draw-in plans projected similar strain rate before break. This were happened as all warp loaded yarn along all draw-in plans contain similar range of stress performance.
Based on Figure 4, there were a fluctuation of stress-strain curve line between all draw-in plans within three different regions. In the first phase, a close stress-strain initial load projected were observed. This were expected during initial tensile load as low stress is needed to elongate the composite. However, in the second

and third regions, DRW 2, 3 and 4 presented greater stress resistance during weft loaded yarn straightening. On the contrary, in the third phase, DRW 1 and 4 were emerged on top of the other draw-in plans. This suggests that there were stretch resistance build-up on weft loaded yarn DRW 1 before it reach the composite failure state.

3.2 Stress – Strain Response on 25 pick.cm^{-1}

Figure 5 and 6 display the stress-strain curve behaviour of 25 pick cm^{-1} woven composite in warp and weft direction. Figure 5 exhibits the stress-strain curve behaviour in warp direction**.** The curve line was classified into three phases. In the first phase, all draw-in plan showed close curve line within 0.6% strain. However in the second phase, DRW 3 recorded the lowest stress-strain curve line in 0.6 to 1.7% strain ranges.
Eventually, DRW 1 and 4 resulted the highest stress-strain curve line in the range of 1.6 to 2.7% strain. In the third phase, DRW 1 showed the lowest curve line in 2.7 to 3.7% strain ranges. Nevertheless, all draw-in plan recorded high fluctuation of stress curve line in the range between 3.7 to 4.5% strain. In general, DRW 1 give the highest stress value at 48 MPa and strain at 5%. In contrast, DRW 2 produce the lowest stress value at 46 MPa and strain at 4.6%.



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ig 5: Stress-strain behavior of 25 pick.cm^{-1} woven composite in warp direction

In general, the close stress-strain curve patterns on warp direction indicated that there are uniform stress build-up distribution along all warp loaded yarns along all draw-in plans within three different regions. Within the first region, linear stress-strain curve lines was noticed between all draw-in plans. This is because low stress amount is needed for initial tensile load. However, in second region, there are slight fluctuation of curve line. This suggests that there were slight stress resistance build-up on warp loaded yarn during warp yarn straightening. The oscillation of maximum stress before composite failure curve patterns indicated that dissimilarity of stress performance on warp loaded yarn between all draw-in plans. DRW 1 and 4 resulted with greater maximum stress due to the least decrease of stress strength after being straighten.
Figure 6 exhibits the stress-strain curve behavior in weft direction. The stress-strain curve line was categorized into three significant phases. In the first phase, it can be seen that all draw-in plan show close curve pattern within 0.7% strain range. However in the second phase, DRW 1 and 4 were emerged above on top of DRW 2 and 3 in the range between 1 to 5.5 % strain. In the third phase, DRW 2 showed the highest stress-strain curve line in 5.5 to 7% strain ranges. In general, DRW 4 result with the highest stress and strain value at 113 MPa and strain at 11%. In contrast, DRW 2 give lowest stress at 108 MPa and strain at 9%.

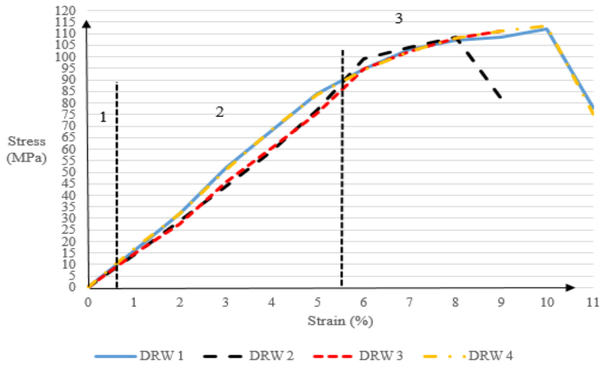

Fig 6: Stress-strain behavior of 25 pick.cm^{-1} woven composite in weft direction.

The 3D angle interlock woven composite stress-strain behaviors on weft was presented in Figure 6. In general, it can be observed that there were a variation of stress-strain curve line between all draw-in plans within three different regions. In the first phase, a close stress-strain curve suggested that low stress is needed to elongate at the initial tensile load. On the other hand, in the second phase, it can be seen that there were stress build-up during weft straightening on DRW 1 and 4. The greater stress-build up on weft loaded yarn was assisted by the high distribution of fibre volume fraction (FVF) percentage content. The increases of weft density resulted to greater FVF percentage and thus produce greater stress resistance.
This findings was correspond with several previous studies (13 - 15). In the third region, the fluctuation of maximum stress before failure between all draw-in plans was recorded. This suggests that there were inconsistent of stress performance of weft loaded yarn after straightening. The inconsistent of stress-strain performance based on each draw-in plan was caused by different amount of yarn interlacement. It can be observed that, DRW 1 and 4 recorded greater maximum stress due to least yarn interlacement and low crimp percentage. Thus, low stress reduction of weft loaded is produced during woven composite deformation until failure.

4. Conclusion

The experimental stress-strain results of 3D angle interlock woven composite were recorded. Two different weft densities and four different draw-in plan of woven composite samples were tested to allow better understanding of stress-strain responsiveness. From the results obtained, 25 pick.cm^{-1} of weft density recorded the highest stress value at 113 MPa and strain value at 11%. It was noticed that DRW 1 exhibited an interesting stress-strain curve behavior of woven composite as compared to the other counterpart draw-in plan. In general, DRW 1 showed similar stress-strain curve line with other draw-in plan when the strain load was low. However, DRW 1 curve line were emerged on top of other draw-in plan as the strain load was high. This resulted different outcome of stress-strain based on different draw-in plan.

Acknowledgement

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