

Mechanical Performance of Cementitious Composites Reinforced with Pultruded Jute/Polymeric Matrix Fabric

Messiry ME*, Tarfawy SE and Deeb RE

Faculty of Engineering, Textile Engineering Department, Alexandria University, Egypt

Abstract

Substantial progress on developing fiber reinforced cement-based composites has been made recently. Fiber Cement Sheets (FCS) are particularly suitable for the use behind tiling in wet areas, considerable use as backer boards for counter tops, wet area internal lining boards. The present work investigates the pultrusion of a jute fabrics reinforced by Polymeric matrix material (Concrete 1315 M) which has excellent resistance to most aqueous substances and liquids, including sea water, brackish water, effluent and raw sewage, acids of low concentration, alkalis, oils (mineral and organic), thus protects the jute fabrics improving durability of fiber cement sheets (FCS). Enhance the adhesion between the natural fibers and cementation composite results in the improving of composite's strength and toughness as well as the flexure strength and bending stiffness. In this study, the influence of a fabric treatment of the textiles to reinforce cement materials as well as fabric structure and the resin properties has been investigated. For the hybrid jute fabric reinforced cementitious composites, the integrated performance, mechanical properties, particularly bending stiffness and cracking response, were evidently influenced by the fabric structure and the resin properties. The mechanical properties were evaluated by performing 4-points bending as well as tensile tests. Pultrusion jute reinforced Polymeric matrix material increases the tensile strength, Modulus of elasticity, and the Modulus of rigidity and reduces the breaking elongation. Flexural strength of fiber cement sheets (FCS) has been significantly improved using pultrusion of the Jute/Polymeric Matrix Fabric. It is observed that bonding between cement and jute fabric after pultrusion is excellent and no sign of delamination is noted. These changes in the fabric properties made it more suitable to be used in the production of the cementitious thin sheets.

Keywords: Jute; Fiber cement sheets; Jute/Polymeric matrix fabric; Pultrusion

Introduction

Natural fibers have come into the use after centuries, which have been used to reinforce materials for over 3,000 years [1]. It has been around a decade that natural fibers have started to be used again. Now they are being highly recommended because of being naturally derived from plants and due to their characteristics of being lightweight compared to glass and carbon fibers [2]. These reinforcements are reusable, good insulator of heat and sound, degradable and have a low cost. It is being used widely for building purposes, in cars etc. The most important of the natural fibers used in composite materials are flax, hemp, jute, kenaf and sisal, due to their properties and availability; they are similar in the morphologies [3,4]. These fibers are composed mainly of cellulose and some lignin and often are called ligno-cellulosic fibers. Generally five main reasons are mentioned which make the application of natural fibers attractive: (1) their specific properties, (2) their price, (3) their eco-friendly advantages, (4) good mechanical properties and low density, and (5) their recyclability [5-7].

Enhancing the adhesion between the natural fibers and matrices material results in the improving composite's strength and toughness made it potential for the reinforced composites. The characteristics of such composites permit the material to be tailored to any desired shape while meeting the performance, durability, cost requirements, lightweight; having high strength and stiffness to weight ratios; and providing good chemical, fatigue and corrosion resistances. These outstanding properties made composites to be the leading material in today's engineering applications [8].

The mechanical properties of a natural fiber-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length and orientation, in addition to the fiber-matrix interfacial bond strength [9-17]. A strong fiber-matrix interface bond is critical

for high mechanical properties of the composites. A good interfacial bond is required for effective stress transfer from the matrix to the fiber whereby maximum utilization of the fiber strength in the composite is achieved. Modification to the fiber also improves resistance to moisture induced degradation of the interface and the composite properties. In addition, factors like processing conditions/techniques have significant influence on the mechanical properties of fiber reinforced composites.

Jute textile reinforced polymer composite system was developed and its tensile, flexural behavior was characterized and compared with that of carbon textile (CFRP) and glass textile (GFRP) reinforced polymer composite [10].

Jute is abundantly available in many developing nations and is a suitable low-cost, strong and durable building material [11]. Jute fibers, as a natural reinforcing agent, are about seven times lighter than steel with reasonably high tensile strength values (in the range of 250–300 MPa). Although many studies have been conducted to study the mechanical properties of cement composites reinforced with jute fiber, they have still not been put into much use practically. The inclusion of jute fiber has proved to be instrumental in increasing physical characteristics and mechanical strengths of cement composites. Test studies showed a huge amount of increase in tensile, flexural, and impact strength.

***Corresponding author:** Messiry ME, Faculty of Engineering, Textile Engineering Department, Alexandria University, Egypt, Tel: 035921675; E-mail: mmessiry@yahoo.com

Received May 19, 2015; Accepted May 25, 2015; Published June 08, 2015

Citation: Messiry ME, Tarfawy SE, Deeb RE (2015) Mechanical Performance of Cementitious Composites Reinforced with Pultruded Jute/Polymeric Matrix Fabric. J Material Sci Eng 4: 173. doi:10.4172/2169-0022.1000173

Copyright: © 2015 Messiry ME, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

In performance, due to interlacing of yarns in textile, the inter-laminar/through-the thickness/ impact properties of composite are improved; matrix cracks, originated inside the yarns, do not propagate through the material, but are stopped when the yarn changes its direction [12]. The latter mechanism leads to higher energy absorption capabilities in crash resistant applications. Traditional reinforced concrete is a typical composite that consists of a brittle matrix (concrete) and ductile fibers (steel bars) [13]. However, the weakness of concrete such as shrinkage during coagulation and hardening, low tensile strength, lacking crack resistance, high brittleness, and small ultimate extension lead to wide cracks which is considered as a main reason for a great loss of durability in service life for ordinary reinforced concrete structures. Many attempts have been focused on resolving this problem. Textile-reinforced mortar (TRM) may be considered as an alternative to FRP, providing solutions to many of the problems associated with the performance of strengthened members [14]. The study concludes that woven jute FRP is a suitable material which can be used for flexural up gradation of reinforced concrete beams [15]. The application of woven jute FRP sheets showed a better performance in increasing the ultimate flexural strength capacity. Jute as a natural fiber is used as a reinforcing agent to improve the physical and mechanical properties of cement mortar [16]. It was concluded that though the toughness index as well as the post cracking resistance energies are substantially improved with the increase in polymer strength, the flexural modulus is found to decrease as compared to control mortar specimen. Pultrusion is a process, much simpler than other processes like filament winding or resin transfer molding, to obtain large composite structures, using low cost facilities, tools and materials [17]. In particular, in the pultrusion process continuous fibers are pulled through a resin bath within a heated die. Inside the die, the resin cures and solidifies in a laminate with the same cross-sectional profile of the die. A puller continuously draws fibers through the die, and a travelling cut-off saw cuts the profiles to the desired lengths. The result is a thick material where different layers (roving, continuous filament mats, woven fabrics) are combined to obtain the required properties.

The main goal of this study is to investigate the effect of pultrusion of jute fabrics reinforced by Polymeric material, which is surface treatment of the textiles fabric to introduce new mesh, to be used as preform for textile-reinforced mortar (TRM). For the hybrid jute fabric reinforced cementitious composites, the integrated performance, mechanical properties, particularly bending stiffness and cracking response, were investigated.

Material and Methods

The cementitious composites consisting of pultruded jute fabrics of different specifications using a Polymeric matrix material with altered properties were used for reinforced cementitious samples.

Material

Jute fabric specifications: Table 1 gives the specifications of the jute fabric samples used.

Matrix material: Polymeric matrix material (Concresive 1315 M) is used owing to its low viscosity that will allow deep penetration into very narrow spaces between the fibers and cavities, superior adhesion to dry surfaces and excellent resistance to most aqueous substances and liquids, such as sea water, acids of low concentration, alkalis and oils (mineral and organic). It has low water absorption as 0.34%, strength 0.018 GPA, and flexural strength 0.055 GPA.

Cement: Portland cement, type “Ordinary”, CIM.I (42.5 N) produced by Alex. Portland Cement Company is used with all specimens.

Composite manufacturing

In this study, manufacturing of the hybrid jute/polymer fabric reinforced cementitious composites were carried through using the pultrusion of a jute fabrics reinforced by Polymeric matrix material (Concresive 1315 M). Different fabric designs were fabricated as given in Table 2. This method could guarantee a better bond between the

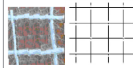

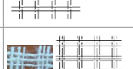
Fabric code	Design	Fabric weight g/m ²	Weft count tex	Warp count tex	Fabric thickness (mm)	Ends /cm	Picks/cm	Fabric tensile strength (N)	Elongation to fracture (%)
1/1		64	300	300	0.38	1	1	68	14.64
2/2		110	2	2	0.38	2	2	129	17
3/3		180	2	2	0.38	3	3	170.6	18.37

Table 1: Fabric specifications.

Sample number	Fabric code	Epoxy component blending ratio	Fabric weight gm/m ²	Percentage of fabric in the sample(α1) %	Percentage of polymer in the sample(α2)%	Percentage of cement in the sample(α3)%
1	1/1	1:0.6	623.22	0.640	5.094	94.266
2	2/2	1:0.6	726.88	1.100	5.587	93.313
3	3/3	1:0.6	838.67	1.800	5.916	92.284
4	1/1	1:0.8	762.876	0.640	6.378	92.982
5	2/2	1:0.8	850.87	1.100	6.728	92.172
6	3/3	1:0.8	953.14	1.800	6.969	91.231
7	1/1	1:1	506.667	0.640	4.021	95.339
8	2/2	1:1	657.53	1.100	4.949	93.951
9	3/3	1:1	776	1.800	5.339	92.861

Table 2: Composite samples specifications.

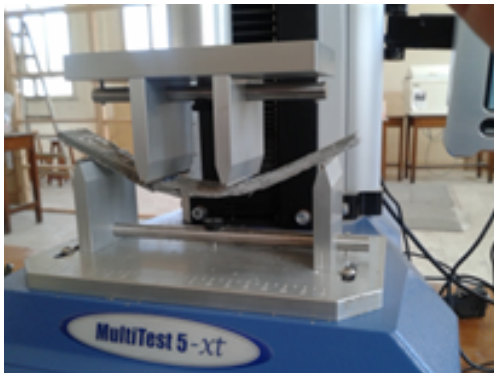
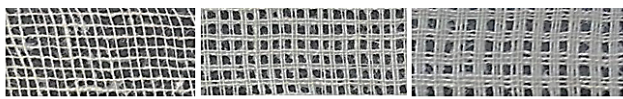


Figure 1: Flexural Strength Tester.



(a) 1x1 (b) 2x2 (c) 3x3

Figure 2: Pultruded Jute Samples.

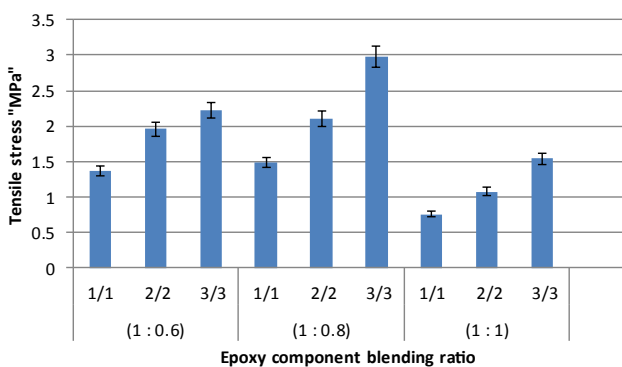


Figure 3: Tensile strength of jute cement composite with different polymer hardener ratio

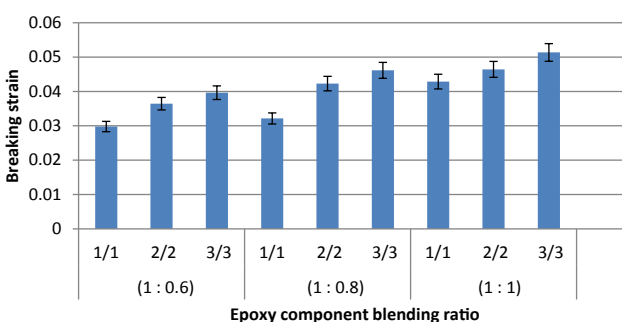


Figure 4: Breaking strain of jute cement composite with different polymer hardener ratio

fibers and the cement matrix as well as to protect the jute fabric preform from being affected by the exposed moisture.

Testing methods

All the composite samples were tensile strength and 4-point bending tested according to ASTM.

Tensile strength

The tensile test, a uniaxial load was applied through both ends of the specimen was performed on the Mecmesin (MultiTest 5 – xt) testing machine, with load capacity 5 KN and loading rate was 1 mm/minute according to ASTM D3039. Sample dimensions were overall length of 200 mm, width of 25 mm, and thickness 5 mm. Young's modulus (E) was calculated from the stress strain curve.

Four point flexure test: The four point flexure test, as shown in Figure 1, was performed on the Mecmesin (MultiTest 5 – xt) testing machine with load capacity 5 KN and displacement speed of 1 mm/minute, according to ASTM C348-80. Specimens had an overall length of 200 mm, a width of 25 mm, and average thickness 5 mm. Readings of the bending force in Newton and deflection were recorded. Four samples were tested and average results have been reported.

Calculations

i. Flexural Strength is calculated by the formula:

$$\sigma = 3Fa / (bd^2)$$

in 4-point test of rectangular specimen

Where;

L – Specimen length; F – total force applied to the specimen by two loading pins; b – specimen width; d – specimen thickness; a - distance between the supporting and loading pins.

ii. Bending stiffness is calculated by the formula:

$$K = F/w$$

Where;

F – Total force applied to the specimen by two loading pins; w – maximum deflection.

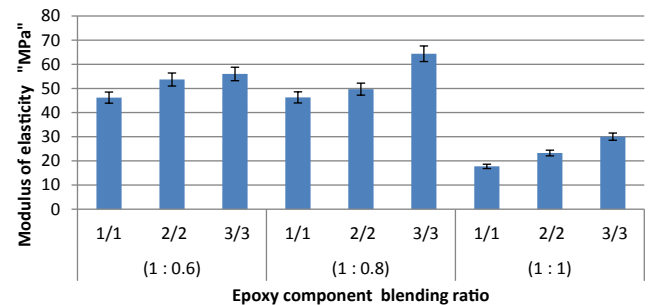


Figure 5: Modulus of elasticity of jute cement composite with different polymer hardener ratio



(a) 1:0.6 (b) 1:0.8 (c) 1:1

Polymer to hardener blending ratio

Figure 6: Mechanism of failure of the jute cement beam under tensile load.

Test specimen preparation

For testing the mechanical properties of the composite, all the specimens were fabricated by using hand lay-up method and the curing of the samples was done in standard atmosphere for one week.

The specimens were prepared in two steps;

Firstly: the preparation of the fabric preform using pultrusion method, in which the jute fabric was pultruded through the resin material (Concresive 1315 M) applying different ratios of base to hardener (1: 0.6, 1: 0.8 and 1: 1) of the polymer. Figure 2 shows the pultruded samples.

Secondly: the preparation of the final samples by fabricating the reinforcement in the middle of the cement samples, for tensile strength and flexure testing with average weight 50 grams, and in specimen dimensions 200×25×5 mm.

Results and Discussions

Tensile strength

Figures 3-5 show comparison of the tensile stress, tensile strain and the modulus of elasticity of the different samples. It can be noticed that for all chemical components ratio, tensile strength, breaking strain and modulus of elasticity depend on polymer hardener ratio, increasing the hardener ratio results in less strength, higher breaking strain, and lower modulus of elasticity.

The use of different preform structure leads to change of the mechanical properties too. From the analysis of the results it can be concluded that the samples of 3/3 design have the higher mechanical properties when using polymer with hardener ratio (1:0.8). This may be due to the fact that the size of the spaces between the yarns bundles gives the possibility for the cement to penetrate and to form micro

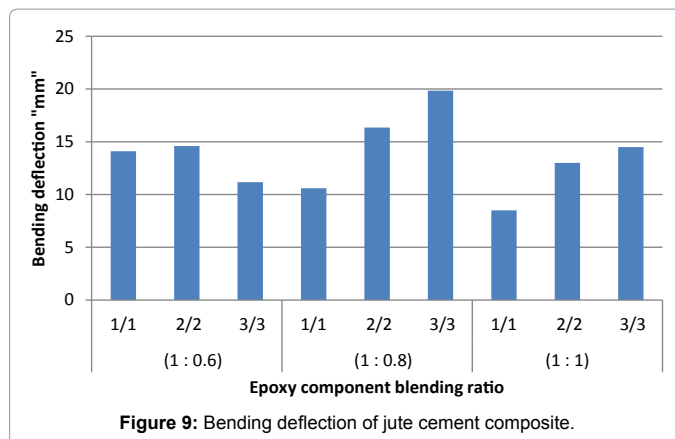


Figure 9: Bending deflection of jute cement composite.

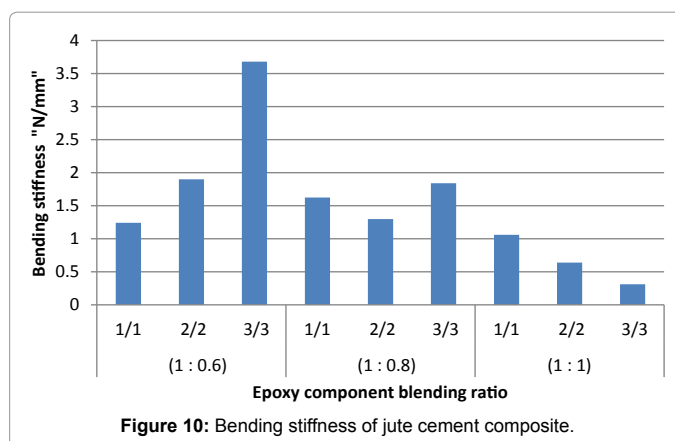


Figure 10: Bending stiffness of jute cement composite.

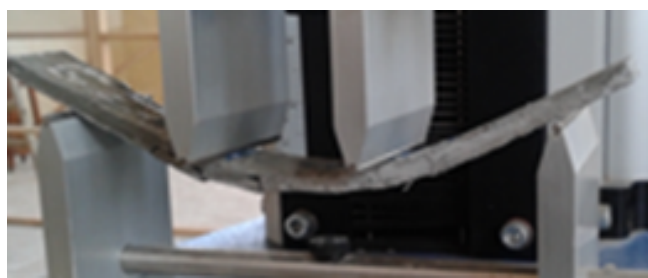


Figure 7: Four points bending of jute cement composite.

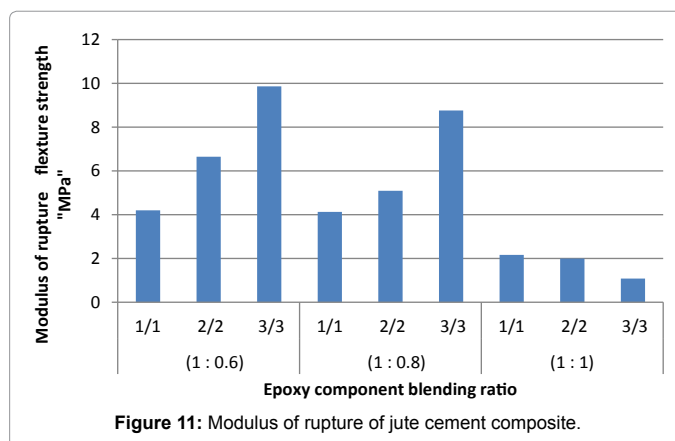


Figure 11: Modulus of rupture of jute cement composite.

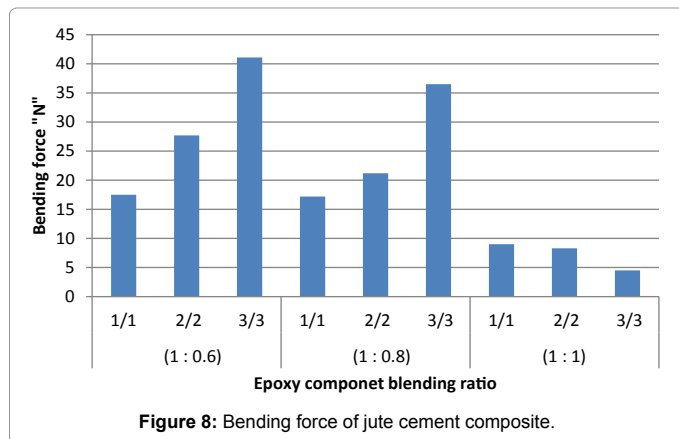


Figure 8: Bending force of jute cement composite.

piles which will increase the utility of fabric/polymer strength and thus increase the breaking strain. Figure 6 shows the failure of the samples with different polymer with hardener ratio.

Four point bending

Figure 7 shows the deformation of pultruded jute cement composite during the 4 point bending test which indicates the improvement of the bending stiffness due to the presence of pultruded jute fabric.

Figures 8-11 display the results of the different samples testing. It can be noticed that for all chemical components ratio, bending force, bending deflection and bending stiffness, depends on polymer hardener ratio, increasing the hardener ratio results in less bending

force, lower bending deflection and lower flexural strength. Moreover, the fabric design has significant effect on the bending properties. Figure 12 demonstrates the profile of samples under bending while Figure 13 illustrates the failure cases of pultruded jute cement composite.

Failure mechanisms

The pultruded jute fabric cement composite introduced a new mechanism of failure in the cement sheet than jute fabric cement composite [18]. Figure 14 illustrates the change of the tensile force of the different component of the composite versus the polymer hardener ratio. The use of different preform design leads to change of the mechanical properties too. The cement was passed through the unit cell between the warp and the weft so it was permitted to produce one solid sheet. The mesh reinforcement with good adhesion prevented the delamination phenomena to take place. Figure 15 shows how the pultruded jute fabric is embedded with the cement and no delamination was noticed. The second difference in the mechanism of failure is that the pultruded jute fabric will be strengthened by the penetration of the polymer inside the yarns, thus increasing the fabric strength, as shown in Figure 16, while reducing the breaking strain.

From the analysis of the results it can be concluded that the samples of 3/3 design have the higher mechanical properties when using polymer with hardener ratio (1:0.8). The percentage of pultruded jute ($\alpha_1 + \alpha_2$) in the composite will play a decisive rule to determine the tensile strength



Figure 15: Pultruded jute cement composite failure.

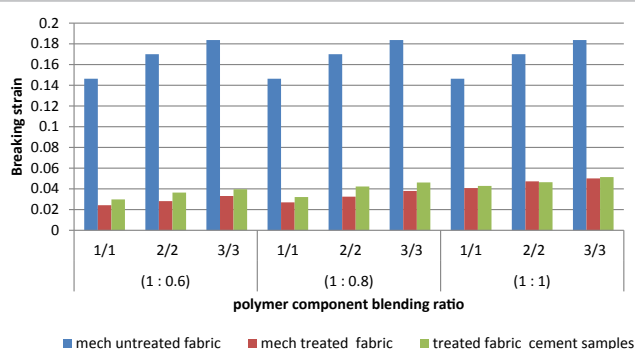


Figure 16: Breaking strain of pultruded jute cement composite components.

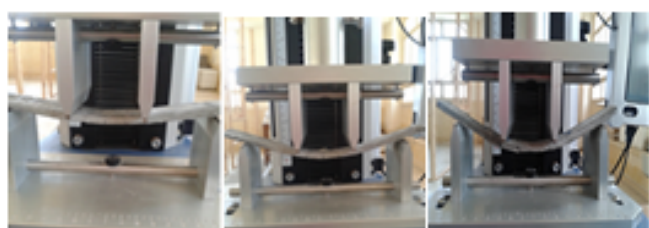


Figure 12: Deformation of the jute cement beam under bending load.

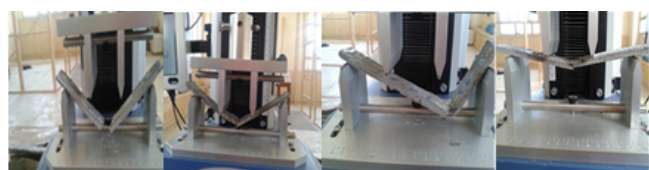


Figure 13: Failure of the jute cement beam under bending load.

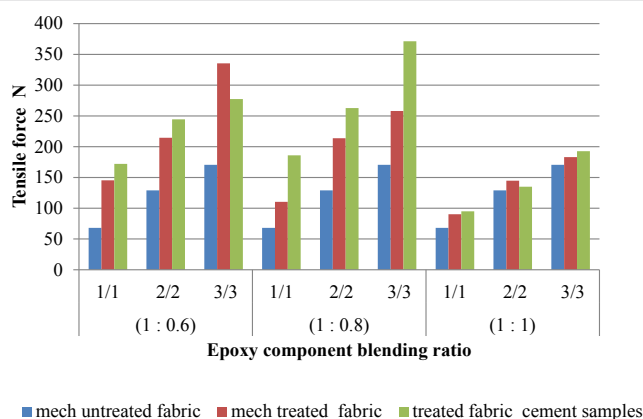


Figure 14: Tensile strength of pultruded jute cement composite components.

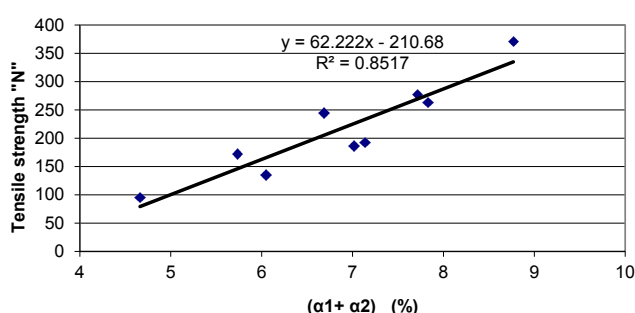


Figure 17: Relation between fabric and resin percentage and tensile strength.

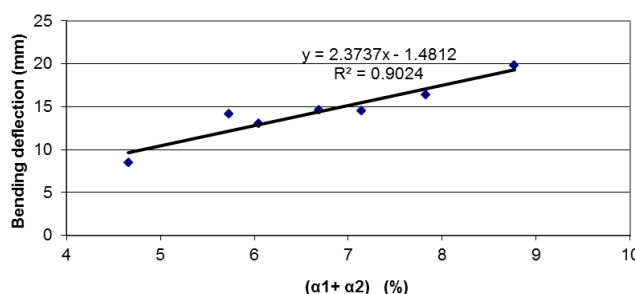


Figure 18: Relation between fabric and resin percentage and bending deflection.

of the pultruded jute cement composite. Figure 17 shows the relation between tensile strength of the composite and percentage of pultruded jute. The bending deflection is found to be highly correlated to the percentage of pultruded jute ($\alpha_1 + \alpha_2$) as it is illustrated in Figure 18.

Conclusion

The suggested technique for the processing of jute cement composite by using pultruded jute fabric using Polymeric matrix material

(Concrete 1315 M) proved to produce jute cementitious composite with improved tensile properties as well as bending stiffness. The tensile strength of the jute cementitious composite is highly correlated to the pultruded jute fabric ratio. 3/3 fabric design is recommended with polymer hardener blending ratio 1:0.8. The suggested technique gives a high bending deflection depending on pultruded jute fabric ratio.

References

1. Taj S, Munawar M, Khan S (2007) Natural Fibre-Reinforced Polymer Composites. *Proc. Pakistan Acad. Sci.* 44: 129-144
2. Deepa B, Pothan L, Mavelil-Sam R, Thomas S (2011) Structure, properties and recyclability of natural fiber reinforced polymer composites. *Trans world Research Network* 37: 102-120.
3. Yu L, Dean K, Li L (2006) Polymer blends and composites from renewable resources. *Progress in Polymer Science* 31: 578-602.
4. Panthapulakka S, Zereshkian A, Sain M (2006) Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites. *Bioresource Technology* 97: 265-272.
5. Huang X, Netravali A (2007) Characterization of flax fiber reinforced soy protein resin based green composites modified with nano-clay particles. *Composites Science and Technology* 67: 2005-2014.
6. Dweib M, Hu B, Donnell A, Shenton H, Wool R (2004) All natural composite sandwich beams for structural applications. *Composite Structures* 63: 147-157.
7. Netravali A, Chabba S (2003) Composites get greener. *Materials today* 6: 22-29.
8. Navaid M (2010) Global Sensitivity Analysis of Parameters in Puck's Failure Theory for Laminated Composites. San Diego State University.
9. Vadlamani D (2007) Strain Energy Density Based Failure Criterion for GFRP Coupons Under Tension and Bending. West Virginia University.
10. Sen T, Reddy H (2013) Strengthening of RC beams in flexure using natural jute fiber textile reinforced composite system and its comparative study with CFRP and GFRP strengthening systems. *International Journal of Sustainable Built Environment* 2: 41-55.
11. Mukhopadhyay S, Khatana S (2014) A review on the use of fibers in reinforced cementitious concrete. *Journal of Industrial Textiles*.
12. Kindo S (2010) Study on Mechanical Behavior of Coir Reinforced Polymer Matrix Composites. Bachelor of Technology in Mechanical Engineering.
13. Li Q, Xu S (2011) Experimental Research on Mechanical Performance of Hybrid Fiber Reinforced Cementitious Composites with Polyvinyl Alcohol Short Fiber and Carbon Textile. *Journal of Composite Materials* 45: 5-28
14. Gopinath S, Murthy A, Iyer N, Prabha M (2014) Behaviour of reinforced concrete beams strengthened with basalt textile reinforced concrete. *Journal of Industrial Textiles*
15. Sen T, Jagannatha H (2013) Pretreatment of Woven Jute FRP Composite and Its Use in Strengthening of Reinforced Concrete Beams in Flexure. *Advances in Materials Science and Engineering* 1: 1-15.
16. Chakraborty S, Kundu S, Roy A, Adhikari B, Majumder S (2013) Polymer modified jute fiber as reinforcing agent controlling the physical and mechanical characteristics of cement mortar. *Construction and Building Materials* 49: 214-222.
17. Scalici T, Fiore V, Orlando G, Valenza A (2015) A DIC-based study of flexural behaviour of roving/mat/roving pultruded composites. *Composite Structures* 131: 82-89.
18. El Messiry M, Mito A, Al-Oufy A, El-Tahan E (2014) Effect of fabric material and tightness on the mechanical properties of fabric-cement composites. *Alexandria Engineering Journal* 53: 795-801.