3D Angle Interlock Woven Fabric Mechanical Tensile Strength Based On Various Fabric Weft Densities

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ABSTRACT

3D angle interlock is one of many textile woven structures that have shown prominent mechanical tensile strength properties towards technical application such in transportation, structural reinforcement, and sport purposes. This paper intends to show the influence of fabric weft density parameter towards mechanical tensile strength performance of 3D angle interlock woven fabric. The woven fabric samples were fabricated with two different weft densities parameters which were 22 and 25 pick.cm^{-1} (ppcm). The tensile strength test on woven fabric sample was tested accordingly to the American Standard for Testing and Materials (ASTM). The results revealed that highest fabric weft density at 25 pick.cm^{-1} contributed to the highest weft crimp percentage at 4.7 % and weft stress performance at 67.2 MPa.

Keywords: *3D angle interlock, woven fabric, fabric weft density, mechanical tensile strength*

1.0 Introduction

Textile fabric is one of the textile material which can be manufactured either by using weaving, knitting or non-woven techniques. Textile woven fabric consists of two sets of yarn interlacement; warp (vertical) and weft (horizontal) directions. In general, woven fabric can be categorized based on conventional 2D and 3D woven fabrics. Studies have shown woven fabric have a prominent strength-to-weight ratio factor which important for the composite application [1 - 4].

2D woven fabrics are produced by interlacing of warp and weft yarns at 90 degrees crossover points. Theoretically, weft direction will have

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low interlacement point than warp [2, 4]. Thus, low yarn interlacement will improve the tensile strength due to fewer built-in stress. This will help to receive better resistant of tensile force during woven fabric elongation. Several types of 2D textile weave structure such as plain, twill, honeycomb, and satin are commonly manufactured for textile composite application. Previously, conventional 2D woven fabric such as plain and twill weaves were extensively being used on composite application. Though, a lack of delamination resistance of 2D woven composite have led to low durable performance. Thus, 3D woven fabric was invented to improve the delamination resistance [3 - 6].

Generally, 3D woven can be categorized into several types of structures namely layer-to-layer, multilayer, angle-interlock and orthogonal. Among these structures, 3D angle interlock displayed the most prominent use in technical textile application. The 3D angle interlock woven fabric has enticed attention from numerous researchers to explore the potential of mechanical behaviour 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].

There are several parameters involved towards the result of the mechanical tensile strength performance of woven fabric. Researchers have suggested that fabric physical properties such as fabric weft density, and yarn crimp plays a significant variables towards the tensile strength outcomes [2, 3, 7, 8, 12] of textile woven fabric. A variety of textile weave structures between 2D plain, satin, twill and 3D woven fabric resulted to different yarn interlacement points. S. Dai *et. al* [8] and J.S Jones *et. al* [10] studied 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. The amount of yarn interlacement will contribute to distinctive percentage of yarn crimp. Several studies [13, 14, 15] on the investigation of different yarn crimp percentage indicated that high crimp value will reduce the maximum stress performance of woven fabric than least crimp presence.

3D woven fabric displayed better tensile strength than conventional 2D woven fabric. S.V Lomov et. al [12] concluded that single ply 3D E-glass orthogonal exceeded the tensile strength by 4 % than four layers of 2D E-glass plain weave. This outcomes portrayed that 2D plain weave consists of higher yarn interlacement that 3D orthogonal, in which has resulted in lower tensile strength performance.

Fabric density or known as the compactness of fabric indicated the number of warp and weft yarn presence in the centimeter square of fabric area. High number of yarn presence per unit area will result in more compact woven fabric. Extensive studies have displayed that high amount of fabric density will substantially improve the tensile strength performance particularly [8, 12, 14].

2.0 Experimental Design

The 3DAI woven fabric samples was manufactured by using a Sulzer Rapier Loom. Two different groups of fabric weft density were set during the weaving sample production which were 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 fix at 16 end.cm^{-1} throughout weaving production. Figure 1 shows the actual set of loom used during weaving production.

Figure 1: A sulzer rapier loom machine

The 3DAI woven fabric samples were constructed based on two different polyester yarns configurations. The warp (vertical) direction, 90^{o} was assembled based on spun polyester yarn while the weft (horizontal) direction, 0^{o} was made with plied multifilament polyester yarn. Figure 2 displays the 3DAI woven fabric sample.

Figure 2: Actual sample of 3DAI woven fabric

Table 1 exhibits the fabric physical parameters construction properties of 3DAI woven fabric sample based on two different sets of fabric weft densities which were 22 and 25 pick.cm^{-1}

Table 1: Fabric physical construction parameters

Physical Characteristics	Properties
Yarn Count	
Warp (spun yarn)	26 Tex
Weft (plied multifilament)	100 Tex
Fabric Density	
Warp	16 end.cm^{-}1
Weft	22 and 25 pick.cm^{-1}

Several fabric physical analysis such as fabric weight, yarn crimp and mechanical tensile strength of 3DAI woven fabric were performed accordingly to the ASTM standard procedure. The details of these tests were described in the following section.

2.1 Fabric weight

Weight of fabric was measured by determining the mass per unit area of fabric. ASTM D3776M - 09a (2013) standard test method for mass per unit area (weight) fabric was followed. Equation 1 below shows on how to determine the average fabric weight. The average results from three samples of fabric weight (W) is multiplied with 100 g/cm^2 to get the average of mass per unit area of woven fabric in g/cm^2.

$$\mathrm{W} \times 100\ \mathrm{g/cm^2} \qquad (1)$$

2.2 Fabric Crimp

The measurement of the length of woven fabrics made from the yarn and the actual yarn length after being pulled out from the woven fabric were determined according to the Standard Test Method for Yarn Crimp and Yarn Take-up in Woven Fabrics procedure, ASTM D3883-04(2012) [16]. Equation 2 below shows the percentage of yarn crimp presence calculation formula. The length of yarn being pulled out (Y) and the length of yarn at interlacing state on woven fabric (X) were divided by the length of yarn at interlacing (X). Then, the results were multiplied with 100 %.

$$\frac{\mathrm{Y}-\mathrm{X}}{\mathrm{X}} \times 100\% \qquad (2)$$

2.3 Uniaxial Tensile Woven Fabric

The uniaxial tensile strength test were performed on woven fabric samples in warp and weft directions. The main purpose of this analysis is to determine the maximum breaking strength and elongation point of woven fabric. The test was conducted according to the standard test method for breaking force and elongation of textile fabrics (Strip Method) ASTM D 5035 – 11(2015) procedure [17]. Three woven fabric samples for each direction, warp and weft were tested by using Instron testometric strength tester to obtain the average mean result. Figure 3 displays the diagram of woven samples for tensile test.

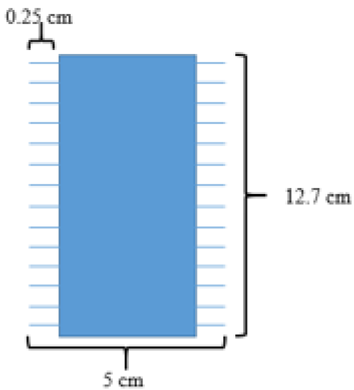

Figure 3: Woven fabric tensile sample analysis

The woven fabric sample were cut to dimensions 5 x 12.7 cm for each warp and weft directions. The standard requires yarn removed at both fabric selvedges at 0.25 cm. The woven fabrics were then placed on a tab length for tensile strength test. Figure 3.11 shows sandpapers with medium level of 80 grit particle are applied on the tab length of each end point of woven fabric to improve the slippery resistance of woven fabric. The tensile test analysis were performed at cross head 10 mm/min with 20 kN of load cell.

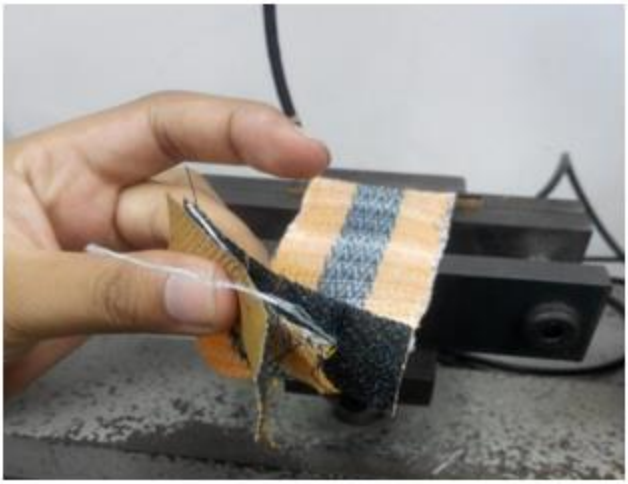

Figure 4: Sandpaper with 80 grit particle applied on the tab length of woven fabric

Equation 3 was used to determine the tensile stress (□) of woven fabric. The maximum force (F) was divided with cross-sectional area of woven fabric (A) to calculate the result which were measured in megapascal (MPa). At equation 4, the strain value will determine based on the original length of woven fabric and the extension length of woven fabric. The strain results were measured in percentage (%). Young modulus of woven fabrics were determined by dividing stress (□) over strain (□) value as shown in Equation 5. The results were measured in gigapascal (GPa).

$$\text{Stress } (\partial) = \frac{\text{F}}{\text{A}} \qquad (3)$$

$$\text{Strain } (\varepsilon) = \frac{\Delta \text{L}}{\text{L}} \qquad (4)$$

$$E = \frac{\partial_{\text{upper}} / \partial_{\text{lower}}}{\varepsilon_{\text{upper}} / \varepsilon_{\text{lower}}} \qquad (5)$$

3.0 Results & Discussion

This section discussed the outcome presented on the fabric weight, fabric crimp and mechanical uniaxial tensile strength analysis of 3DAI woven fabric.

3.1 Fabric weight

The weight of fabric measurement was influenced by fabric weave structure warp and weft fabric density, yarn linear density, different number of weft density and different draw-in plan. 3D angle interlock woven fabric weight is shown in Figure 6. It can be seen from the figure that high number of weft density have resulted heavier fabric. The heaviest fabric weight is 35.6 g/cm^2 on 25 ppcm while the lightest fabric weight is 34.53 g/cm^2.

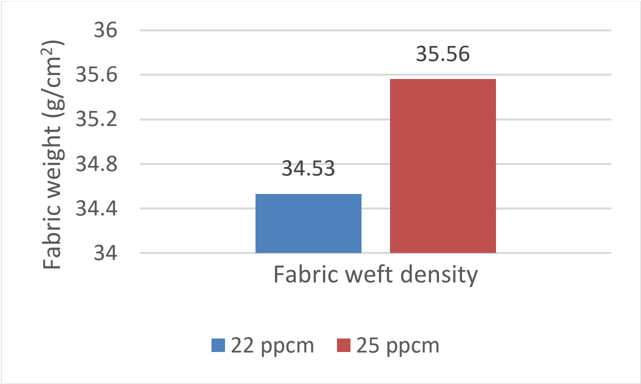

Figure 6: Fabric weight results

The experiment shown that the increase number of weft density resulted heavier fabric. It can be noticed that, an elevation number of weft density gave high value of yarn interlacement. Consequently, greater yarn interlacement will result in greater yarn crimp presence. Thus, an increment of crimp percentage will produce heavier woven fabric property.

3.2 Fabric crimp

Fabric crimp is based on the length of interlaced yarn after being pulled out from the woven fabric. Yarn crimp is influenced by the weave structure factor, fabric density and different draw-in plan factor. Figure 7 and 8 showed the results of yarn crimp presence on warp and weft directions respectively.

Based on Figure 7, it can be seen that, 25 ppcm displayed the highest warp crimp percentage with 9.5 %. On the other hand, 22 ppcm produced the lowest warp crimp percentage with 8.9 %.

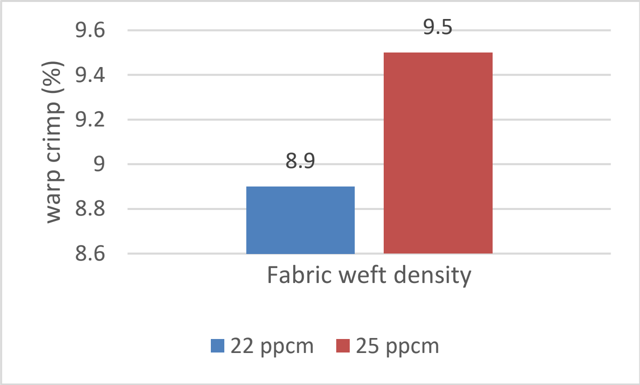

Figure 7: Warp crimp percentage of 3DAI woven fabric

Figure 8 presented that the highest weft crimp percentage is 4.7 % on 25 ppcm while the lowest weft crimp percentage is 4.2 on 22 ppcm weft density.

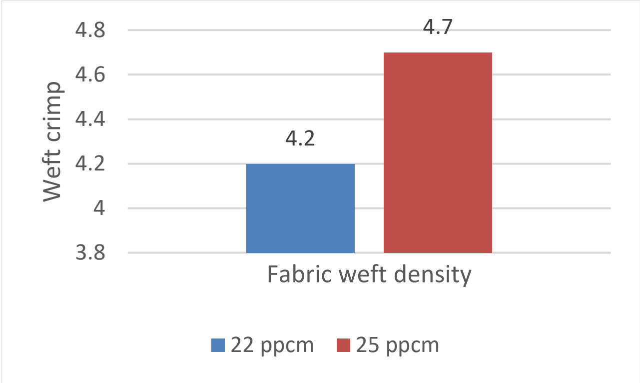

Figure 8: Weft crimp percentage of 3DAI woven fabric

Woven fabric construction primarily based on the interlacement of two sets of yarns; warp and weft directions. The observation on this study have shown that, warp direction gave higher percentage of crimp than weft direction. This is due to higher warp yarn tension in weaving than weft yarn. High yarn interlacement will produce high crimp percentage. Consequently, fabric crimp will influence the uniaxial tensile stress-strain behavior of 3DAI woven fabric [13 – 15].

3.3 Uniaxial tensile strength of woven fabric

The uniaxial tensile of woven fabric were influenced with the stress, strain, and fabric density factors. Fabric stress is referred as measurement of force required per total fabric area while fabric strain is referred as the amount of length of fabric stretch before it breaks. Table 2 exhibits the summary results of stress-strain performance of 3DAI woven fabric based on two different sets of fabric weft densities which were 22 and 25 ppcm.

Table 2: Summary of 3DAI woven fabric stress-strain performance

Weft density (ppcm)	Direction	Stress (MPa)	Strain (%)
22	Warp	31.9	16.0
	Weft	52.1	4.0
25	Warp	24.3	13.0
	Weft	67.2	5.8

It can be seen from the table that, the highest warp stress value was 31.9 MPa on 22 ppcm at 16.0 % strain. However, the lowest warp stress value is 24.3 MPa on 25 ppcm at 13 % strain. Conversely, the highest weft stress value is 67.2 MPa on 25 ppcm at 5.8 % strain while the lowest weft stress value is 52.1 MPa on 22 ppcm at 4 % strain. Figure 9 displays the uniaxial tensile stress-strain behavior of 3DAI woven fabric on warp direction.

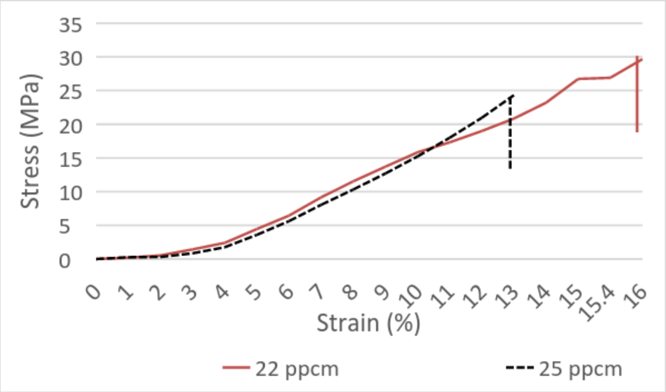

Figure 9: Warp stress-strain behavior of 3DAI woven fabric

Higher weft density, 25 ppcm will enhance the warp crimp percentage on woven fabric and thus results in low tensile stress-strain performance than lower weft density, 22 ppcm. Moreover, a comprehensive analysis showed similar curve line between 22 and 25 ppcm within the initial 4 % of strain.

This situation occurred because both sets of woven fabric recorded of almost an identical warp density which is 16 epcm. Greater crimp percentage will produce long decrimping curve line than lesser crimp percentage. Consequently, long decrimping line reduced the individual loaded yarn stretch resistance and thus contributed to low maximum stress performance. The outcome presented were consistent with a previous study [5] that suggested high yarn interlacement points significantly increased the yarn crimp presence and reduced the uniaxial tensile stress value.

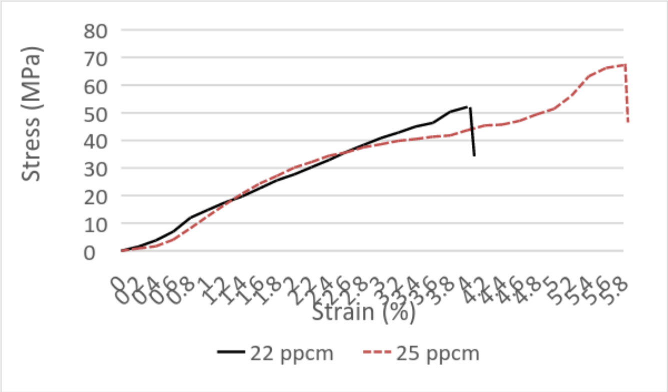

Figure 10: Weft stress-strain behavior of 3DAI woven fabric

Based on the Figure 10, it can observed that 22 ppcm exhibited shorter region of decrimping than 25 ppcm within 0.4 % of strain. Higher weft density will results in more yarn insertion on weft direction and thus produce additional yarn interlacing compared lower weft density [2, 4]. However, 25 ppcm gave the highest stress performance with 67.2 MPa than 22 ppcm with 52.1 MPa. Higher amount of fabric weft density on 25 ppcm indicated that the number of weft yarn presence in that direction are greater than 22 ppcm. Thus, the increases amount of individual yarns on 25 ppcm gave better stress build-up during fabric extension.

4.0 Conclusion

From the present study, it can be conclude that higher amount of fabric weft density will significantly improve the uniaxial tensile of 3DAI woven fabric performance. Highest fabric weft density, 25 pick.cm^{-1} will elevate the yarn interlacement point and thus contribute to the maximum crimp presence on both warp and weft directions. The increase of yarn crimp percentage exhibit longer decrimping region during fabric extension than least crimp presence. Eventually, greater individual yarn damage due to the long decrimping curve line will result to low uniaxial tensile stress-strain performance of 3D angle interlock woven fabric.

5.0 Acknowledgement

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