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Effects of Fabric Pattern on the Mechanical Properties of Cotton Fabric/Unsaturated Polyester Composites

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Authors' contributions

This work was carried out in collaboration between all authors. Author EOA prepared the composites, performed all analysis and wrote the draft and final manuscript. Authors BMD and USI designed the study and managed the analysis of the work and corrected the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the effects of fabric patterns on the properties of cotton fabric/unsaturated polyester composites made from coarse plied yarns.
Place and Duration of Study: Department of Textile Science and Technology, Ahmadu Bello University, Zaria, Nigeria, between January to December, 2014.
Methodology: Four different coarse yarns of known count were plied to obtain a single strand which was woven (plain and twill) and knitted into fabrics of different patterns. The fabrics were coated with unsaturated polyester resin as matrix, applying both single and two layers of fabrics to form laminate configurations using hand layup. The tensile properties of the fabrics, tensile properties, flexural properties, impact strength and hardness of the textile composites were studied.
Results: The plying and fabrication conferred significant reinforcement on the composites for the different mechanical properties tested. The tensile strengths of the plain, twill and knitted fabrics

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were 13.67MPa, 13.14MPa and 4.55MPa respectively. The knitted fabric recorded the highest breaking elongation of 82.1%. The tensile and flexural strengths of the composites were improved by 75-81% with respect to the neat polyester resin. Composites with twill fabrics gave the best tensile and flexural strengths of 18.5MPa and 62.32MPa with flexural modulus of 4.43GPa, closely followed by plain (3.35GPa) and knitted (3.23GPa) fabric composites. The impact test showed that the knitted composites absorbed more energy than the twill and plain fabric composites in that order. Increase in fabric layers also led to increases in the mechanical properties tested, but the increases were not geometrical. SEM images showed that the morphologies of the fractured surfaces were in line with the yarn orientations in the fabric cross-section with reduced fiber pull out.

Conclusion: It's concluded that cotton fabrics made from coarse plied yarns can be used as reinforcements in textile composites.

Keywords: Fabrics; mechanical properties; plied yarn; scanning electron microscopy; textile composites.

1. INTRODUCTION

The attractiveness of natural fiber-reinforced composites in research areas are due to the non-recyclability, high density and the health hazards of composites reinforced with fibers such as glass, carbon and aramids [1,2] and their disposals [3]. The use of cotton fibers in unidirectional continuous or discontinuous form or randomly oriented, have always posed the problem of low mechanical properties and pull-out of fibers. Researches on textile technologies such as weaving, knitting and braiding have led to the formation of textile composites with higher mechanical properties, as continuous orientation of fibers is not restricted at any point [4]. When comparing all reinforcement forms, utilization of traditional high-performance reinforcements is preferred in fabric form rather than fiber and yarn [5]. Fabric is easier to handle and could maintain its dimensional stability during the composite fabrication in comparison to the other forms. Works on fabric composites include: woven banana [6], Jute fabrics [7], Hemp fabrics [8], Sisal fabrics [9], and Flax fabric [10]. Cotton fibers grow in balls, around the seeds. It is one of the most common agro-based fibers that have enormous potential in composite manufacture due to its cost-effectiveness and renewability. It is also versatile, nonabrasive, biodegradable and compostable with good insulating properties. Several investigations on cotton fibers and fabrics have been reported [11-17]. Plied yarns were found to induce normal forces between fibers and this increases inter-fiber friction leading to improved strength of the resultant yarn. Magdi et al. [18] when plying 90/1 Ne compact combed yarn, found that good yarn quality at 16% noil percentage can be obtained, which may be due to the fact that twisting two yarns together improves their tensile strength, elongation and regularity. Whatever be the fiber material, fiber pattern has been found to influence the composite properties based on the morphological and structural parameters [19]. This study is aimed at assessing the mechanical properties of cotton fabrics of different weave pattern, made from thick plied yarns and their use in composite reinforcement as low cost building materials and partition panels. Very few studies on the cotton-fabric coated thermosetting composites have been reported so far. Woven and knitted cotton fabrics made from plied yarns and their use as reinforcements for unsaturated polyester resin, to the best of the authors' knowledge, are yet to be reported.

2. MATERIALS AND METHODS

2.1 Materials

The 100% cotton yarns of 2.5 Neβ (4ply) used for the study were made by Zaria Industries Limited, Kaduna Nigeria. NYCIL Nig. Ltd, Ikeja Lagos supplied the polyester resin used with Methyl Ethyl Ketone Peroxide (MEKP) as the catalyst. The yarn parameters are shown in Table 1.

2.2 Fabric Production

The plain and twill fabrics were woven at the Department of Industrial Design, Ahmadu Bello University, Zaria using the AD-A-HARNESS loom (model B4 D). The knitted fabrics were produced on flatbed weft knitting machine using the adequate tension that corresponds to the required density of the woven fabrics. The construction parameters for the woven and knitted fabric used are shown in Table 2.

2.3 Composite Preparation

The unsaturated polyester resin was mixed with the MEKP catalyst and naphthalene cobalt accelerator in the ratio 100:1:1. The composites were prepared by hand-layup. The fiber volume fractions for the composites with single and double layers of fabrics are 0.40 and 0.79 respectively. Composites were obtained by impregnating the woven fabrics with the polyester matrix at room temperature of 27±2°C and relative humidity of 65% in a flat mold with dimensions 150 mm x 150 mm x 6 mm. Special care was taken to ensure that the correct amount of unsaturated polyester was used in addition to being evenly spread out.

2.4 Preparation and Cutting of Composite Specimens

The composite samples were cut into different shapes in accordance with standard specifications for various tests using a motorized jigsaw (model: GST 85 PBE).

2.5 Testing

2.5.1 Tensile properties of fabrics

Tensile tests were carried out on the fabric samples (plain, twill and knitted) prior to composite fabrication using Instron Tensile Tester, model 1025. The mean breaking load and extension at break were determined using an average of five samples with dimensions of 150 mm x 50 mm in accordance with ASTM D5035-11, carried out in the machine direction.

2.5.2 Tensile and Flexural properties of composites

Tensile tests and 3-point flexural tests were conducted with Instron 4204 Universal testing machine. Tensile tests were performed at a strain rate of 10mm per min and gauge length of 150 mm according to ASTM D3039-08. Flexural testing was also carried out in accordance with ASTM D 790-08, at a crosshead speed of 5mm/min and a span length of 60 mm. The dimensions of the specimens in each case were 150 mm x 20 mm x 6 mm. An average of five samples was tested in each case.

2.5.3 Impact properties

Charpy impact test was performed in accordance to ASTM D256-10. Composites with different textile fabrics were subjected to low velocity impact (25 Joules) test on an instrumented impact tester with semi-spherical impactor (model SI-1C3). The machine consists of a suspended pendulum with a mass of 2.0 kg dropped at a velocity of 3.8 m/s using sample dimensions of 150 mm x 20 mm x 6 mm. At least five replicate specimens were tested and the results were presented as an average of tested specimens.

2.5.4 Hardness

Hardness Test was performed on the composite samples using Indentec of Type 8187.5 LKV Model B with 1/16″ Steel ball indenter and a major load of 60 kg. In accordance with ASTM D785-08 standard for composites, the specimens were prepared for Rockwell-B hardness test. The specimen size was 6 mm thickness, 25 mm width and a length of 25 mm. Averages of five samples were tested in each case.

2.5.5 Scanning electron microscopy

The morphologies of the fractured surfaces were observed by scanning electron microscope (SEM) at room temperature. A PHENOM ProX SEM with field emission gun and accelerating voltage of 15 KV was used to collect SEM images for the composite specimen. The samples were made conductive by coating with Os with the use of vacuum sputter coater and the fractured surfaces were viewed.

Table 1. Yarn parameters

Sample	Strength (N)	Count (Neß)	Elongation at break (%)	Hairiness(H)	Evenness (%)
Yarn	37.13	2.5	9.97	5.73	10.55

3. RESULTS AND DISCUSSION

3.1 Fabric Production

Photographs of the yarn used for the production of the fabrics as well as the obtained fabrics are shown in Fig. 1. These comprise of plied cotton yarn (a), weft knitted fabric (b), plain woven fabric (c) and twill woven fabric (d).

3.1.1 Fabric parameters

The parameters for the fabrics used are shown in Table 2.

3.2 Tensile Properties of the Fabrics

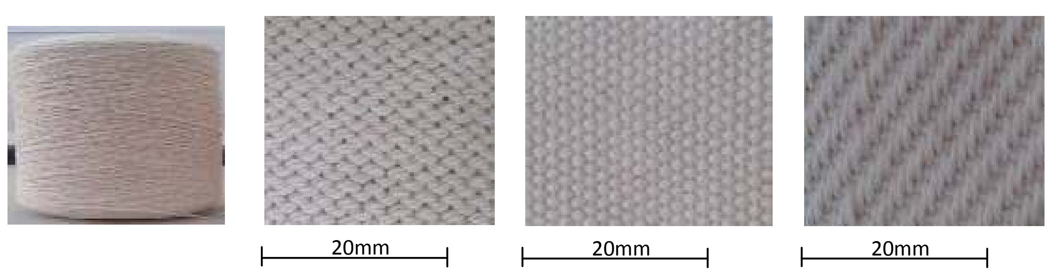
Fig. 2 shows that the plain fabric gave the highest tensile strength (13.67MPa) more than twill (13.14MPa) and knitted fabric (4.55MPa). This trend was reported by Nassif [20] whose work was on the mechanical properties of micro polyester woven fabrics and also by Malik et al. [21] who investigated the influence of plain and twill (3/1) weave designs on the tensile strength of PC blended fabrics. They found that plain fabric samples have considerable high tensile strength as compared to twill fabric samples at the same fabric properties. The superior strength of the plain weave over twill might be unexpected because of high crimp associated with plain fabrics which leads to lower mechanical properties as reported by Saiman et al. [22] who researched on the effect of fabric weave on tensile strength of woven kenaf reinforced unsaturated polyester composite. Campbell [23] reported that disadvantages of plain weave are the frequent exchanges of position from top to bottom made by each yarn. This waviness or yarn crimp reduces the strength and stiffness of the composite. However, it can be seen in Fig. 2 that the difference in strength is not so significant and could have been as a result of the thickness of the twill fabric which is within permissible experimental error as shown in Fig. 2. The tensile strength of the knitted fabric was very poor compared to the other fabric samples tested. The elongation at break was highest for the knitted fabrics (82.1%) and least for the twill fabric (29.2%) as shown in Fig. 3. The interlocking loops on the knitted fabrics can be said to be responsible for the highest breaking elongation recorded among the three set of fabrics. The tensile strength of the fabrics was greatly improved when compared to the ones made from unplied yarns [24].

3.3 Tensile Properties of Composites

The fabrics improved the tensile strength of the composites as compared to neat polyester by 40-81% for the different patterns (Fig. 4). The tensile strength of the composites was found to be highest for those with twill fabric, followed by that of plain fabric and then the knitted fabrics. The relationship between strength and fabric layers appears to be linear; increasing the number of fabric plies from single to double brings about a corresponding increase in the mechanical properties of the laminates.

The result here is similar to that of Song et al. [8] who showed that twill woven hemp fabric composites showed better mechanical strength, than plain woven hemp fabric composites and this is due to the structure of the twill fabrics, such as fewer interlacing and closer packing.

The modulus of elasticity was highest for the plain fabric composites (1.15GPa), greater than twill (1.01GPa) and knitted (0.78GPa) composites (Fig. 5). A similar trend was reported by Pothan et al. [9] who conducted tensile and impact studies of woven sisal fabric-reinforced polyester composites prepared by RTM technique. In their study, both tensile and impact properties were found to be maximum for composites made with twill woven fabric in the study where fiber bundles were used in the weft direction.



(a) Plied cotton yarn (b) Weft Knitted (c) Plain woven (d) Twill woven

Fig. 1. Yarns and fabrics used for composite reinforcement

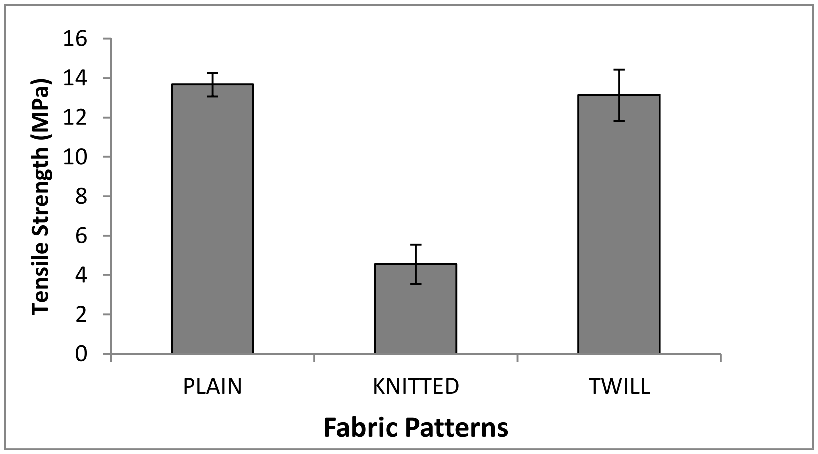


Fig. 2. Effects of fabric pattern on the tensile strength of cotton fabrics

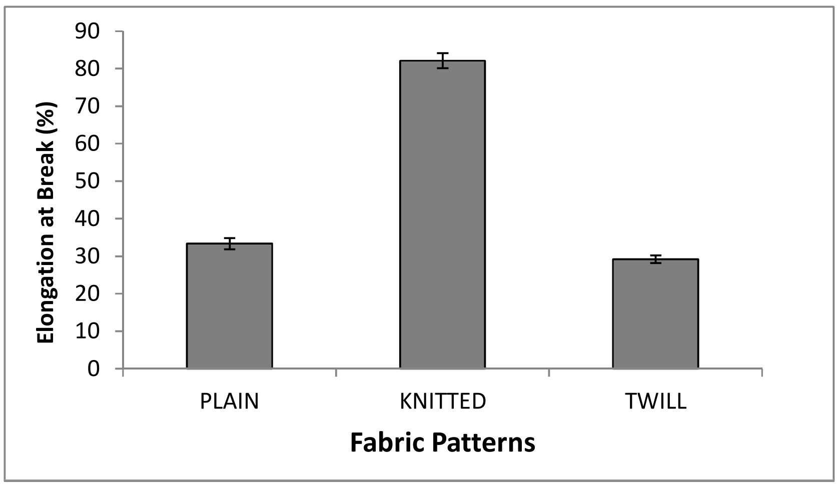


Fig. 3. Effects of fabric pattern on the elongation at break of the cotton fabrics

Increasing the number of fabric plies to two (increase in volume of reinforcement) also led to increase in the tensile strength and moduli of the composites, though the increase was not geometric (Figs. 4 and 5). One would have expected the obtained strengths to double when the fabric layers were doubled, the increase was not doubled but with substantial improvement in tensile strength.

3.4 Flexural Properties of Composites

It can be seen in Fig. 6 that embedding cotton fabrics in polyester resin increased the flexural strength. For the single fabrics, there were 47%, 32% and 20% increases in flexural strength for the twill, plain and knitted fabric composites respectively, with respect to the polyester matrix (35.56MPa).

This behavior is attributed to the nature of the different patterns and the bonding of the fabric with the polyester matrix. Doubling the fabric layers also gave a significant increase in the flexural strength and modulus of the composites. Twill fabric composites gave the highest strength (95.21MPa) and modulus (5.81GPa) while knitted composites gave the least flexural strength (68.78MPa) and modulus (3.84GPa) as shown in Fig. 7. The high values are indication of the high resistance of the composite specimens to bending. It can finally be said that the relationship between strength and fabric layers appears to be linear; increasing the number of fabric plies brings an increase in the tensile and flexural properties of the laminates. This result is also similar to findings by Abounaim et al. [25] who produced 2D composites from knitted preforms and investigation showed that the mechanical properties of 2D composites seemed to be greatly affected by different arrangements of yarns.

3.5 Impact Strength

Fig. 8 shows that the Charpy impact strength of the unsaturated polyester resin was improved by about 105% when the fabrics were coated with the resin. Single layer knitted fabric composites recorded the highest impact strength of 33.8 kJ/m^2. This is closely followed by the plain fabric (31.7 kJ/m^2) and the twill fabric (30.8 kJ/m^2) composites.

The performance of knitted fabrics (52.9 kJ/m^2) as compared to woven fabrics is better possibly due to the isotropic nature of the knitted fabrics which reduced the rate of crack propagation. The energy absorbed by the composites did not follow the same order as in the case of single fabric layer; the twill fabric composites were second best (46.7 kJ/m^2) and this could be due to the fabric thickness as a result of the method of interlacing of the yarns in the fabric cross-section (Table 1). It was observed that the combination of the fabric layers helped in decreasing the overall failure function, thus improving the impact damage resistance. This behavior is in line with the findings of Bannister and Herszberg [26] who reported that a higher percentage of impact energy in the range 0–10 Joules is absorbed by a weft-knitted glass reinforced composite (Vf = 50%) than was absorbed by an equivalent woven fabric. Yahaya et al. [27] conducted Charpy's impact test to analyze the effect of woven fiber layering sequence on the energy absorption capability of the hybrid composites. In terms of layering numbers, it was found that 4-layer hybrid laminates displayed a higher Charpy's impact properties compared to 3-layer hybrid laminates.

Based on the significant improvements in tensile strength (Fig. 4), flexural strength (Fig. 6) and impact strength (Fig. 8) it could be inferred that cotton fabrics of different pattern can adequately serve as reinforcements in polyester matrix composites. This is in contradiction to usual observation that cotton fibers in unidirectional, continuous, discontinuous or randomly oriented form have always posed the problem of low mechanical properties and pull out of fibers [5] thus, limiting the potential of cotton fibers as reinforcing filler.

3.6 Rockwell Hardness Test

The inclusion of the cotton fabrics improved the Rockwell hardness of the composites as compared to the polyester resin (20.6 HRF) by about 26-45% for both the single and double fabric laminates (Fig. 9). Composites with twill fabrics had the highest hardness with Rockwell number of 23.6 HRF and 26.6 HRF when reinforced with single and double layers respectively. The hardness of the knitted fabric composite was found to be minimal with a value of 21 HRF and 23 HRF for the single and double layers respectively. This is expected as cotton fibers have high modulus than UP and hence, confer high rigidity to the composites. Al-Mosawi [28] found that polymers have low hardness, an indication of the lowest value for araldite resin before reinforcement. But this hardness value greatly increased when the resin was reinforced by hybrid fibers, which decreased the penetration of the test ball to the surface of composite material and by consequence raised the hardness of the material.

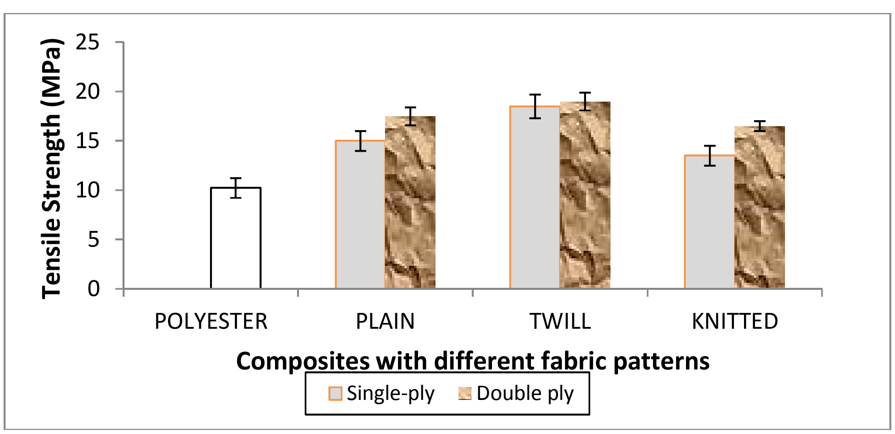


Fig. 4. Effect of fabric pattern on the tensile strength of cotton fabric/UP composites

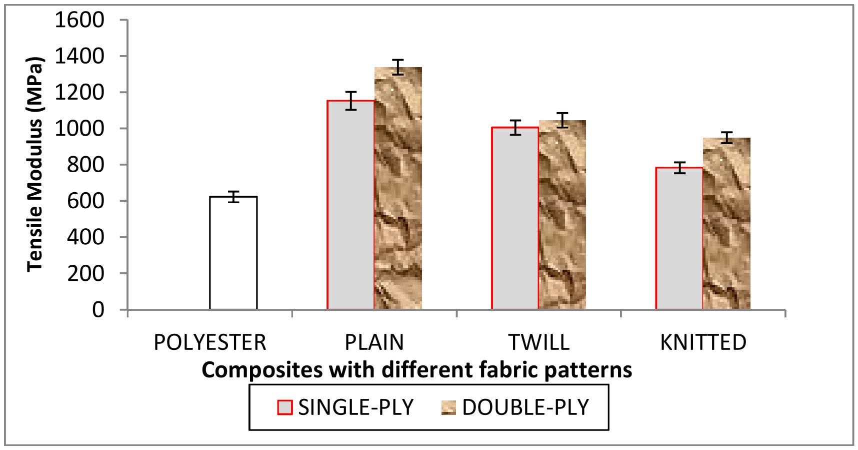


Fig. 5. Effect of fabric pattern on the tensile modulus of cotton fabric/UP composites

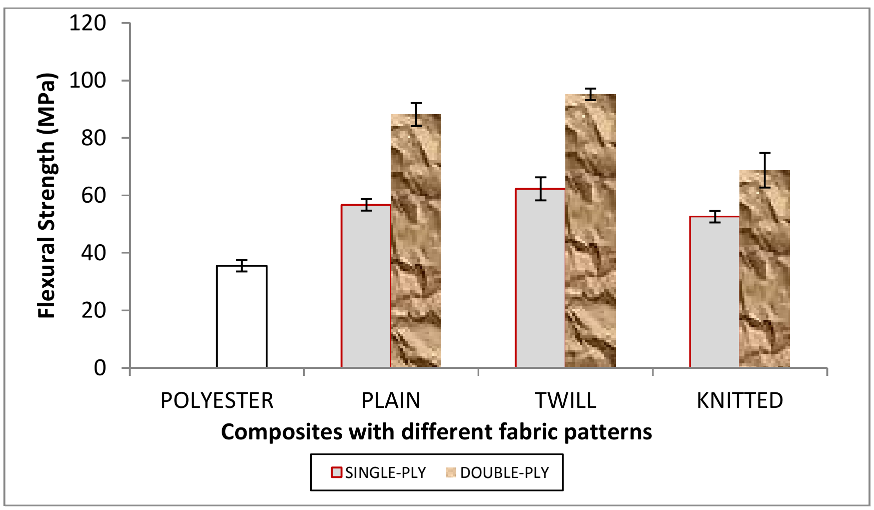


Fig. 6. Effect of fabric pattern on the flexural strength of cotton fabric/UP composites

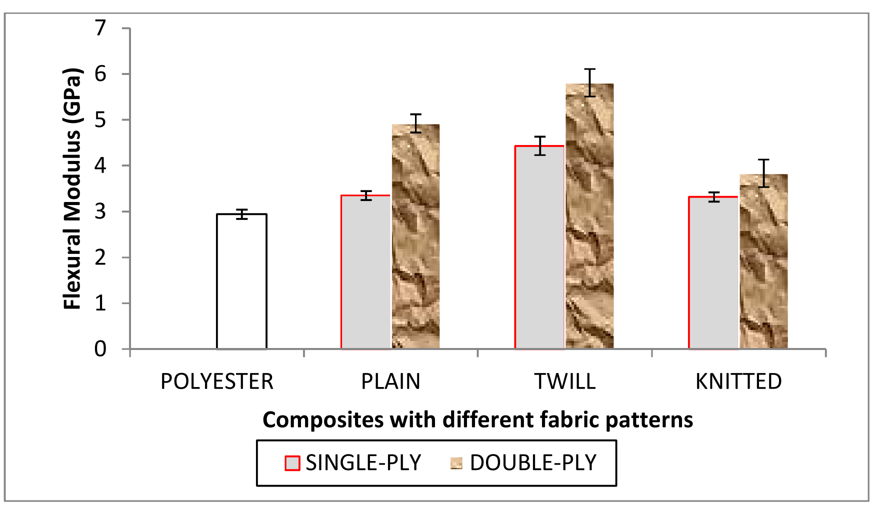


Fig. 7. Effect of fabric pattern on the flexural modulus of cotton fabric/UP composites

3.7 Morphology of Fractured Composites

The SEM micrograph of the tensile fractured surfaces of the twill and plain fabric composites are shown Fig. 10. Fibers pull-out occur mainly due to the poor interfacial bonding at the interphase of the fiber and matrix, but, It can be seen that fiber pull out is not visible because of the weave pattern which predominated. There is a sort of fibrillation of the fibers in the fabric cross-section and surface failure is contributed by matrix brittle fracture (cracking) and fiber fracture as indicated in both micrographs.

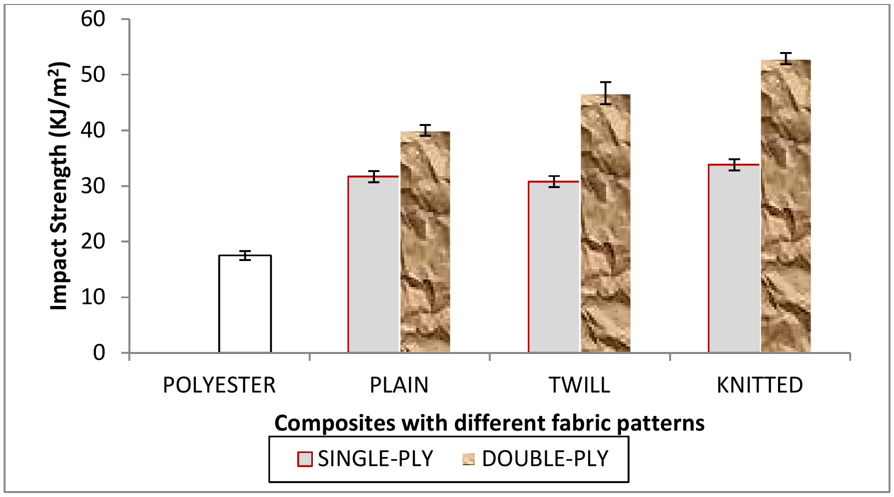


Fig. 8. Effect of fabric pattern on the impact strength of cotton fabric/UP composites

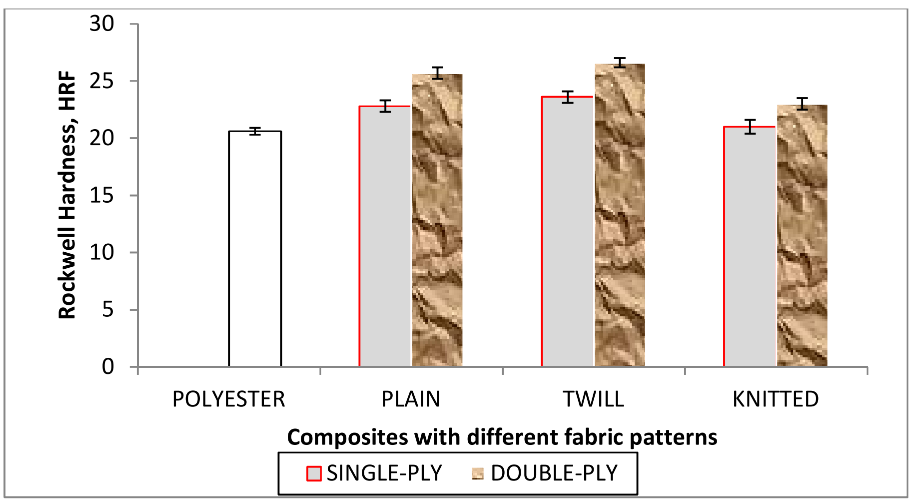


Fig. 9. Effects of fabric pattern on the hardness strength of cotton fabric/UP composites

Table 2. Fabric parameters

Fabric samples	Fabric thickness (mm)	*EPI	*PPI	Warp cover factor	Weft cover factor	Fabric cover factor (%)	Fabric weight (g/m^2)
Plain fabric	2.04	16	16	10.12	10.12	56.9	489
Twill fabric	2.35	31	21	19.61	13.28	81.6	492
		Stitch density					
Knitted fabric	2.35	12					490

**EPI = Ends Per Inch; *PPI = Picks Per Inch*

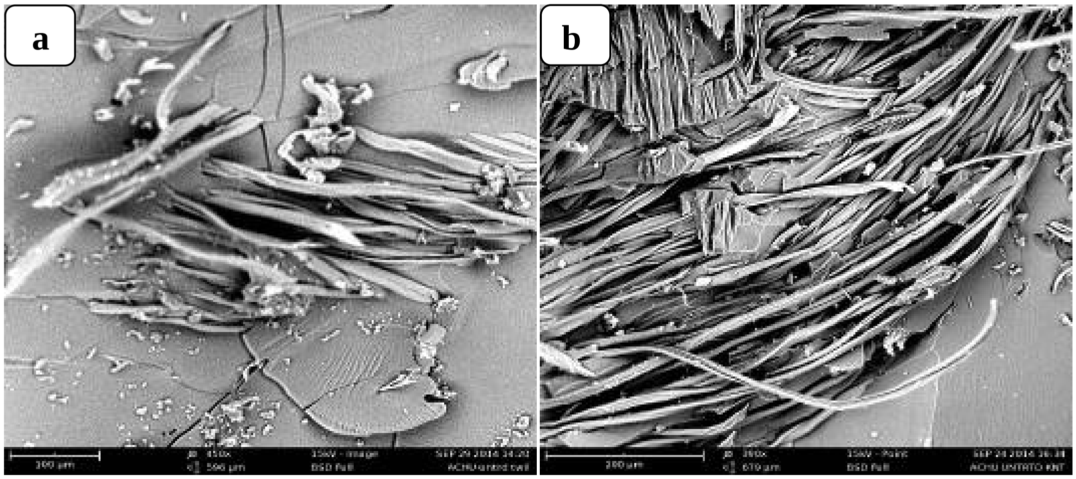


Fig. 10. SEM micrograph of the tensile fractured surfaces (a) Twill woven fabric (b) Plain woven fabric

4. CONCLUSION

It was established that the weave type has great influence on the tensile properties of woven fabrics as shown by the two woven patterns (plain and twill) and the weft knitted fabric. The tensile properties of the knitted fabrics are poor in comparison with the other types of fabric used for reinforcement, but they have good energy absorbing characteristics on the composites.

The resistance to bending was best for composites reinforced with twill fabric as they are stiffer than plain and knitted fabrics, both when singly and doubly reinforced. Improvement in hardness of the composites is not as significant as other mechanical properties tested.

The relationship between strength and fabric layers appears to be linear; increasing the number of fabric plies brings about a corresponding increase in the mechanical properties of the laminates.

The plying and fabrication of textile fabrics conferred significant reinforcement on the composites. This study thus, contributed significantly in resolving the problem of low mechanical properties and fiber pull out normally exhibited by cotton fiber composites. It has been demonstrated that cotton fabrics when made from plied yarn can function as reinforcement in textile composites.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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