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Mechanical Properties of Plied Cotton Fabric-Coated Unsaturated Polyester Composites: Effects of Alkali Treatments

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Abstract This paper presents an experimental investigation on the mechanical properties of cotton fabric/polyester composites. Plied yarns (4-plies) of known count were woven and knitted into fabrics of different architectures. The cotton fabrics were subjected to chemical modifications using sodium hydroxide and its influence on some mechanical properties were analyzed. The fabrics were coated with unsaturated polyester resin as matrix. The tensile and flexural properties, impact strength and hardness of the textile composites were studied. Result indicated that alkali treatment improved the tensile strength and breaking elongation of the fabrics. The mechanical properties were found to depend on the fabric architecture; plying and fabrication conferred significant reinforcement on the composites for the different mechanical properties tested, which is an indication that woven and knitted cotton fabrics can function as reinforcement in textile composites. Increase in number of fabric layers brought about a corresponding increase in mechanical properties. Morphological studies showed that composites with treated fabrics exhibited better interfacial bonding between the matrix and reinforcement compared to other combinations as evidenced by less cracking of the matrix before fracture.

Keywords Fabrics, Mechanical properties, Plied yarn, Surface treatment, Textile composites

1. Introduction

Finding replacements for synthetic fibers such as glass, carbon have been in the front burner over the years. The main impetus in pursuing the use of natural fiber reinforced polymer composites instead of synthetic fiber reinforced polymer composites is the ecological benefit due to the problem associated with their disposal [1]. Among the natural fibers, cotton could be regarded as one of the most popular fibers used in several applications varying from common fabrics to composites [2-5]. Others include the hybridization of cotton with other natural fibers [6-8]. Works on the coating of polyester resins with improved mechanical properties have also been reported [9]. Composite panels reinforced with cotton fibers to examine the mechanical properties of such panels for use in secondary structural members such as wall or door systems was developed by Raftoyiannis [10]. The results from the study showed that the structural performance of cotton fiber composites is satisfactory for structural parts with low requirements, such as wall panels or doors. Chaudhary and Gohil [11] also presented results from experimental work on Cotton Polyester Composite (CPC) made from polyester resin reinforced with cotton fibers. The results from their study revealed that the structural performance of cotton fiber composites was satisfactory and may be used for structural applications. Rajpar et al., [12] examined the effect of the cotton fiber on mechanical properties of lower structural applications when added with the polyester resin. Relative effect of the cotton as reinforcing agent was examined and they observed that developed composite specimen possessed significant improvement in mechanical properties; tensile strength was improved as 19.78% and modulus of elasticity was increased up to 24.81%.

A plied yarn (also known as ply or folded yarn) is composed of two or more single yarns twisted together. Two-ply yarn, for example is composed of two single strands of yarn and three-ply yarn is compose of three single strands. Plied yarns have been found to induce normal forces between fibers and this increasing inter-fiber friction leads to improved strength of the resultant plied yarn. Magdi et al. [13] 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.

In comparison to the various reinforcement forms, utilization of traditional high-performance reinforcements is preferred in fabric form rather than fiber and yarn [14]. This is because fabric is easier to handle and could maintain its

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dimensional stability during the composite fabrication in comparison with the other forms as they interconnect with each other [15]. Several works have been carried on the use of fabrics coated with different resins which include: Sisal fabric [16-17], Banana fabric [18-19], Jute fabrics [20-21], Hemp fabrics [22-23], date palm fabric [24], flax fabric [25].

The choice of unsaturated polyester matrix system is borne out of the fact that it is one of the most commonly used thermoset polymers [26].

It has been found that the change induced by the alkali treatment is the disruption of hydrogen bonding in the network structure, which increases surface roughness [27]. Moderate or short time alkali treatments have been reported to significantly improve the mechanical properties, impact, fatigue and dynamic behavior of fiber-reinforced composites [28]. Similar results were also obtained by a large number of authors, who used different types of vegetal fibers, sodium hydroxide concentrations and polymeric matrices [16, 29-30].

The aim of this work is to find a solution to the low mechanical properties usually recorded with fibers of natural origin and their use in composites. There are few reports on cotton-fabric coated thermosetting composites so far. Woven and knitted cotton fabrics made from thick plied yarns and their coating with unsaturated polyester resin, to the best of the author's knowledge, is limited.

2. Materials and Method

2.1. Materials

100% cotton yarns of 236 Tex (4ply) used for this study were made by Zaria Industries Limited, Zaria, Nigeria. The polyester resin used was supplied by NYCIL Nig. Ltd, Ikeja Lagos. Methyl Ethyl Ketone Peroxide (MEKP) was used as the catalyst.

2.2. Fabric Production

The plain and twill fabrics were woven at the Department of Industrial Design, Ahmadu Bello University 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 1. Some of the fabrics were soaked in a solution containing NaOH for 1 minute and were classified as "treated" fabrics.

2.3. Composite Preparation

The unsaturated polyester resin was mixed with the MEKP catalyst and naphthalene cobalt accelerator in the ratio 100:1:1 using hand-layup. The fiber volume fractions for the composites with coated 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 in a mold with dimensions 150mmx150mmx6mm.

2.4. Preparation and Cutting of Composite Specimens

The prepared composite samples (150mm x 150mm x 6mm) were then cut into different shapes in accordance with the standards for various ASTM tests using BOCSH motorized jigsaw (model: GST 85 PBE).

2.5. Mechanical Testing

2.5.1. Tensile Properties of Fabrics

Tensile test was carried out on treated and untreated fabric samples. An Instron "Model 1026" with 5000N load cell was used for these testing with a cross head speed of 250mm/min and in accordance with ASTM D5035 11 Standard method. The tests on the fabric samples were carried out in the machine direction. At the end of the tests, numerical and graphical plots of the data were obtained through the computer inter-faced with the instrument.

2.5.2. Mechanical Properties of Composites

Both 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 150mm in accordance with ASTM D3039 08. Flexural testing was also carried out in accordance with ASTM D790 08, at a crosshead speed of 5mm/min and a span length of 60 mm. The dimensions of the specimens in each case were 150mm x 20mm x 6mm.

2.5.3. Impact Properties

Charpy Impact test was performed in accordance to ASTM D256 10. Composites with different textile architectures were subjected to low velocity impact (25 Joules) test on an instrumented impact tester with semi-spherical impactor. The machine consists of a suspended pendulum hammer with a mass of 2.0 kg dropped at a velocity of 3.8 m/s.

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 60kg. According to ASTM D 785 08 standard for composites, the specimens were prepared for Rockwell-B hardness test with dimensions 6mm thickness, 25mm width and a length of 25mm.

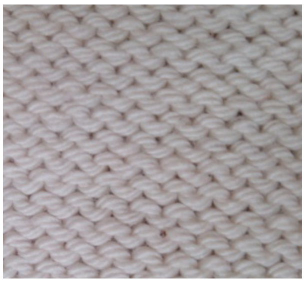
2.5.5. Scanning Electron Microscopy

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 15KV 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.

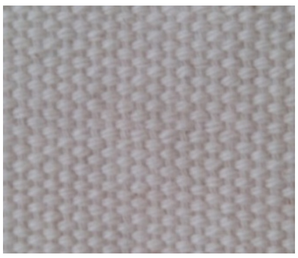
3. Results and Discussion

3.1. Fabric Production

Figure 1 shows samples of the yarn used for the weaving of the fabrics as well as the fabrics coated to form the composites. These comprise of weft knitted (a), plain woven fabric (b) and twill woven fabric (c).



(a) Weft Knitted



(b) Plain woven fabric

(c) Twill woven

20mm

Figure 1. Photographs of fabrics used for composite preparation

3.1.1. Yarn and Fabric Parameters

The parameters for the yarns and fabrics used for the purpose of this research work are shown in Table 1.

3.2. Tensile Properties of the Fabrics

It can be seen that the tensile strength of all the fabrics increased by 4 - 30% after being treated for 60 seconds with 20% NaOH as shown in Figure 2. Tensile strength was highest for the plain fabric (13.67MPa) than twill (13.14MPa) and knitted fabrics (4.55MPa) when untreated, a trend also reported by Nassif [31] whose work was on the mechanical properties of micro polyester woven fabrics and also by Malik et al., [32] 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 counts. The superior strength of plain fabric over twill fabrics is unexpected because of high crimp associated with plain fabrics which leads to lower mechanical properties as reported by Saiman et al., [33] whose research was on the effect of fabric weave on tensile strength of woven kenaf reinforced unsaturated polyester composite.

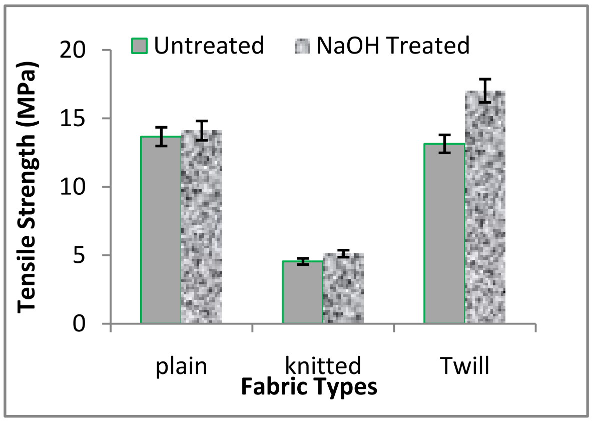


Figure 2. Effect of alkali on the tensile strength of the fabrics

Table 1. Yarn and Fabric Parameters

Yarn and Fabric Samples	Yarn strength (N/Tex)	Yarn count (Tex)	Fabric Thickness (mm)	EPI	PPI	Warp cover factor	Weft cover factor	Fabric cover Factor (%)
Yarn	0.16	236						
Plain fabric			2.04	16	16	10.12	10.12	56.9
Twill fabric			2.35	31	21	19.61	13.28	81.6
				Stitch	**density**			
Knitted fabric			2.35	12				

Similarly, Campbell [34] reported that the 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 Figure 2 that the difference in strength is not so significant and could have been as a result of the thickness of twill fabric. On treatment, twill fabric gave higher tensile strength than the plain fabric. The tensile strength of the fabrics was greatly improved when compared to the ones made from unplied yarns [35]. A Similar trend was reported by Das and Chakraborty [36], whose studies showed that mechanical properties of cellulose fibers increased with alkali treatment.

It can be seen that there is 31-57% improvement in the breaking elongation of the treated fabrics with respect to the untreated ones with the knitted fabric recording the highest elongation at break (Figure 3). Fiber shrinkage and increase in fabric density could be responsible for this increase. 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 effect of using different mercerization media on some mechanical properties of local plant bast fibers, Roselle (*Hibiscus sabdariffa*), kenaf (*Hibiscus cannabinus*), okra (*Hibiscus esculentus*), Baobab (*Adansonia digitata*) was studied by Modibbo *et al.,* [37] who mercerized with various concentrations of 10 - 25% of NaOH solutions. The result showed proportional increase in the breaking load with increase breaking elongation up to elastic point (1.5 mm).

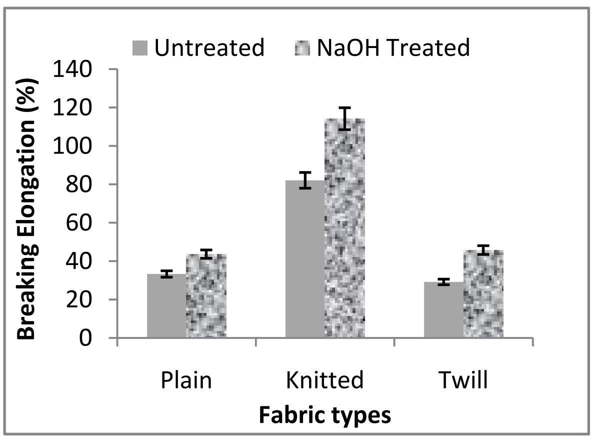


Figure 3. Effect of alkali on the breaking elongation of the fabrics

3.3. Tensile Properties of Composites

From the results of tensile test shown in Figure 4, it is indicated that the maximum tensile strength for the composites occurred with twill fabrics for both the untreated and treated fabric samples with the knitted fabric having the least strength. The fabrics increased the strength by 32-81% with respect to the unsaturated polyester matrix showing the positive role of the cotton fabrics in the composite samples. With NaOH treatment, the tensile strength increased by 40-119% (Figure 5). Pothan *et al.,* [17] 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. It can be said that the higher tensile strength of the composites with modified fabrics as compared to the untreated ones, may be due to the alkali which improves the adhesive characteristics of fabric surface by removing natural and artificial impurities thereby producing a rough surface topography [27]. This has increased the proportion of the effective surface area available for contact with the unsaturated polyester matrix polymer. Therefore, the composites were able to sustain higher loads before failure occurred compared to the neat unsaturated polyester matrix. Similar improvement in the tensile properties of alkali-treated natural fibers reinforced composites was reported by Yahaya et al., [38] who reported that treated woven kenaf improved tensile properties of composites.

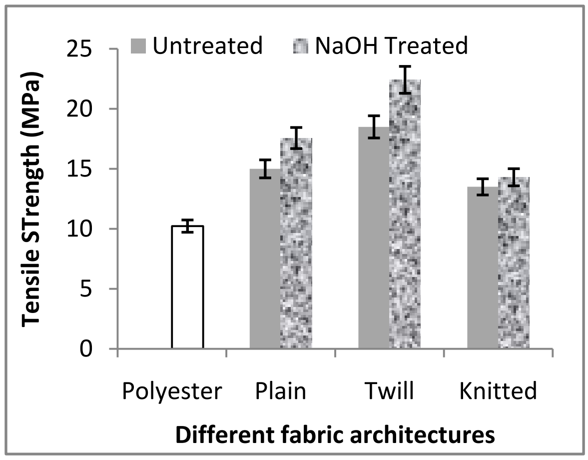


Figure 4. Effect of alkali on the tensile strength of cotton fabric/UP composites

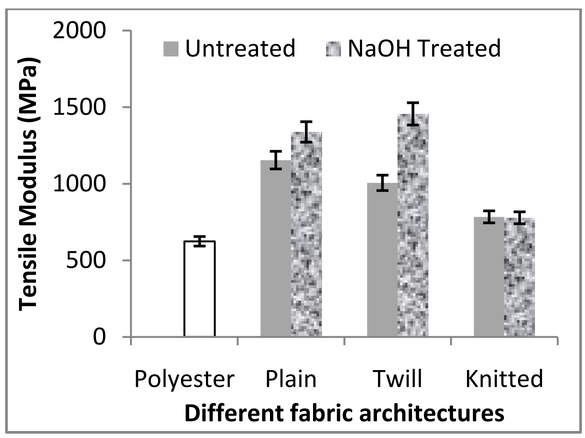


Figure 5. Effect of alkali on the tensile modulus of cotton fabric/UP composites

Generally, mechanical properties of the woven composites made from alkali-treated fabrics are superior to the untreated fabrics. This is in consonance with the experimental results obtained in this work.

The fabric also improved the modulus of elasticity for both the untreated and treated composite specimens with respect to the neat unsaturated polyester matrix (Figure 5). Composites with knitted fabrics gave the lowest tensile modulus both when treated and untreated.

3.4. Flexural Properties of Composites

The results show that coating cotton fabrics from plied yarn with polyester resin increased the flexural strength by 48 – 75% and the modulus by 13 – 51% with respect to the neat polyester composite. The alkali treated fabrics further improved the flexural strength and modulus by 93% and 65% respectively which can be considered to be high. Composites with twill and knitted fabrics recorded the highest and lowest strength and modulus respectively (Figures 6 and 7). This shows that cotton fabric-coated composite is stiffer and stronger than virgin unsaturated polyester.

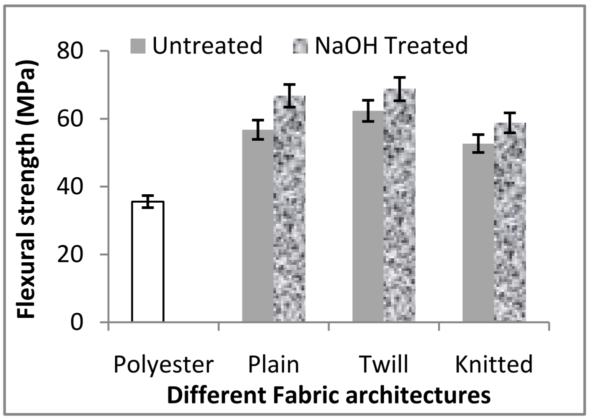


Figure 6. Effect of alkali on the flexural strength of Cotton fabric/UP composites

A similar finding on cellulosic fibers was reported by Boynard *et al.,* [39] who studied the flexural properties of Luffa fibers-reinforced polyester composite. They noticed that the flexural modulus increased by 14% after alkali treatment of the fibers.

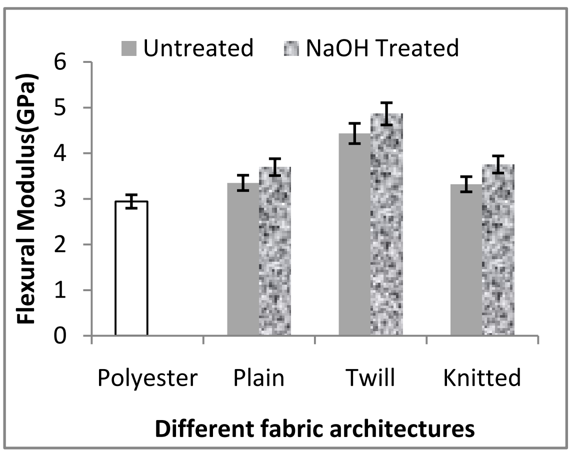


Figure 7. Effect of alkali on the flexural modulus of Cotton fabric/UP composites

Improvement in the flexural strength and modulus were also reported by Cao *et al.,* [28] who worked on the Mechanical Properties of Biodegradable Composites Reinforced with Bagasse Fiber before and after alkali treatments. They found that the flexural properties increased with alkali treatment and explained this enhancement in terms of the increase in fiber roughness and contact area.

3.5. Impact Properties

It was found that fabric architecture and alkali treatment are crucial factors in determining the response of composite materials to impacting force. The impact strength of the unsaturated polyester was improved by about 76-93% when coated with the untreated fabrics for the various architectures. The alkali treatment further improved the impact strength by 86-104% (Figure 8). Composites with knitted fabrics recorded the highest impact strength of 33.8kJ/m^2 and 35.8 kJ/m^2 for the untreated and treated samples respectively. The performance of knitted fabrics as compared to woven fabric is better and they showed better impact resistance due to higher isotropic behavior.

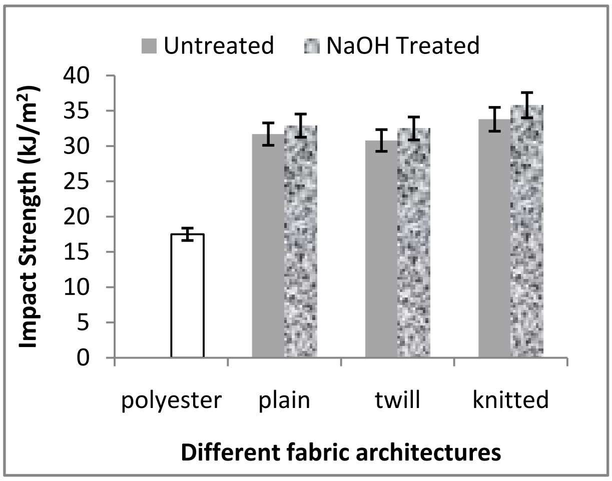


Figure 8. Effect of alkali on the Impact strength of Cotton fabric/UP composites

This occurrence can be attributed to the homogenous distribution of the fabrics in the matrix which resulted in a better ply nesting and close association of the knitted loops within the fabric layers, thus subduing the propagation of crack or delamination growth. Similar investigations by Bannister and Herszberg, [40] showed that higher percentage of impact energy in the range 0–10 Joules was absorbed by a weft-knitted glass reinforced composite (V_f = 50%) than was absorbed by an equivalent woven fabric. The findings also indicated that the damaged area was approximately six times larger for the knitted fabric than that of woven fabric, probably as a result of the increased crack initiation sites in the knitted architecture. Ruan and Chou, [41] compared woven fabric composites and knitted fabric composite and their findings showed that knitted composites exhibited better resistance to impact.

Based on the significant improvements in tensile strength (Figure 4), flexural strength (Figure 6) and impact strength (Figure 8) it could be inferred that cotton fibers can adequately serve as reinforcements in polyester matrix composites. The finding here is a significant one revealing that cotton fibers in the form of textile fabrics of different architecture can 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 [14] thus, limiting the potential of cotton fibers as reinforcing filler.

3.6. Hardness

The inclusion of the cotton fabrics improved the Rockwell hardness of the polyester resin by about 2 - 22% for both the treated and untreated composites with respect to the neat polyester matrix (20.6 HRF). Composites with twill fabrics improved the hardness of the composites better than other architectures (25.2 HRF) as shown in Figure 9. The hardness of the knitted fabric composite was the least with a value of 21 HRF. The alkali treatment showed a positive effect on hardness. The variation in the hardness is caused by the difference in hardness between resin and fabric materials.

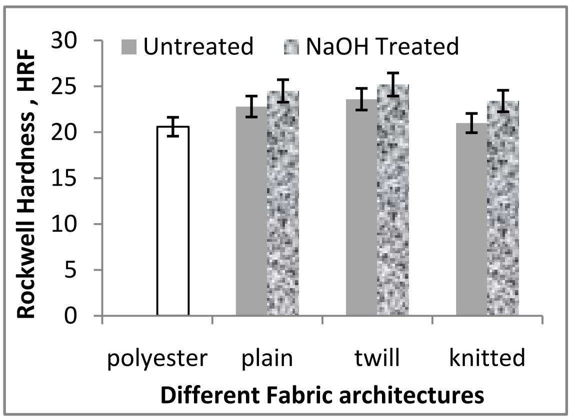


Figure 9. Effect of alkali on the hardness of Cotton fabric/UP composites

A similar trend was reported by Al-Mosawi [42] who 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, due to distribution of the test load on fibers which decreased the penetration of the test ball to the surface of composite material and by consequence raised the hardness of the material. Cotton has higher modulus than Unsaturated Polyester and higher rigidity and hence the composites are more rigid.

3.7. SEM Analysis of Fractured Surface

It can be observed from the Scanning Electron Micrograph of the fractured surfaces that matrix cracking occurred during the brittle failure (Figure 10a). Debonding and fiber pulled-out as the main fracture mode of composites was very visible (Figure 10b) thus, leading to voids. Composites coated twill fabrics showed more fiber pull out and voids than other fabrics. The composites with treated fabrics exhibited better interfacial bonding between the matrix and reinforcement (Figure 10b and 10c) compared to the untreated (Figure 10a) as evidenced by less cracking of the matrix before fracture.

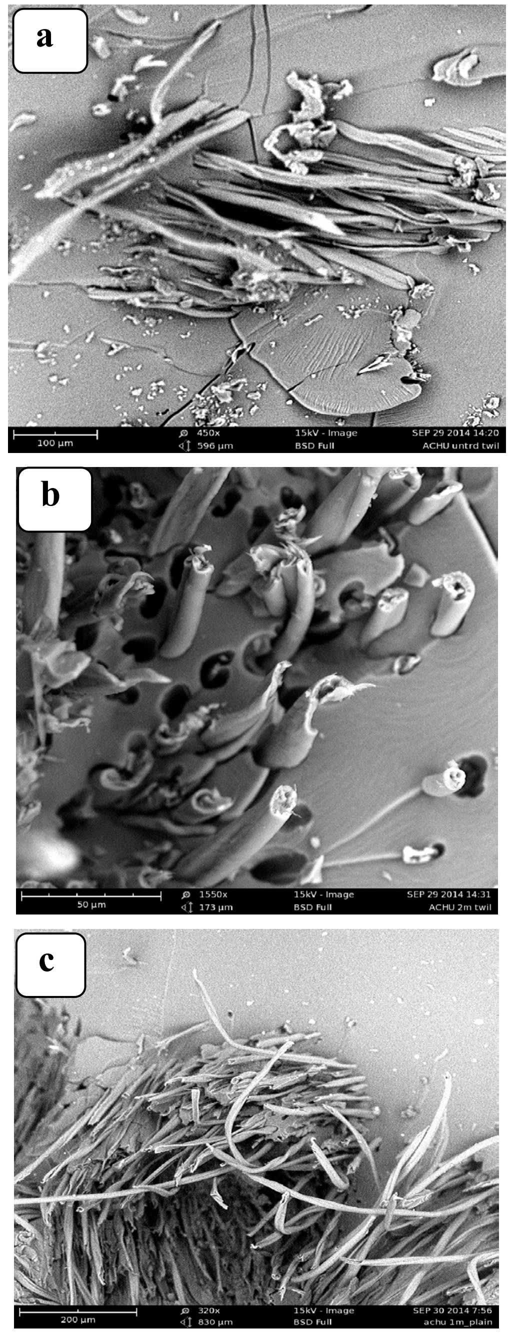


Figure 10. SEM micrograph of the fractures composites (a) with untreated twill woven fabric (b) with treated twill fabric (c) with treated plain fabric

4. Conclusions

This work reported on the successful fabrication of cotton fabric-coated unsaturated polyester composites using plied yarns and the study of the effect of alkali treatment. The following conclusions can be drawn:

The plied yarns used for the fabrics conferred significant reinforcement on the composites and has contributed significantly in resolving the problem of low mechanical properties and fiber pull out normally exhibited by cotton fiber composites. The study has demonstrated that woven and knitted cotton fabrics can function as reinforcement in textile composites.

Alkali treatment has been found to improve mechanical properties of cotton fabric coated textile composites for the different architectures.

The resistance to bending was best for composites coated with twill fabric as they are stiffer than plain and knitted fabrics, both when treated and untreated.

Fabric architecture is an important factor in determining the response of composite materials to deformation. Composites coated with knitted fabrics have better response to impacting forces than other fabrics with good energy absorbing characteristics. Improvement in hardness for the various composites coated with this fabric is minimal (about 15% with respect to the uncoated).

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