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Effect of Weaving Structures on the Mechanical Properties of Woven Fabric Reinforced Composites

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ABSTRACT

Now days the use of woven fabric as a reinforcing material in composites manufacturing sectors have been increased due to their advantages like toughness, dimensional stability and good impact resistance. The effects of different fabric materials namely weave designs (plain and basket) and fabric crimp on the mechanical properties of woven fabric reinforced composites via bio resin were evaluated. The morphological and tensile properties of composites were analyzed through the scanning electron microscope (SEM) and Shimadzu tester respectively. The results revealed that woven basket fabric reinforced composite had better tensile strength and had a promising future compared to plain woven fabric reinforced composites. The tensile strength of green composite structure reinforced by basket weave was enhanced by 15% as compared with plain weave within similar composite elongation range. Similarly, basket weaving pattern reinforced green composite had higher modulus compared to plain woven fabric reinforced composites.

Keywords: Basket weave, Plain weave, Tensile strength, Weave Construction, Woven fabric

1. INTRODUCTION

Textile fabrics fabricated by weaving, knitting and nonwoven technology have been rapidly increased and becoming an attractive research areas in composite researchers and industries as compared with conventional laminated composites. Woven fabric is a type of textile fabrics which are manufactured by weaving machine by interlacing of two set of threads called warps and wefts. The warps (vertical yarn) and the wefts (horizontal yarn) are interlaced at 90^0 each other. The strength of woven fabric depends on the weaving patterns [1-3]. According to Das 2010 report, the major elements and critical factors which are controlling the properties of fabric are yarn properties, fabric count and weave design [4, 5]. The manipulation and changing of these critical factors would help to manufacture fabrics with different weave design and results fabrics having different physical and mechanical properties [4, 5]. The mechanical strength of woven fabrics have been affected by the interlacing of warp and weft yarns at the crossing points [6]. When woven fabrics are exposed to uniaxial or biaxial loads, the threads in the woven structures such as fiber to fiber or yarn to yarn are developed frictions at fabric interlacing points and results high stress is happened in the fabric [7]. Lee et al 2001 was reported as all weaving activities such as shedding, weft insertion and beat-up process are significantly affected the mechanical strength of the warp and weft yarns and results yarn damage [8, 9]. Also, the mechanical performance of woven fabric was affected by weave design and structure (construction) such as plain, twill and satin. The structure of woven fabrics are determined by many factors like yarn properties, crimped percentage, weaving density and direction [10].Weaving density may be presenting in many ways one of them is crimped percentage, which plays an important role in the configuration of weaving characteristics and calculated by Equation 1.

$$Weaving\ Crimp\ \% = \frac{(\textbf{Straightened yarn distance} - \textbf{Yarn in fabric distance}) * \textbf{100\%}}{\textbf{Yarn in fabric distance}} \qquad \text{(Eq 1)}$$

The rapid growths in the textile technology such as weaving, nonwoven, braiding and knitting have been triggered to improve the physical and mechanical properties of composite material [11, 12]. The performance of woven reinforced composite materials are governed mainly by the nature and properties of resin and the reinforcing textile materials. The strength of textile materials such as fiber and fabric reinforced composite structures are depends on the fiber strength, type of fiber, amount of fiber, fiber length and type of weave. Also, the mechanical strength of composite dependents on the stress transfer between reinforcing textile materials and matrix [13]. Alavudeen et al. 2015 studies were found that plain fabric made of banana/kenaf reinforced polyester composite showed improved tensile properties compared to the twill fabric weave design [14]. Wahab et al 2014 reported that, on woven composite revealed that the performance of woven kenaf composite were affected by yarn size and weave design that determine the woven fabric porosity and crimp percentage [15-19]. This research work was focused on the effects of weave designs on the tensile properties of textile woven fabric reinforced composite.

2. MATERIAL AND METHOD

2.1. Materials

Textile fabrics as reinforcing materials, especially woven fabrics made from enset fibers and bio resin materials were used for this study.

Woven Fabric Construction: Two type of woven fabrics designs are used for this study, i.e. plain and special basket weave construction. The general weave constructions are given in Figure 1a and 1b respectively.

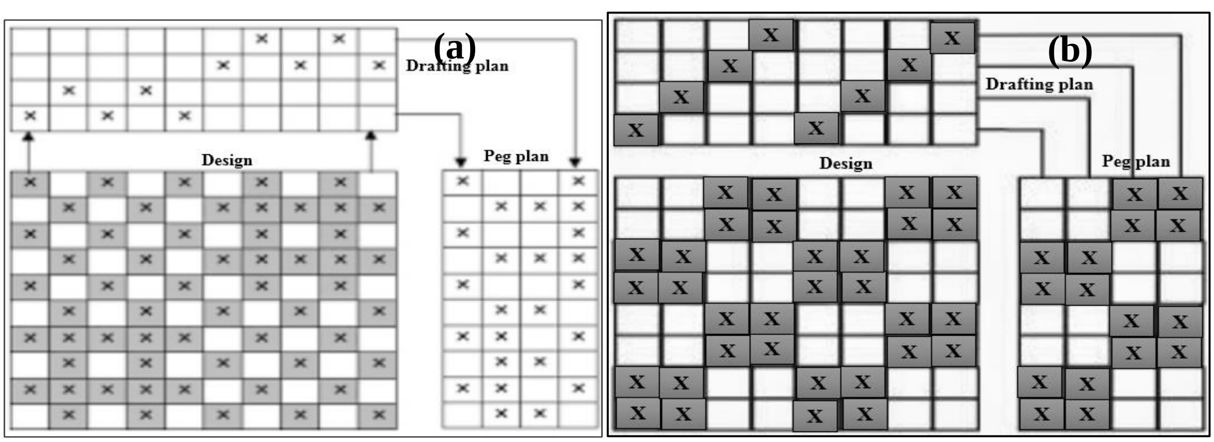

Figure 1. Weave Construction: (a) Plain weave (b) Basket weave

Plain: The plain weave is the simplest type of weave construction and formed by interlacing warp and weft yarns as shown in Figure 2a.

Basket: Basket weave is basically similar to plain weave except that two or more warp yarn alternately interlace with two or more weft fibers. Special arrangement of one warp crossing two wefts were designated 1 x 2 basket as shown in Figure 2b.

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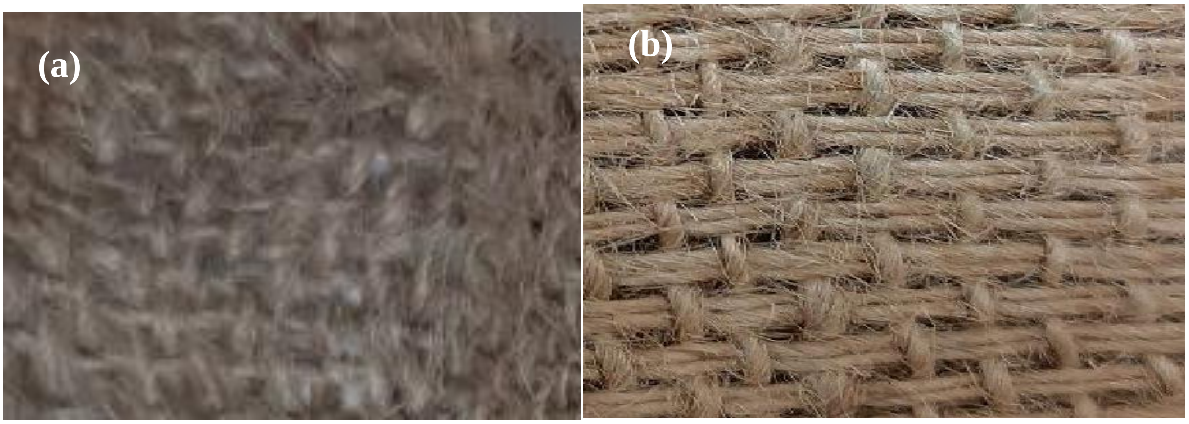

Figure 2. Woven Fabrics: (a) Plain woven fabric (b) Basket woven fabric

2.2. Methods

Composite structures were manufactured by hand layup techniques using textile woven fabrics having different weave construction as a reinforcing materials. The effect of weave construction on composite mechanical strength was studied. The morphological analysis was done by scanning electron microscope.

Volume Fractions of Composite

The density of the enset fabric and plain and basket woven fabric reinforced composites were measured based on ASTM D3800-99. The samples of were conditioned for 24 h and their average density of enset fabric and composite of five specimens were taken and recorded. The experimental fiber volume fraction (Vf) and resin volume fractions of composite (Vr) was calculated by using Equation 2, 3, 4, and 5.

Volume of fibers (Vf) = Vf = Wf/Wr (Eq 2)

Fiber to resin volume ratio (Vf/Vr) = (Wf/Wr) x (ρr/ρf) (Eq 3)

Bio resin volume (Vr) = 1/(1+(Vf/Vr)) (Eq 4)

Theoretical volume of fibres (Vf) = 1 – Vr (Eq 5)

Where, (W/ρ) are the known weights and density of enset fabric and bio resin. Based on the determined volume fraction of composite enset fabrics and bio matrix, voids (Vv) in the composites were calculated according to Equation 6.

Vf = 1 – Vr – Vv) (Eq 6)

Morphological Observation

The morphological analysis of enset fabric reinforced composite structures were analyzed by using optical microscopic and Evo-scanning electron microscope. Gold was used to coat the specimens to enhance the surface conductivity.

Tensile strength Test

Tensile strength testing of enset fabrics reinforced composite materials were measured by Shimadzu test machine based on ASTM D638-10 standard. The load cell had 5 KN capacity and the jaw moved at the rate of 100 mm/min during tests. For this study, flat shoulder specimens having 300 millimeter length and 50 millimeter width were used for tensile strength test.

3. RESULT AND DISCUSSION

3.1. Volume fraction of green composite

Fiber volume fraction of enset plain or basket woven fabric reinforced composite structure is the ratio of fiber volume and composite volume, which are generally dependent on the density of material used in composite manufacturing. Table 1 revealed that, the fiber volume fractions of plain enset woven fabrics were found to be less than basket enset woven fabric. Moreover, the weight fraction of plain and basket enset weaves were 27.59 % and 32.37 % respectively. Also, basket woven structures had higher void content with highest density and percentage of fiber volume.

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Table 1. Volumetric composition of woven fabrics composite

Weave design of reinforcement	Density (g/cm^3)	Reinforcement		Bio resin volume (Vr) (%)	Void Volume Fraction (%)
		Fiber Weight Fraction (%)	Volume of fibers (Vf) (%)		
Plain	1.30	27.59	30	72.41	0.01
Basket	1.83	32.37	35	67.62	0.5

3.2. Mechanical Strength

Tensile properties of plain and basket weave enset fabric reinforced green composites were summarized in the Table 2, Figure 3a and 3b. The test results shown that, green composite structure reinforced with with basket weaving pattern had better tensile properties compared to plain weave fabric reinforced composite. The tensile strength of green composite structure reinforced by basket weave was enhanced by 15% as compared with plain weave within similar composite elongation range. In the case of plain and basket weave, yarns movement in the warp and weft direction is straight and uniform. This result revealed that yarns orientation of woven fabric in the warp and weft directions were influenced the tensile properties of green composites. Similarly, basket weaving pattern reinforced green composite had higher modulus compared to plain as shown in Table 2.

Table 2. Tensile properties of composite structure reinforced with fabrics having different weave constructions.

Type of weave	Fiber volume fraction (%)	Average Max. Force (N)	Average Max. Elongation (%)	Young's modulus (GPa)
Plain weave	27.59	2731.07	6.26	4.75
Basket weave	32.37	3104.21	6.84	6.29

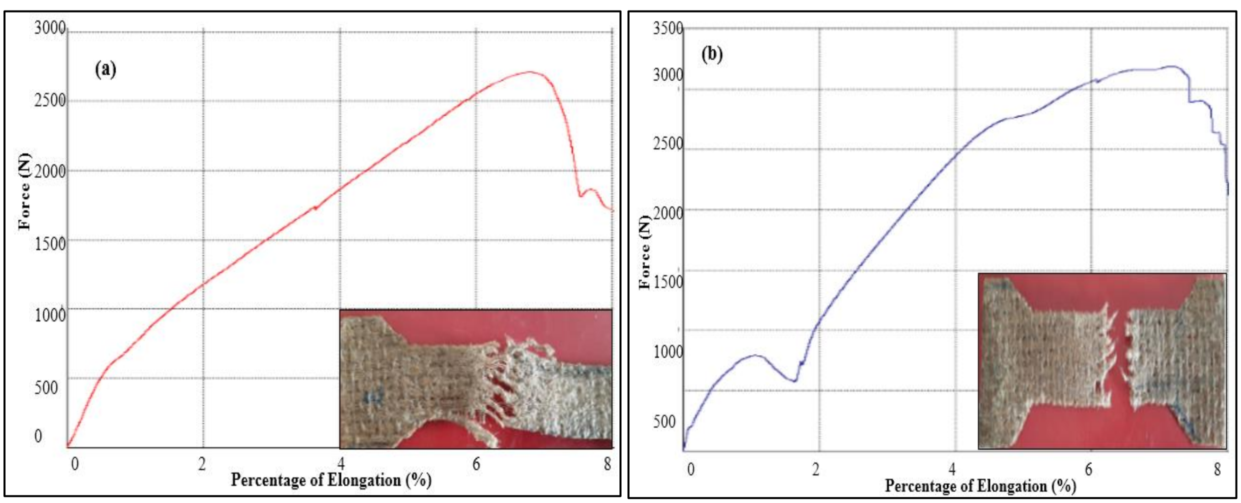

Figure 3. Tensile strength of composite reinforced with weave constructions: (a) Plain weave fabric (b) Basket weave

3.3. Effect of fabric crimp on composite structure

During the interlacements of warps and wefts, a certain amount of unevenness is imparted to the warp and weft threads of a woven fabrics, this waviness is called crimp [20]. Denser weave packing actually causes more void in the textile architecture and thus more matrix material and a lower fibre volume fraction in the composite [20, 21]. Crimp is expressed as percentage and it vary from 2% to as high as 30% depending on various parameters like threads/cm, Tex of yarns, characteristics of raw materials [20, 21]. The test result confirmed that lower crimp means straighter yarns, which translates into better composite mechanical properties in the basket weave structure. Also, the percentage of crimp was varies widely in plain and basket weave structure which were directly related to the amount of reinforced fabrics (yarns) and bio resins used in composite manufacturing. Also it was create void and pours structure in the composite and propagated the crack of the composite easily as shown in Figure 4.

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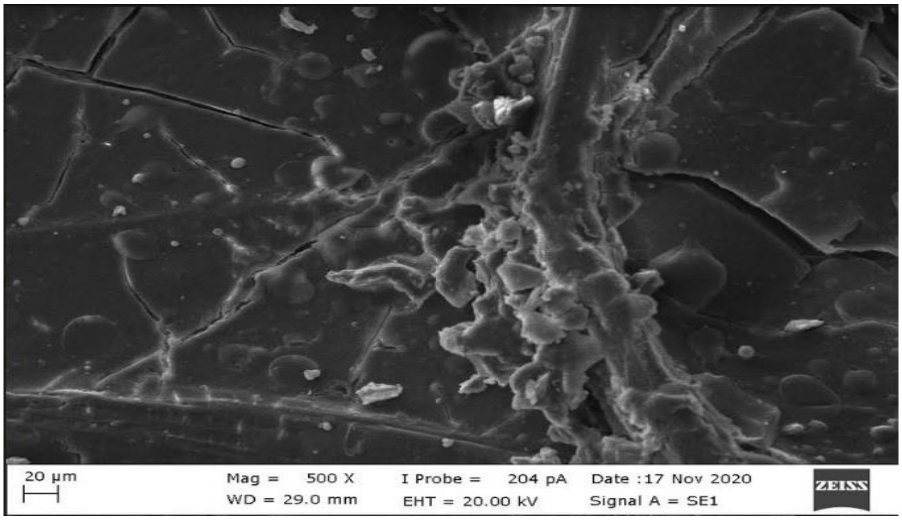

Figure 4. Crack propagation due to fabric crimp

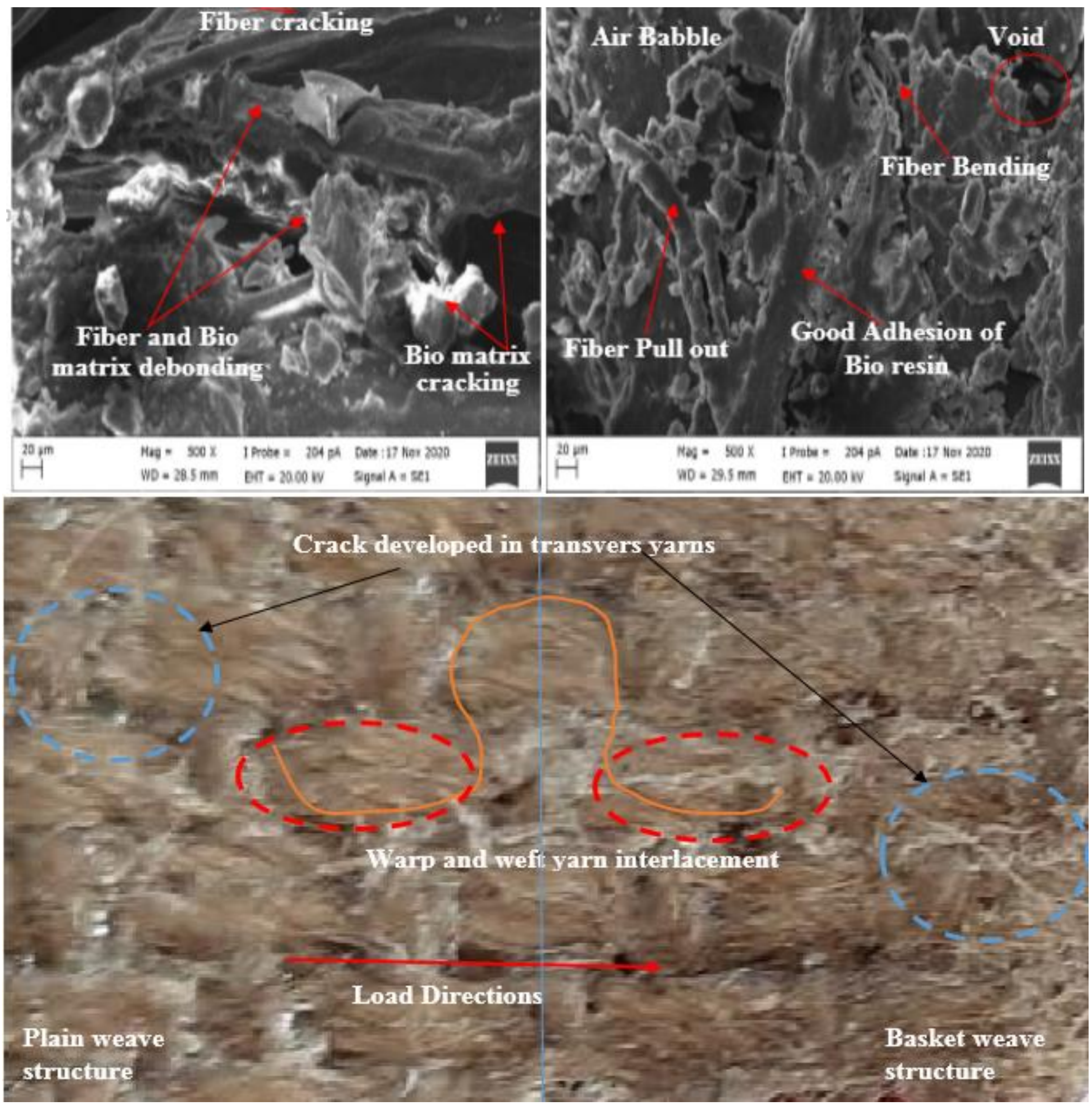

Figure 5. Development of failure perpendicular to the loading direction: (a) SEM view (b) Optical microscope view (X25)

3.4. Morphology

The surface morphology of woven fabric was investigated and studied by considering the phenomena occurred during interlacement of warp and weft yarns as shown in Figure 5. Optical and Scanning electron microscope (SEM) views were used to analyze the effect of weave on the tensile properties of green composite as shown in Figure 5a and 5b. Figure 5a and 5b revealed that, basket fabric reinforced green composite had lower damage of yarns near to the bio matrix than plain weave. This was because of low stress transfer on the outer layer of reinforcing basket fabrics. The distribution of porous area, voids and cracking in case of basket weave reinforced composite was symmetric and un-modal. The morphology of the fabrics were affected by the location of the fiber which was used for fabric manufacturing as shown in Figure 5b. Also, the observation shown in Figure 5 a and 5b, plain weave fabric (yarns) reinforced composite had a lot of holes structure both in the longitudinal as well as transversal direction than basket weave fabric reinforced composite which would significantly influenced the tensile properties of the composite.

4. CONCLUSION

This research was focused on the effects of weave designs on the mechanical behavior of woven fabric reinforced composite structure for light weight application. The test result revealed that, the mechanical properties of woven fabric reinforced composite materials were affected by the weave design, fabric crimp and fabric count. But, weave design was the more influential factor that affected most of the mechanical properties of composite structures. Basket weaves have better mechanical strength because of their weaving structure that had better interlocking between the yarns and absorbed sufficient bio resin to wet all the specimens in the composites. Also, the SEM investigations were confirmed that plain weave structure had higher failure during specimens test, this was due to poor adhesion within the composite structure and failed by yarn pullout, yarn to bio resin deboning and some voids.

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Conflict of Interest:

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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