

Investigation of Tension and Compression Behaviour of Polymer Matrix Composite with Jute Fibers as Reinforcement

Dr. Chandrashekhar Bendigeri¹, Jwalesh H.N.²

¹ Associate Professor, Department of Mechanical Engineering,

University Vishveshvaraiyah College of Engineering (UVCE), K.R.Circle, Bengaluru-560 001, India

E-mail Id:csb.login@gmail.com

² P.G. Student, Department of Mechanical Engineering,

UVCE, K.R.Circle, Bengaluru-560 001, India

E-mail Id:jwalesh.haasana@gmail.com

Abstract

The polymer matrix composites with natural fibers have been in use with various industries such as automotive, aerospace, construction and others for different applications. In pursuit to gaining popularity, a natural fiber reinforced polymer composite (NFRPC) with polyester as matrix and jute fabric as a reinforcement along with alumina as particulate material has been synthesized to investigate its mechanical properties. The study evaluates the effectiveness of natural fiber materials as reinforcement, as they are available in abundant, biodegradable and cost effective. The specimens are prepared using three laminates of size 310 x 310 x 4 mm, produced by hand layup process. Three specific compositions A, B and C with 18%, 22% and 26% by weight of jute fabric along with 8% of alumina and rest of the weight fraction constituted of polyester resin respectively were used to prepare the laminates. The water jet cutting process was employed to cut the specimens as per the ASTM standard dimensions from the laminates. There were 3 specimens for each of the compositions prepared. The specimens were subjected to mechanical characterization tests of tension and compression using Universal Testing Machine (UTM). The specimens with 26% weight percentage of jute fabric have exhibited excellent strength results in both tension and compression tests

Keywords: Natural fibers, NFRPC, ASTM, Laminate, Hand Layup, Water Jet Cutting, UTM.

1. Introduction

Composites are a amalgamation of two or more materials yielding properties superior to those of the individual ingredients. One material is in the form of a particulate or fiber, called the reinforcement or discrete phase. The other is a formable solid, called the matrix or continuous phase. The region where the reinforcement and matrix meet is called the interface. Composite properties are determined by chemical and mechanical interaction of the combined materials

In historical terms the composites have been in use over centuries. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500B.C.), Israelites using bricks made of clay and reinforced with straw and laminated metals in forging swords (A.D. 1800). In the 20th century, modern composites were invented in the 1930s with glass fibers as reinforcement with resins. Boats and aircraft were built out of these glass composites known as fiberglass.

2. Natural Fibers

Natural fibers have been used to reinforce materials for over 3000 years. More currently they have been employed in combination with polymers. Many types of natural fibres have been investigated for use in polymers including flax, hemp, jute, sisal and banana. Natural fibres have the advantage that they are renewable resources and have marketing appeal. These agricultural wastes can be used to prepare fibre reinforced polymer composites for commercial use. Application of composite materials to structures has presented the need for the engineering analysis the present work focuses on the fabrication of polymer matrix composites by using natural fibers like coir, banana and sisal which are abundant nature in desired shape by the help of various structures of patterns and calculating its material characteristics(flexural modulus,

flexural rigidity, hardness number,% gain of water) by conducting tests like flexural test, hardness test, water absorption test, impact test, density test, and their results are measured on sections of the material and make use of the natural fibre reinforced polymer composite material for automotive seat shell manufacturing. Present day natural fibers reinforced composites have other commercial applications in aerospace interiors, sound / noise control, house interior decorations and others.

3. Literature Survey

The literature survey outlines some of the recent reports published in various publications and journals related to Natural Fiber Based Polymer composites. In addition to NFRPC, review also performed on the literature of various natural fibers, their usefulness as a reinforcement material, mechanical and structural properties. PMC materials being used in various industrial, automotive, aerospace and other applications are also being discussed. The review will be categorised under the following headings to provide the insight of the study

- Review of natural fibers
- Compositions of PMC
- Mechanical property studies
- Study of Hybrid Composites

Natural fibers in simple definition are fibers that are not synthetic or manmade. They can be sourced from plants or animals. The use of natural fiber from both resources, renewable and non renewable such as oil palm, sisal, flax, and jute to produce composite materials, gained considerable attention in the last decades, so far. The plants, which produce cellulose fibers, can be classified into bast fibers (jute, flax, ramie, hemp, and kenaf), seed fibers (cotton, coir, and kapok), leaf fibers (sisal, pineapple, and abaca), grass and reed fibers (rice, corn, and wheat), and core fibers (hemp, kenaf, and jute) as well as all other kinds (wood and roots). Natural fibers are used in tandem to synthetic fibers such as E-glass and S-glass as they possess relatively low density, large availability, cost effectiveness, ease of manufacturing and processing [1].

Mohanty et al. [3] studied the influence of different surface modifications of jute on the performance of the biocomposites. More than a 40% improvement in the tensile strength occurred as a result of reinforcement with alkali treated jute. Jute fiber content also affected the biocomposite performance and about 30% by weight of jute showed optimum properties of the biocomposites. Modification to the fiber also improves resistance to moisture induced degradation of the interface and the composite properties [6]. In addition, factors like processing conditions/techniques have significant influence on the mechanical properties of fiber reinforced composites [7]. Mechanical properties of natural fibers, especially flax, hemp, jute and sisal, are very good and may compete with glass fiber in specific strength and modulus [8, 9].

A number of investigations have been conducted on several types of natural fibers such as kenaf, hemp, flax, bamboo, and jute to study the effect of these fibers on the mechanical properties of composite materials [10-13]. Schneider and Karmaker [14] developed composites using jute and kenaf fibre and polypropylene resins and they reported that jute fibre provides better mechanical properties than kenaf fibre.

Sudhir.A et al. [15] performed the research activity by preparing hybrid composite material using sisal/jute fibers of 0/40, 10/30, 20/20, 30/10, 40/0 weight fraction ratios while overall fiber weight fraction was fixed as 0.4 weight fraction. The tensile and flexural properties were carried out using hybrid composite samples. The results indicated that addition of sisal fiber in jute/epoxy composites up to 50% weight fraction results increasing the mechanical properties. The best results were observed in 20/20 ratio for tensile strength and bending strength equal to 39.93 and 88.55 MPa respectively.

4. Methodology- Specimens Preparation

The methodology adopted for preparation of experimental specimens of tension and compression is as follows.

- 1. Selection of materials:** The objective of the experiment is to synthesize a composite material with natural fibre and petroleum based synthetic matrix material along with particulate material to increase the bonding strength of the matrix. The materials chosen to synthesize the composite material are Polyester Resin as a matrix material Jute Fabric (Woven) as reinforcement material Aluminium Oxide (Al_2O_3) or alumina as particulate material
- 2. ASTM standards selection for the specimen types / preparation:** The ASTM standards referred for polymeric composites testing and procedural requirements are ASTM D3039 / D3039M – 14 for tension and ASTM D3410 / D3410M – 16 for compression test specimens. The specimen dimensions for the tension and compression test are as shown in following Figure 1(a) and (b). The dimensions are in mm and the drawings are not to scale.

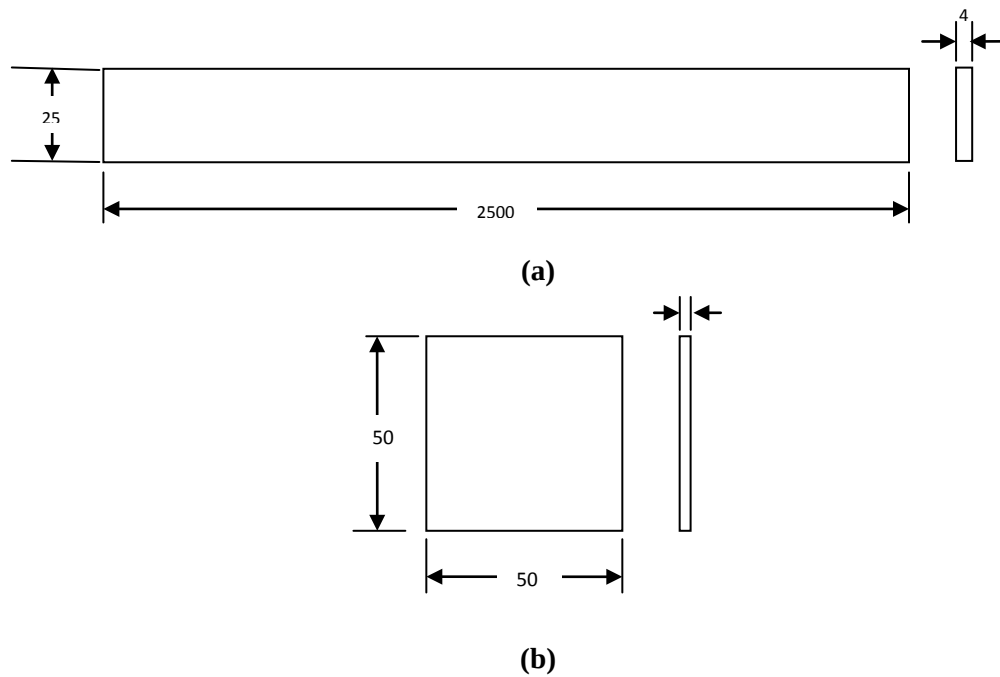


Figure 1: (a) and (b): Tension and Compression specimen dimensions.

3. **Selection of tools / mould to prepare the specimens:** The specimen's preparation process being adopted is to create a laminate structure measuring 310 *310 *4 mm. A surface plate with smooth, constant surface been adopted. On this surface, the laminate dimensions are marked and a double sided glue tape is pasted on the marking to form the boundary of the laminate. The model surface plate with laminate boundary is as shown in the Figure 2.

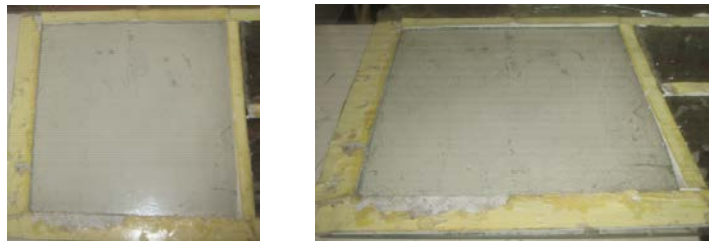


Figure 2: Surface plate with laminate boundary for laminate preparation

4. **Rule of mixture for materials composition:** ROM is an important parameter to identify the quantities / composition of the different materials to be added to form the composite. It also reflects the density of the composite material to be formed and provides better utilisation of the different materials. The following formula is used to calculate the density of composite material

$$\rho_c = V_m * \rho_m / V_c + V_r * \rho_r / V_c + V_p * \rho_p / V_c$$

ρ_c is density of laminate ; ρ_m, ρ_r and ρ_p is density of individual constituent materials of matrix, reinforcement and particulate respectively.

V_c is volume of laminate: V_m, V_r and V_c are volume fractions of individual materials of matrix, reinforcement and particulate respectively.

The materials weights percentage used for the preparation of laminate as per ROM is as shown in the Table 1

Table 1: Materials and Compositions for UTM tests

Sl. No.	Material	Composition A Wt. %	Composition B Wt. %	Composition C Wt. %
1	Polyester Resin	74	70	66
2	Jute Fabric	18	22	26
3	Aluminium Oxide (Al ₂ O ₃)	8	8	8

5. Laminate preparation method-Hand layup Process: Hand Layup process had been used to form the laminates of various compositions that are identified as shown in Table 1. The sample laminate structure prepared by the process is as shown in the following Figure 3.



Figure 3: PMC Laminate

6. Water Jet Cutting: The laminates prepared as shown in Figure 3 are cut to the dimensions as per the ASTM standards as shown in Figure 2 by Water Jet Cutting process. The cutting process enable to cut the specimens of accurate sizes at faster rate and without formation of dust as the entire process carried out in water medium. The following Figure 4 shows the water jet cutting process to get the specimens from the laminates.



Figure 4: Water Jet Cutting process



Figure 5: Tension and Compression specimens

5. Experimentation

Tension test: The test specimens as shown in Figure 5 are subjected to tension test. The test is carried out using UTM with controller and data acquisition systems. Three specimens each of all the noted compositions in the above Table 1 are

subjected to tensile test. The specimens were held in adjustable jaws which were locked once the controller has been switched on and placed in vertical direction. The acquisition system was set to initial loading details with thickness and gauge length of the specimen. The specimens are loaded until the breaking load. The respective readings of the Peak load and Breaking load of tests are recorded with the help of data acquisition system. The recorder also provides the details of the displacement, stress values along with the load applied on the specimens.

Compression test: The compression test specimens as shown in Figure 5 are subjected to test in UTM. The specimens are placed in between the fixed and movable platforms with relative fixtures of the UTM. The movable platform is moved downwards till the specimen gets tightened between the platforms with the help of controller. Once the specimen positioned in the UTM, the compressive load is applied on the specimen by moving the movable platforms downwards. The specimen starts to compress up to a specific load value and later it ceases to take load. The specific load values of the test are captured through the data acquisition system and are listed for each of the specimen tested of the three compositions.

The following Figure 6(a) and (b) represents the tension and compression tests carried out on the specimens shown in Figure 5.

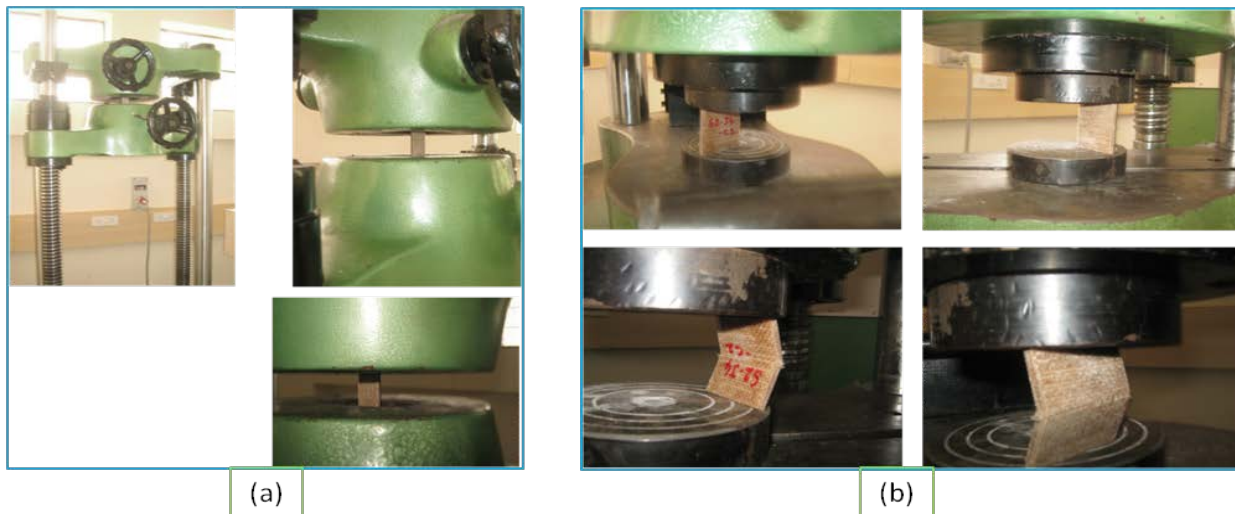


Figure 6(a) & (b): Tension and Compression tests with UTM

6. Results and Discussions

Tension Test: The results of the tension test conducted on the specimens are tabulated in the following Table 2. The test was carried out on three specimens of compositions A, B and C as listed in Table 1. The results shown in the table are the average results of each composition. The weight fraction of jute fabric is taken as reference to indicate the comparative results of the experiments.

Table 2: Tension test results

Sl. No.	Jute Weight Fraction (%)	Peak Load P_{max} (MPa)	Disp.at P_{max} (mm)	Breaking Load (MPa)	Max. Disp. (mm)	Ultimate Stress (MPa/Sq.mm)	Yield Stress (MPa/Sq.mm)	% Elong. (mm)
1	18	7610	4.9	4420	5.6	76	62	3.31
2	22	8340	4.56	4480	4.9	83	47	2.88
3	26	9480	4.2	4740	4.3	82	47	2.52

Disp. – Displacement, Elong. – Elongation

The following analyses are noted as per the result obtained for the tension test of the PMC specimens.

- The peak loads i.e. tensile loads recorded were 7610, 8340, 9480 MPa for 18%, 22% and 26% of jute weight fraction respectively. The result indicates that, there is an increase in tensile load with the increase of weight fraction of reinforcement material.
- The displacements recorded for maximum tensile load i.e. P_{max} are 4.9, 4.56 and 4.2 for volume fractions of 18%, 22% and 36% weight of jute fabric. In this way there is a reduction in displacement as the increase in volume fraction.
- The average breaking loads experienced for the volume fractions of 18%, 22% and 26% weight of Jute fabric are 4420, 4480 and 4740 MPa respectively. The results indicate that there was an increasing trend of breaking load with increased weight fractions of jute.
- The Ultimate stresses experienced with the weight fractions of 18%, 22% and 26% weight of Jute fabric are 76, 83 and 82 MPa respectively. The results show that there was a decrease of stress with the increased weight fraction of 26%.
- The Yield stresses of 62, 47 and 47 MPa were experienced for the weight fractions of 18%, 22% and 26% of weight fractions of jute fabric. The stabilizing stresses at increased weight fractions indicate that the weight fractions increment may not provide resistance to yield stress.
- The percentage elongations of specimens under tensile loading were 3.31, 2.88 and 2.52 for the weight fractions of 18%, 22% and 26% Jute fabric respectively. The resultant shows that there was a decreased percentage of elongation with the increased percentage of weight fractions.

The following Figures 7(a) to (f) indicates the results of tension in graphical approach. The trends indicate the material behaviour in various weight fraction of jute fabric.

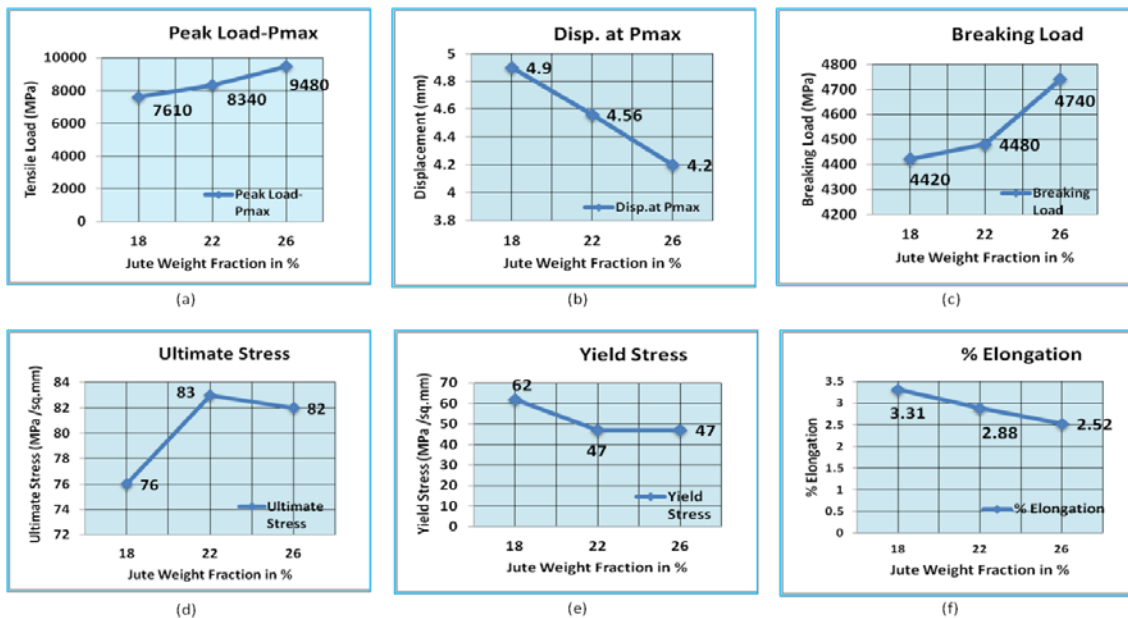


Figure 7(a) to (f): Tension test results

Compression Test: The test provides the material's ability to withstand the applied compressive load and the other mechanical behaviour under the testing with UTM. The below Table 3 shows the average resultants of the compression test performed on the three specimens each of the compositions A,B and C as shown in the Figure 5. The weight fraction of jute fabric is taken as reference to indicate the comparative results of the experiments.

Table 3: Compression test results

Sl. No.	Jute Weight Fraction %	Peak Load P_{max} (MPa)	Displacement @ P_{max} (mm)	Breaking Load (MPa)	Max. Disp. (mm)	Ult. Stress (MPa/sq.mm)
1	18	7180	1.0	4560	3.1	37
2	22	7510	0.6	4590	2.53	39
3	26	13730	2.1	11860	2.66	57

Based on the results the following analyses are derived and listed to showcase the compression strength and other properties of the PMC specimens.

- The maximum compressive load i.e. P_{max} observed for weight fractions of 18%, 22% and 26% Jute fabric were 7180, 7510 and 13730 MPa respectively.
- The breaking load observed for weight fractions of 18%, 22% and 26% of Jute were 4560, 4590 and 11860 MPa respectively. The increased compressive load and breaking load over the wt % of jute is due to the presence jute reinforcement in matrix which makes the composite to be rigid and stiff, thus need higher load to compress between the end fittings.
- There was suitable displacement of specimens w.r.t. to loads under compression and of increasing trend in both the Peak and Breaking load conditions. The relative displacements with respect to weight fractions in both the cases are represented through graphs in Figure 8 (b) and 8 (d).
- The ultimate stress values are of increasing trend due to the incremental loads on each test specimen. The average values for each weight fraction of 18%, 22% and 26% Jute fabric are 37, 39 and 57 MPa /sq.mm respectively. The graphical representation shown in Figure 6.2 (e) denotes ultimate stresses versus weight fractions.
- The maximum compressive load was noted with weight fraction of 26% of weight fraction of Jute at 13730 MPa and minimum load of 7180 MPa at weight fraction of 18% of Jute. The compressive load at 26% of Jute fabric was more, as the specimens become more stiff and to withstand higher loads at initial level i.e. P_{max} and at yield point, known as breaking load. The loads observed were found almost the double than the weight fraction of 22% of Jute weight fraction.

The following Figures (a) to (e) represent the compression test results of the composition A, B and C.

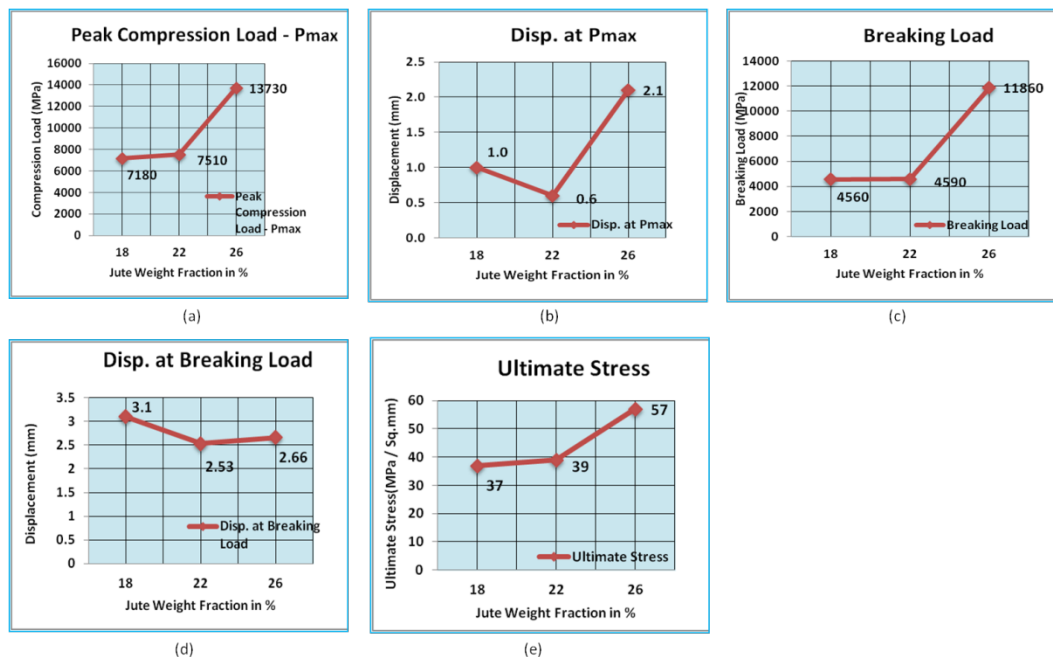


Figure 8 (a) to (e): Compression test results

7. Conclusions

The work presented in this paper evaluated the PMC with jute fabric as the reinforcement for its tension and compression behaviors at different weight fractions of jute. As per the experimentation results the following conclusions have been noted with respect to tension and compression properties of PMC.

- The specimens have sustained higher loads during tension tests with the increased percentage of reinforcement. This implies that the material can be utilized for the purposes where there will be probability of sustaining or withstanding tension loads. For 26% weight fraction of jute; UTS is 9480 MPa, Ultimate stress is 82 MPa / Sq.mm.

2. The higher loads during tension tests does not prompted the specimen for reduced displacement and this nature obviously helpful for the materials being used in any structure with less displacement or minimal movements. Displacement at UTS for 26% jute weight fraction recorded is 4.2 mm.
3. On the contrary, the material does not sustain yield stress with increasing reinforcement material and do become brittle at higher reinforcement percentages .
4. The compressive strength of the specimens has increased at Peak Loads and Breaking Loads. The increased reinforcement percentage of jute fabric also resulted in increased ultimate stress values and the material being noted to be stiff at higher load values. The ultimate compressive load and breaking load recorded are 13730 MPa & 11860 MPa respectively for 26% weight fraction of jute in the PMC.

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