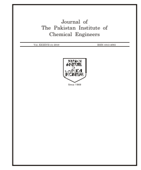
JPIChE 47 (1) 2019: 35-44

Journal of The Pakistan Institute of Chemical Engineers

journal homepage: www.piche.org.pk/journal



Effect of Fabric Modification and Clay Loading on Mechanical Properties of Reinforced Composites

K. Naseer[1], N. Ali[1], W. A. Khan[1], M. Ashraf[1] , I. Shamshad[1], K. Shahzad[2]*

Submitted: 18/04/2019, Accepted: 07/08/2019, Online: 19/08/2019

Abstract

Ethylene terephthalate fabric has been used to strengthen the unsaturated polyester resin. The macroscopic, microscopic and spectroscopic studies of the surface modified polyester fabric, bentonite and unsaturated polyester are comparatively investigated by tensile and flexural testing, scanning electron microscopy (SEM) and x-ray diffraction (XRD). Strong fabric and matrix adhesion is governed by surface modification of polyester fabric with alkali treatment. Compared with neat polyester resin, the tensile strength of chemically modified polyester fabric filled unsaturated polyester composites is 47% increase at 3 wt.% of clay and the flexural strength is increased up to 72%. In order to know the delamination tendency, composites broken in mechanical testing are analyzed by SEM. It indicates that delamination tendency, fiber pullout, fiber de-bonding and fiber bridging are reduced in the composites with modified fabric. XRD patterns show that lattice of 3D knitted fabric and MMT composite is body centered cubic.

***Keywords**: Fabric Composites, 3D Reinforcement, Scanning Electron Microscopy (sem), X-ray Diffraction, Processing Parameters*

1. Introduction:

3D fabric reinforced composites offer great potential in the engineering applications such as chemical processing equipment, sporting goods and in aircraft industry which require high stiffness, strength and fatigue resistance [1-3]. Three dimensional knitted fabric reinforced polymer composites are multi constituent materials, formed by reinforcing 3D knitted fabric in a polymer matrix. Three dimensional knitted fabric, apathetic towards the current technology are distinguished with their particular three dimensional geometry of the yarns in x, y and z direction [4-6].

Fabric composites are used because they have light weight, improved stiffness, corrosion resistance and strength. 2D laminated fabric yarn is aligned in two directions x and y. In these laminates no yarn is aligned in z direction. In these composites, the lack of z direction in reinforcing fibers have disadvantages as they have poor interfacial properties which cause delamination, higher cost and they have low mechanical properties [7-9]. Conventional two dimensional fabric reinforcements have disadvantages such as poor interfacial interaction, lamination and mechanical properties and also higher cost. To improve these problems, rubber toughening of resins, thermoplastic film, chemical treatment of fabric and the method of 100 plies of fabric individually aligned by hand were conventionally used [7, 10,

[1] *NFC Institute of Engineering & Fertilizer Research Faisalabad (IEFR) - Pakistan*

[2] *Institute of Chemical Engineering & Technology, University of the Punjab-Pakistan*

*** Corresponding author:** najafawan@hotmail.com

11]. These methods improve the 2D laminates but they have a number of drawbacks such as in most cases cost of these composite is greater than the enhanced properties [12, 13].

3D fabric laminates are developed to resolve problems associated with of 2D laminates. The work on fracture of knitted fabric composites showed that 2D knitted fabric composite in which the fibers were aligned into 0 to 90 degree showed the fracture occurred due to delamination while the composites which have a mat of chopped fiber in the knitted reinforcement restrain the delamination [14-16].

The developments of 3D knitted fabric composites and their modification during processing can increase mechanical properties and improve lamination, form complex shapes and reduce fabrication cost [2, 17, 18]. The pioneering work stated that 1% PET fibers in the epoxy can doubled the strength of the composite as compared to neat epoxy which is very impressive [19-21].

An alkali treatment is used to increase the matrix and fabric interaction. Enhanced reinforcement is attained with the strong fabric and compatibility of fabric with the matrix. Surface of the PET knitted fabric was modified with alkali treatment to enhance the fabric and unsaturated polyester interfacial compatibility.

The purpose of this research is to fabricate composites and to study their macroscopic, microscopic and spectroscopic characterization. Fracture behavior of these composites is also evaluated to understand the effect of alkali treatment on the de-lamination tendency.

2. Materials And Methods:

2.1 3D Knitted Fabric:

3D knitted fabric was collected from collected from Haining Jinlishi Warp Knitting Co., Ltd. It made up of 20tex polyester spun yarn. 3D knitted fabric is shown in Figure 1.

2.2 Unsaturated Polyester:

Unsaturated polyester was collected from hanghzhou huarn composite materials and Co Ltd. It was clear liquid (ortho - phathalic polyester) of 1.12 * 10^3 kg/m^3 density and viscosity 3.0 - 8.0 Pa.s at 25°C.

2.3 Bentonite:

It was collected from Bentonite performance minerals LLC houstan. It had 200 mesh count ±89, 10% moisture & 500 μm dia.

2.4 Modification of Fabric:

3D knitted fabric was treated with the 2% solution of NaOH at room temperature for 12 hours. Then, fabric was washed with distilled water and dried at room temperature for 24 hours.

2.5 Composite Manufacturing:

Unsaturated polyester resin was measured according to stoichiometric calculations using weight balance. Then, 1.5wt% Acid cobalt was added into the unsaturated polyester and stirrer at 200 rpm for 20 min. Mixing was done using magnetic stirrer and 3 wt%, 5 wt.% and 7wt.% of bentonite was added into the unsaturated polyester and accelerator blend. Stir at 200 rpm for 40 min for soaking of bentonite into the blend andproduce homogenous mixture. 2% MEKP was added and stirrer for 5 min and poured into the mold. Release gel was applied on mold surface to avoid sticking of polymer on mold surface. Solution of PVA was applied on mold surface which formed a thin plastic sheet and used to get a good surface finish of the part. Molds were prepared according to ASTM for tensile and Flexural testing. Table 1 shows the experimental conditions for preparing the samples of 3D knitted fabric.

Table 1: Experimental Conditions for preparing samples

	3D knitted fabric	Clay	Time
		wt%	Min
Polyester	-	-	40
	UNMODIFIED	3	10
		3	20
		3	30
		3	40
		5	10
		5	20
		5	30
		5	40
		7	10
		7	20
		7	30
		7	40
	MODIFIED	3	10
		3	20
		3	30
		3	40
		5	10
		5	20
		5	30
		5	40
		7	10
		7	20
		7	30
		7	40

2.6 Mechanical Testing:

For tensile and flexural tests were performed at NUST ISB on the universal testing machine (AG by Plus Series, Shimadzu Company developed in Japan).

Tensile test was performed in accordance with ASTM D638-10. Tensile test was performed on a dog bone shape samples. Universal Tensile Testing machine was operated at a crosshead speed of 5mm/min at room temperature. Composite dimensions were made according to ASTM standard. A uniaxial load was applied to the ends of the specimens.

Flexural test was performed according to ASTM D790-02. The composite samples were made according to the dimensions as mentioned in the standard. Universal Tensile Testing machine was operated at a crosshead speed of 1.41mm/min at room temperature.

2.7 SEM and XRD Observations:

Samples which are broken during mechanical testing were analyzed by SEM and XRD.

SEM JEOL JSM-6490A has the take-off-angle 35° andthe analytical working distance is 10mm. The microscope has a high resolution of 3.0nm and then the resolution power was changed from 1mm to 100um and also the magnification power was increased up to X10,000 at 10 um and X250 at 100 um.

XRD was conducted with a Siemens diffractometer using STOE powder diffraction system that used Cu K radiation (= 1.5406 Å) with a Scintillation counter detector. Measurements were performed at 20 kV and 5 mA. The data was recorded in the reflection mode in the range 2 using the STOE scan method, the step size was 0.04 degrees and the counting time was 0.5 seconds per step. Divergence slit was 0.5 fixed.

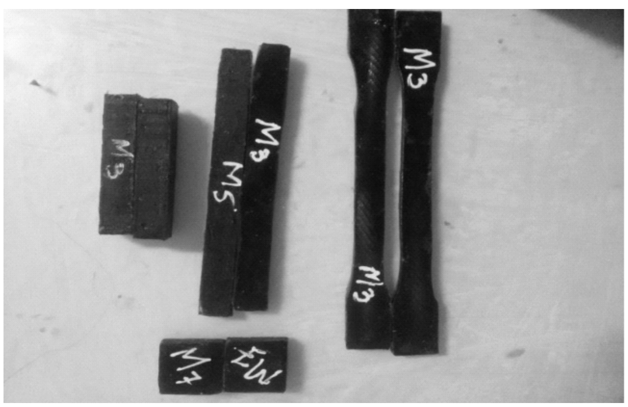


Figure 1: Samples of composite with modified fabric

Figure 2: Tensile testing after fracture

Figure 3: Flexural testing sample after fracture

3. Results And Discussions:

3.1 Mechanical Testing:

In Figure 4 (a) tensile strength of composites was increased with modification of fabric. Modified fibers showed improvement in the strength, this was attributed to the enhanced interfacial bonding between unsaturated polyester and fibers. It is clear from Figure 1, the tensile strength of composite declined with an increase in clay loading. This decline was recognized to the cluster formation which results in poor dispersion of clay. At lower clay loadings strength is higher due to better dispersion of MMT in the unsaturated polyester matrix.

As shown in Figure 4 (b) modified fabric has improved tensile modulus as compared to the unmodified fabric. Higher modulus is due to the increase in matrix and fabric interaction. Tensile modulus of composites was increased due to the brittle nature of composites brought by increase in bentonite percentages.

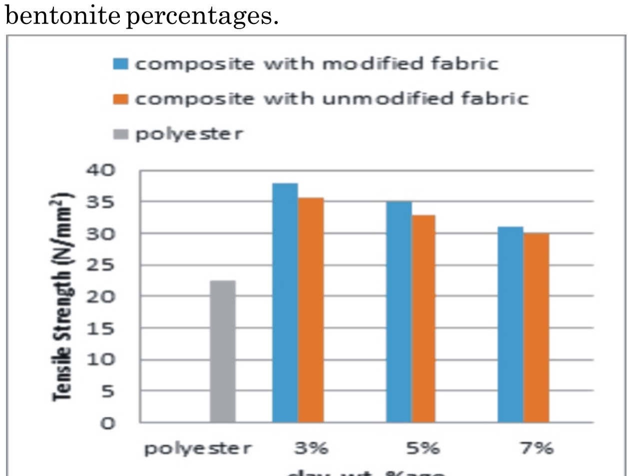


Figure 4(a)

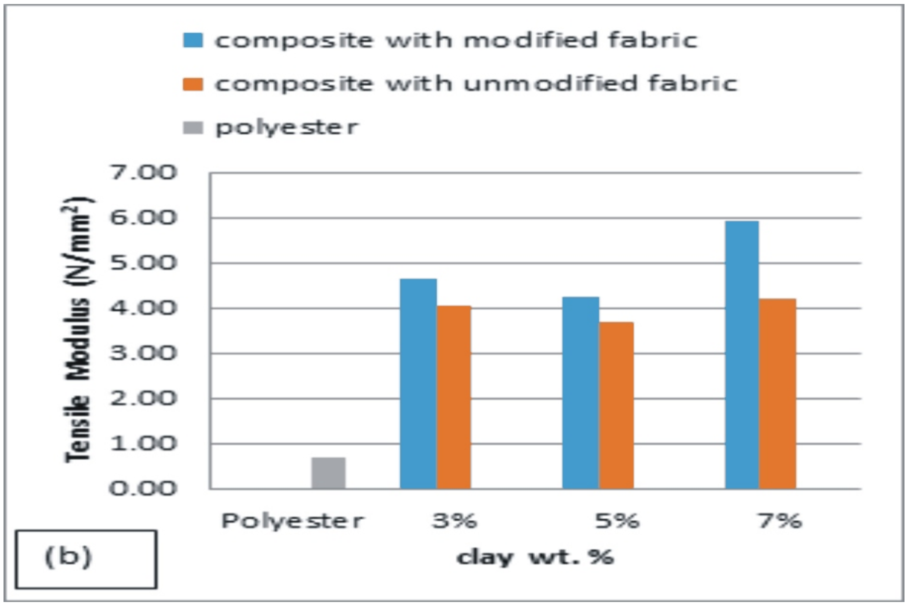
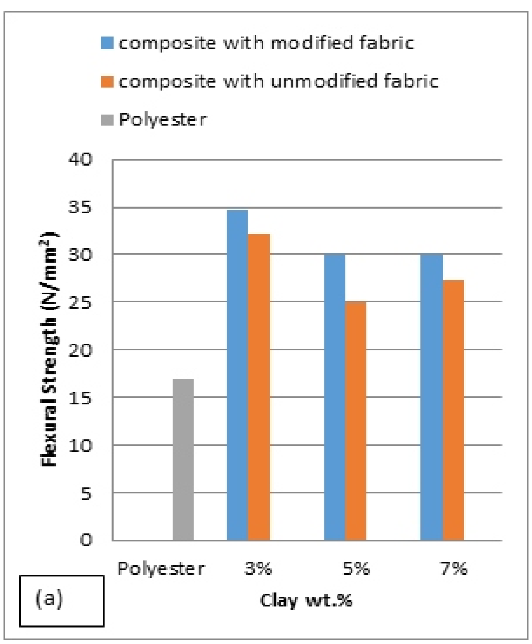


Figure 4: Effect of fabric modification and clay loading on (a) tensile strength and (b) tensile modulus of composite

3.2 Effect Of Modification And Clay Loading On Flexural Strength And Modulus:

From Figure 5, flexural strength of composites increased with modification of fabric. Modified fibers showed improvement in the strength due to the enhanced interfacial interaction between unsaturated polyester and modified fabric. Figure 4 showed the flexural modulus of composite showed an increase at 3 and 5 wt.% of clay attributed to reinforcement effect and modification. But at 7 wt.% clay, the flexural modulus decreased due to cluster formation and improper dispersion of clay in composite. The tensile modulus is also increased due to brittle nature of composite.



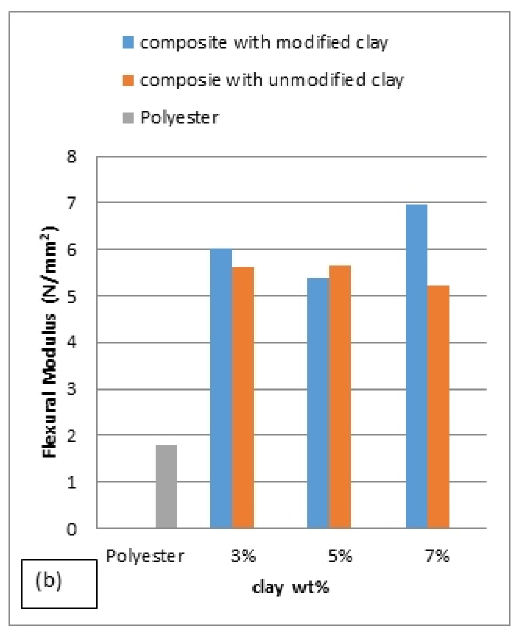


Figure 5: Effect of fabric modification and clay loading on (a) flexural strength and (b) flexural modulus of composite

3.3 Effect of Modification And Clay Loading On Stiffness of Composites:

From Figure 6, stiffness was remained almost same whereas the stiffness at 3 wt.% of clay of modified fabric was slightly higher due to more uniform dispersion of clay in the polymer matrix

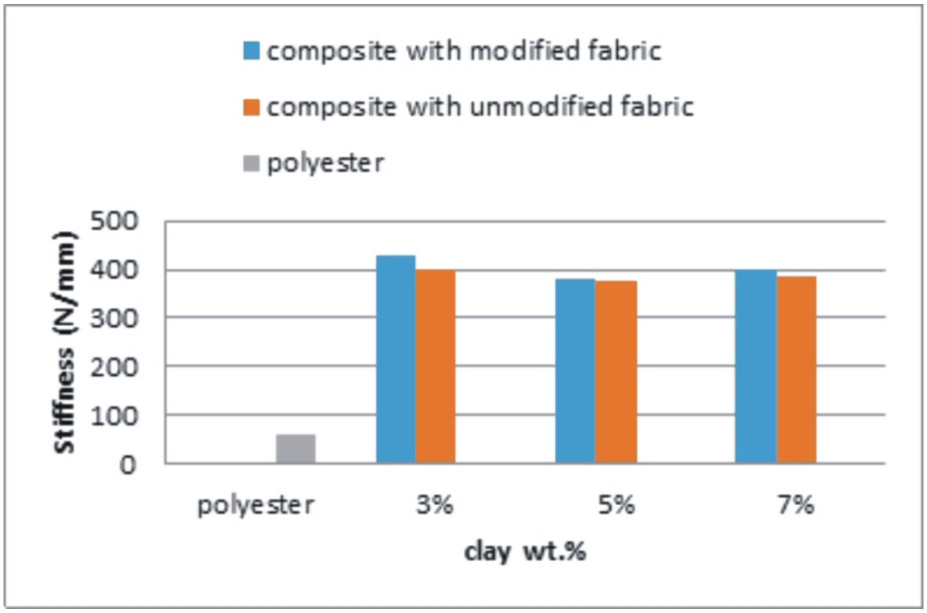
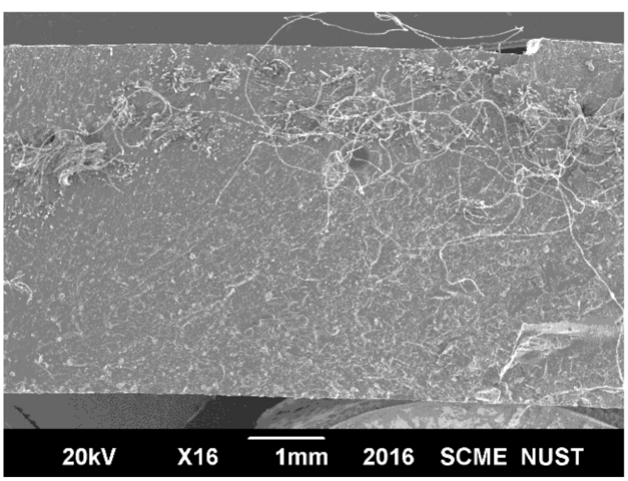


Figure 6: Effect of fabric modification and clay loading on stiffness of composite

3.4 Failure Analysis:

The failure analysis of the composites shown in Figures 7-10 revealed that the problems namely, debonding, fiber friction and fiber pullout.



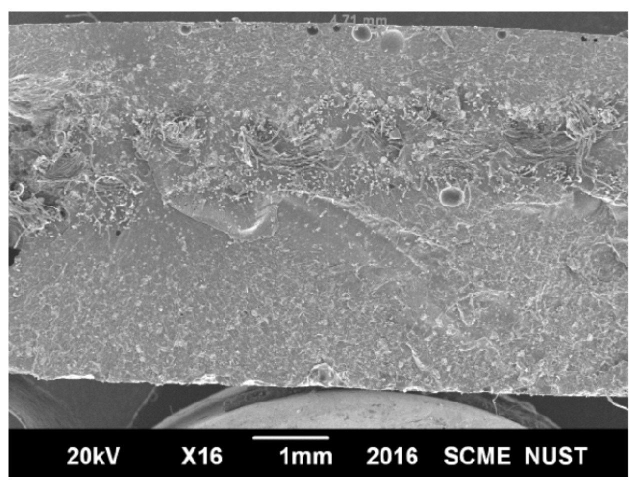


Figure 7: (a) composite with unmodified fabric (b) composite with modified fabric

It is evident from cross sectional SEM images, the composite with unmodified fabric showed excessive fibers pullout. Conversely, the fabric treatment resulted in a decrease in fiber pullout tendency. This decrease fiber pullout tendency in modified composite may be ascribed to enhanced surface roughness and reaction sites brought about by alkali treatment.

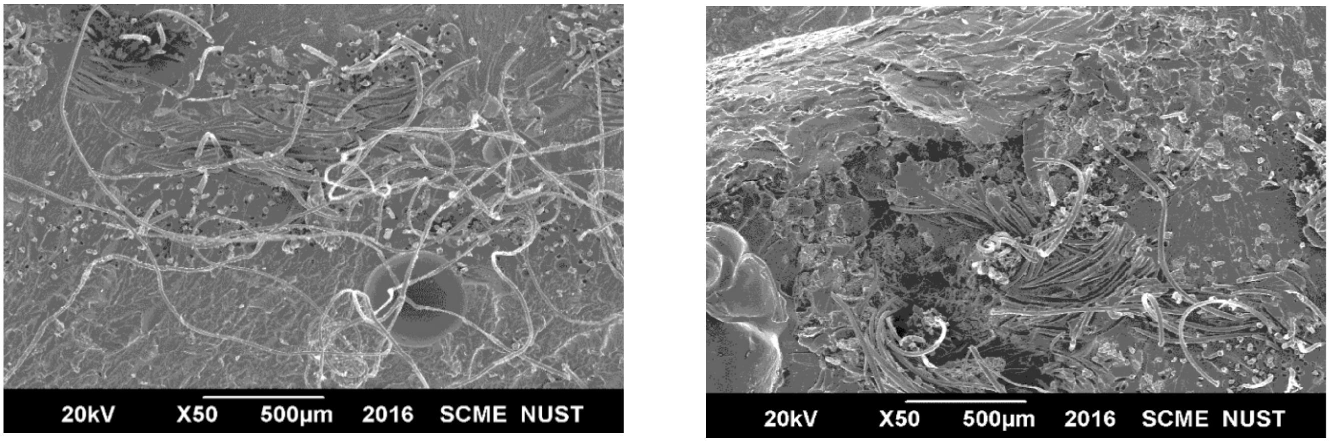


Figure 8: (a) composite with unmodified fabric (b) composite with modified fabric

The above cross sectional SEM images indicate that for composite with unmodified fabric the pullout fibers are long, clean and smooth due to absences of frictional effects. Treating the fabric with alkali enhances the frictional effects thereby, providing extra interaction site.

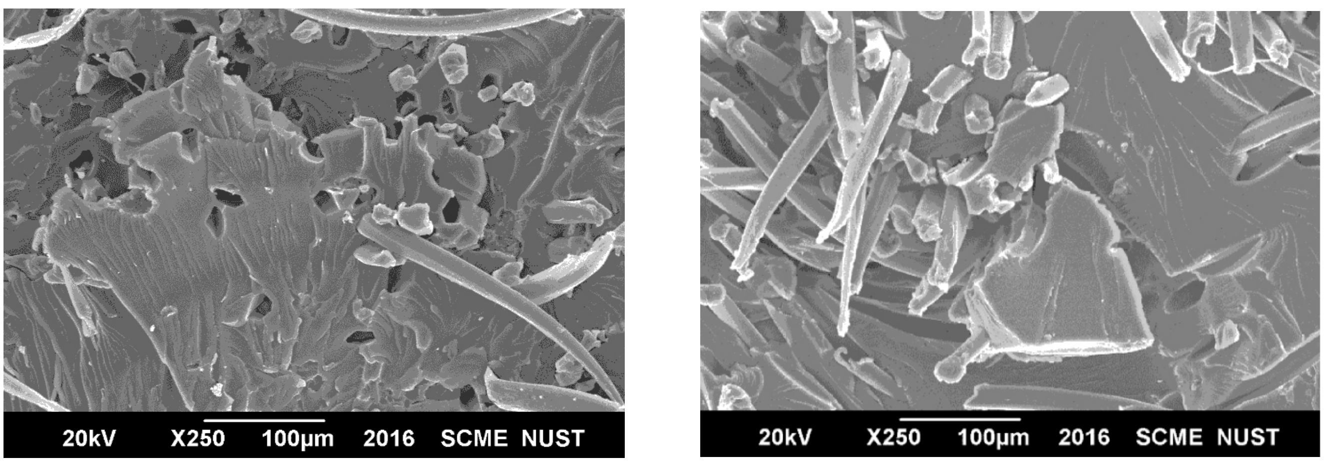


Figure 9: (a) composite with unmodified fabrics (b) composite with modified fibers

The above high resolution cross sectional SEM images indicates that the composite with modified fabric has a lower de-bonding tendency attributed to higher frictional effect and surface roughness.

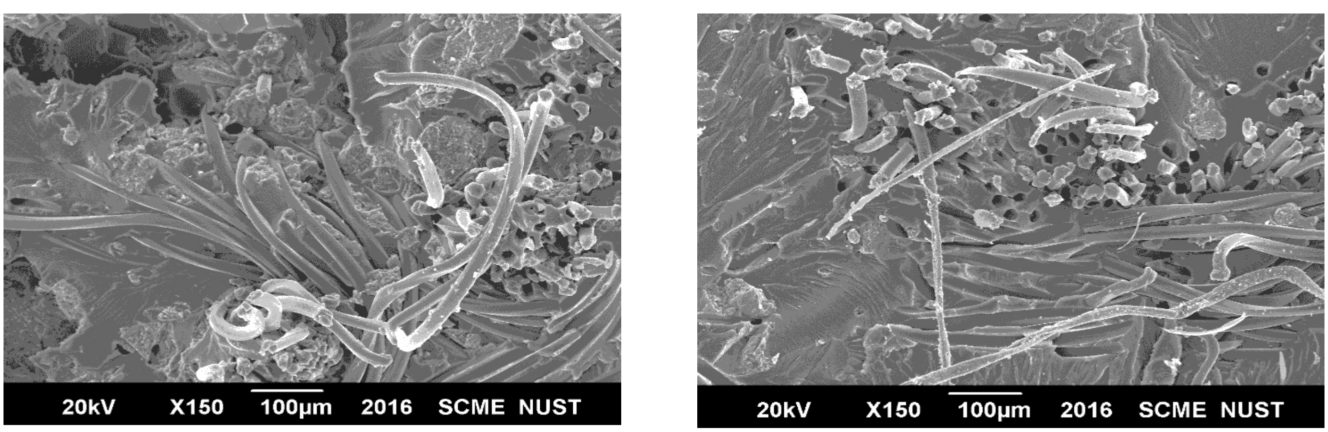


Figure 10: (a) composite with unmodified fabric (b) composite with modified fabric

The above images revealed that treating the fabric with alkali also increases the fiber bridging in the composite ultimately resulting in the higher strength composites.

3.5 Spectroscopic Characterization of Composite:

Figure 11 showed the XRD pattern of composite with unmodified fabric. It is evident from the spectrum of XRD that multiple peaks are present. According to Bragg's equation d-spacing value of some significant peaks [22] was calculated and shown in the Figure 11. This shows that structure of molecules changes in the material changes in the material. The lattice spacing of cubic system was calculated from the following relation:

$$a = d / ((h^2 + k^2 + l^2)) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$a = (\quad /d)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

where a is lattice spacing of cubic crystal and l is wave length of incident wave, h, k and l are Miller indices of Bragg plane. Values of h, l and k indicate that structure of molecules is Body centered cubic (BCC).

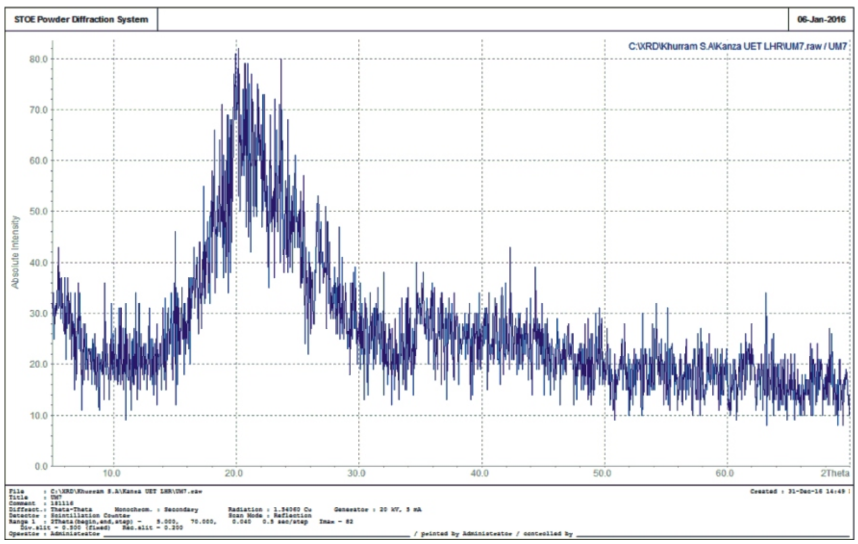


Figure 11: XRD pattern of Composite with unmodified fabric

Figure 8 showed the XRD pattern of composite with modified fabric. It is obvious from the spectrum of XRD that there is one significant peak. This is attributed to uniformity in the structure of the material. According to Bragg's equation d-spacing value of some significant peaks was calculated and shown in the Figure 12. The lattice spacing of cubic system (Figure 13) was calculated and According to Miller,crystal is also Body centered cubic (BCC).

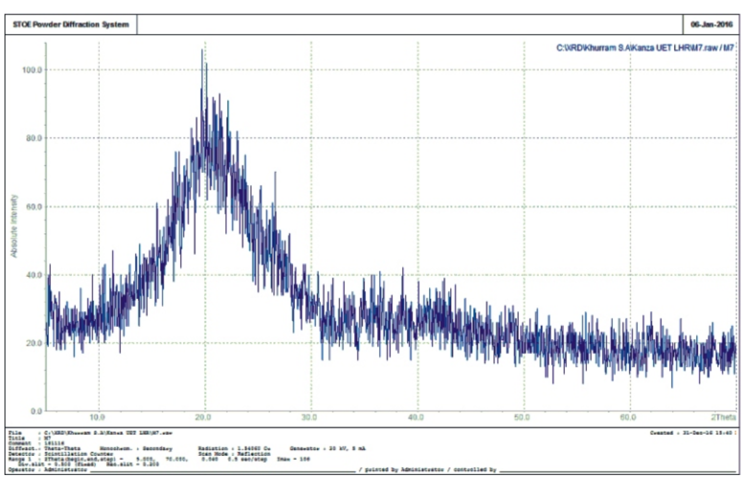


Figure 12: Composite with modified fabric

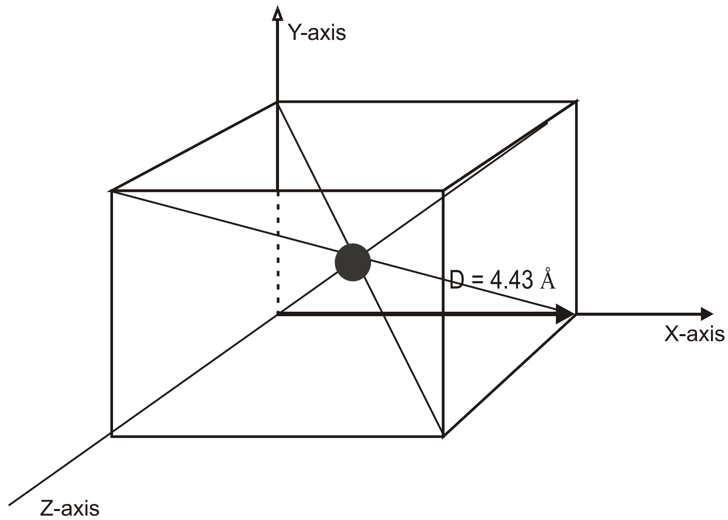


Figure 13: Lattice structure of manufactured 3D composite

Acknowledgment:

The authors are highly thankful to NFC Institute of Engineering & Fertilizer Research- Faisalabad - Pakistan for providing financial as well technical support for this research work.

References:

1. B. T. Astrom, manufacturing of polymer composites: crc press, 1997.
2. l. Tong, a. P. Mouritz, and m. K. Bannister, 3d fibre reinforced polymer composites: elsevier, 2002.
3. J. P. Jose and k. Joseph, "advances in polymer composites: macro and microcomposites "state of the art, new challenges, and opportunities," polymer composites: volume 1, pp. 1-16, 2012.
4. M. Rosso, "ceramic and metal matrix composites: routes and properties," journal of materials processing technology, vol. 175, pp. 364-375, 2006.
5. A. K. Kmetty, t. Ba any, and j. Karger-kocsis, "self-reinforced polymeric materials: a review," progress in polymer science, vol. 35, pp. 1288-1310, 2010.
6. D. Gay, composite materials: design and applications: crc press, 2014.
7. F. C. Campbell jr, manufacturing processes for advanced composites: elsevier, 2003.
8. S. Kumar and y. Wang, "fibers, fabrics, and fillers," composites engineering handbook(a 98-11526 01-24), new york, marcel dekker, inc.(materials engineering., vol. 11, pp. 51-100, 1997.
9. R. F. Gibson, principles of composite material mechanics: crc press, 2016.
10. S. Mazumdar, composites manufacturing: materials, product, and process engineering: crc press, 2001.
11. C. Lofaro, a. Abusafieh, w. E. Webb, and m. Doyle, "resin-soluble thermoplastic veil for composite materials," google patents, 2014.
12. C. Soutis, compressive behaviour of composites vol. 94: ismithers rapra publishing, 1997.
13. K. K. Chawla, composite materials: science and engineering: springer science & business media, 2012.
14. A. R. Torun, "advanced manufacturing technology for 3d profiled woven preforms," 2011.
15. K. Iwashita, "three-dimensional fabric and method for production thereof," google patents, 2006.
16. M. A. Masuelli, "introduction of fibre-reinforced polymersâˆ' polymers and

composites: concepts, properties and processes," in *fiber REINFORCED polymers-the technol*ogy applied for concrete repair: intechopen, 2013.

17. R. Kamiya, b. A. Cheeseman, p. Popper, and t.-w. Chou, "some recent advances in the fabrication and design of three-dimensional textile preforms: a review," composites science and technology, vol. 60, pp. 33-47, 2000.

18. K. Dransfield, c. Baillie, and y.-w. Mai, "improving the delamination resistance of cfrp by stitching "a review"," composites science and technology, vol. 50, pp. 305-317, 1994.

19. I. Srivastava, m. A. Rafiee, f. Yavari, j. Rafiee, and n. Koratkar, "epoxy nanocomposites: graphene a promising filler," graphite, graphene, and their polymer nanocomposites, p. 315, 2012.

20. C. Soutis, "fibre reinforced composites in aircraft construction," progress in aerospace sciences, vol. 41, pp. 143-151, 2005.

21. N. Roy, R. Sengupta, and a. K. Bhowmick, "modifications of carbon for polymer composites and nanocomposites," progress in polymer science, vol. 37, pp. 781-819, 2012.

22. l. B. Mccusker, r. B. Von dreele, d. E. Cox, d. Louã«r, and p. Scardi, "rietveld refinement guidelines," journal of applied crystallography, vol. 32, PP. 36-50, 1999.