Behavior of Concrete Confined by Jute Natural Fiber Reinforced Polymer with Heat Treatment

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ABSTRACT: Jute is a natural fiber with strong tensile strength which could be applied within a natural fiber reinforced polymer (FRP). Since jute cellulose fibers are hydrophilic, contact with water would result in the lower performance of the fiber with regard to reinforcement. This is due to lower adhesion between the hydrophilic fiber and the hydrophobic polymers. Heat treatment has the capability of reducing water content of jute fibers, an effective method to improve the properties of Jute FRP (JFRP) in terms of increasing fiber and polymer collaboration.

This research focuses on conducting an experiment with two major objectives. The first is to investigate the tensile properties of preheated jute composite. A total of thirty composites were tested under various conditions. Temperatures were set at 40 ºC, 80 ºC and 100 ºC with the duration of heating duration from 1 hour, 8 hours and 24 hours on jute before composite molding process. The second, compression test of concrete wrapped with heat treated JFRP. Jute samples were subjected to the same temperature and durations of heating as those used for tensile testing with thirty-three specimens. The result demonstrates that compressive strength of concrete cylinder specimens confined by JFRP with heat treatment significantly strengthened by 35%, 36% and 38% at 80 ºC heat treatment 1 hour, 8 hours and 24 hours, respectively. Furthermore, the hoop strain of JFRP should be investigated intensively for natural fiber reinforced polymer (NFRP) applications.

1 INTRODUCTION

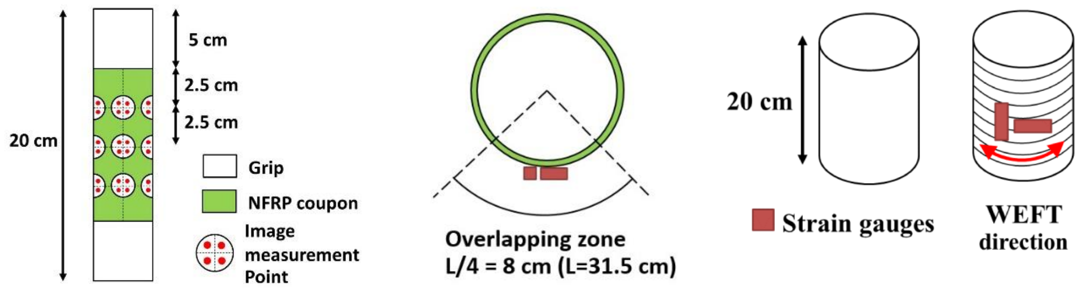
Reinforced concrete (RC) structures without proper seismic design codes and reinforcements reported serious damages during the Mae Lao earthquake in Thailand (Mw 6.3). Fiber reinforced polymers (FRPs) are one of the most effective methods to increase confinement effects of the structure due to their design flexibility, light weight and corrosion resistance (Jawaid *et al*. 2011, Mohammed *et al*. 2015, Yan *et al*. 2016). Conventional FRP such as Carbon FRP (CFRP), Glass FRP (GFRP) and Aramid FRP (AFRP) could be applied as retrofitting method by improving strength and ductility of the structures. However, their high material cost (21 US dollars/kg) makes these FRPs less appropriate for low-cost building. NFRP is one of the most applicable solutions for less industrialized areas since they have lower material cost and use locally available products. Jute is one of the most well-known natural fiber products in Thailand (Horsangchai *et al*. 2016, Jirawattanasomkul 2015). Jute has relatively low material cost (0.5 US dollars/kg) with low environmental impact. However, NFRP such as jute have not been applied in practical structural applications due to insufficient information on structural performance.

Jute cellulose fiber are hydrophilic and hygroscopic (Mokhothu and John, 2015) and could absorb water from the surrounding environment. The higher amount of water would result in lower performance of fiber on reinforcement due to lower adhesion among hydrophilic fiber and hydrophobic polymers. The heat treatment of Jute NFRP (Takemura 2010, Thitithanasarn *et al*. 2011, Sen and Jagannatha 2013) has been studied. This research focuses on the effects of heating pretreatment at various temperature and duration on mechanical properties of jute composite and concrete cylinder wrapped with Jute FRP (JFRP). The result of this study will provide useful information for future JFRP applications.

2 EXPERIMENTAL PROGRAM

2.1 Tensile coupon test

In order to investigate tensile properties of heat pretreatment on JFRP, a total 30 specimens of JFRP with WEFT direction were tested based on JSCE-E541 standard (2000), as shown in Figure 1a. The coupon specimens were denoted with prefix letter “JH-heating temperature-heating duration” for Jute with heat treatment with the following cases: heating temperatures were set to be 40℃, 80℃ and 100℃ with heating duration of 1 hour, 8 hours and 24 hours on jute before composite molding process (Table 1). To prevent slippage of composite specimens during tensile test, grips holder was applied to the specimen. Tensile test method was implemented to measure the tensile strength and strain of each coupon under monotonic horizontal compression using universal tensile testing machine. An image measurement method was implemented to measure tensile strain of each composite specimen.



a) Tensile coupon test of NFRP b) Concrete cylinder

Figure 1. Strength coupon test of JFRP and compression test of concrete cylinder

2.2 Concrete cylinder compression test

A total of 33 concrete cylinder specimens were cast for this experiment. Specimens were denoted as CH-temperature-duration with the following parameters: heating temperatures of 40 ºC, 80 ºC and 100 ºC with heating duration 1 hour, 8 hours and 24 hours on jute fiber. 3 Control concrete specimens without JFRP confinement (denoted as CT) were prepared with diameter 10 cm and height 20 cm. The compressive strength was designed as 21 MPa at 28 days. Normal strength cement with the maximum coarse aggregate size of 20 mm was used for casting process. Concrete were casted, pour and compacted in the mold with standard air curing procedure for 28 days. After 14 days, concrete’s surface was smoothen using disk grinding to attach the jute NFRP sheets with overlapping zone of quarter of diameter, as illustrated in Figure 1b. Jute cloth from different heat pretreatment was wrapped around this cylinder with WEFT direction. Polymer and jute formed the JFRP. An overlapping zone of a quarter circumference of the concrete cylinder was applied for avoiding slippage (Figure 1b). Strain gauges were installed on horizontal and vertical directions of JFRP surface at the middle height of specimens. All cylinder specimens were tested under monotonic concentric compression using Universal Testing Machine.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Coupon test results

Coupon test on 30 specimens provides tensile strength, ultimate strain, elastic modulus and tensile strength increase compared to untreated jute coupon (Table 1). Two regions of elastic modulus were presented as initial elastic modulus (E_1) for proportional limit region of coupon specimens and second stage elastic modulus (E_2) for elastic limit region. Composites expressed failure in either end-grip or mid-height of specimens (Figure2). All NFRP coupon specimens display linear stress-strain relationship (Figure 3). Considering average values of all JFRP coupons (Table 1), jute with heat treatment 80 °C for 24 hours showed the highest value of tensile strength (244 MPa) with the highest value of initial elastic modulus (17,425 MPa). The highest ultimate strain value is expressed as jute coupon with heat treatment of 40 °C for 8 hours (2.4%).

Table1. Tensile properties of coupon specimen

Specimen	Thickness (mm)	Average Tensile Strength (MPa)	Initial Elastic Modulus E_1 (MPa)	2^{nd} stage Elastic Modulus E_2 (MPa)	Average Ultimate Strain (%)	Tensile Strength Increase (%)
JH0	0.18	203	14485	10002	2.2	0
JH40-1h	0.18	225	14399	9549	2.3	11.0
JH40-8h	0.18	225	15236	10384	2.4	11.2
JH40-24h	0.18	224	15373	10971	2.2	10.3
JH80-1h	0.18	233	15206	10604	2.3	15.0
JH80-8h	0.18	240	14163	10358	2.1	18.2
JH80-24h	0.18	244	17425	12506	2.2	20.2
JH100-1h	0.18	225	16100	11264	2.3	11.2
JH100-8h	0.18	226	16665	11868	2.2	11.6
JH100-24h	0.18	231	16450	11940	2.3	14.1

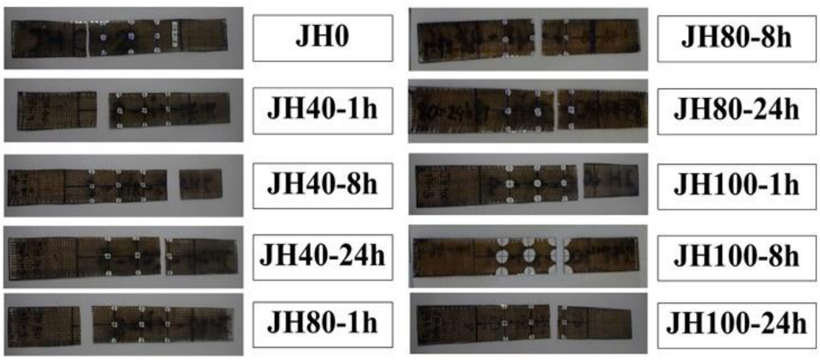


Figure 2. Failure modes of Jute coupon specimens

3.2 Cylinder test results

3.2.1 Failures modes

Heat treatment effect of JFRP confined cylinders could be observed on ultimate compressive strength experimental result in Figure 4 (a). As the heating temperature increases, confined cylinder expresses higher ultimate compressive strength with a maximum compressive strength at 80°C for 24 hours duration as 47.53 MPa with ultimate strength improvement of 38.42 % compared to JFRP confined specimen without heat treatment. In contrast, heat treatment of 100°C shows lower compressive strength compared to 40°C and 80°C JFRP confined specimens.

Figure 4 (b) demonstrates failure modes of concrete specimens confined with preheat treatment JFRP after compression test. All JFRP confined cylinder specimens failed under mechanism of JFRP lateral ultimate tensile failure simultaneously with dramatic sounds of rupture.

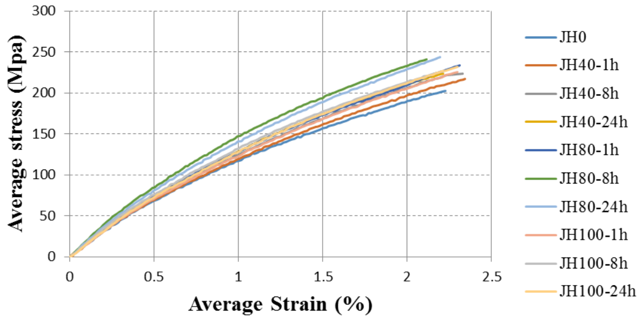
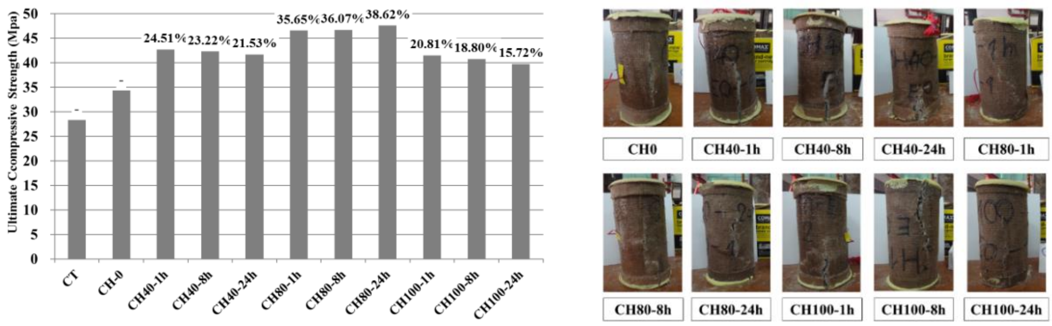
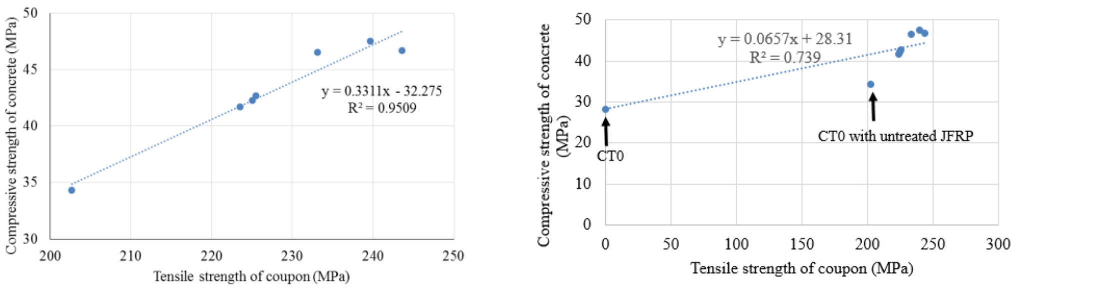


Figure 3. Average stress-strain relationship of coupon specimens



a) Ultimate compressive strength comparison b) Failure of concrete specimens

Figure 4. Compressive strength test of JFRP confined cylinders



a) Heat pretreatment of JFRP on cylinder b) Control cylinder and untreated JFRP compare to JFRP heat treatment

Figure 5. Strength relationships of JFRP coupons and Jute FRP confined concrete cylinders at temperature 0-80 °C.

The strength relationship among JFRP coupons and Jute FRP confined concrete cylinders was demonstrated in Figure 5. At temperature 0-80 ºC, the relationship of tensile strength of coupon and the JFRP confined concrete cylinder was linear regression as shown in figure 5 (a) with R^2 value of 0.9509. Figure 5 (b) shows the relationship of all treatment between the reference point, which is the case without JFRP confinement, and the cases with confinement. Those relationships imply that the coupon test results would be able to predict the compressive strength of the concrete cylinders. However, more data collection is necessary for the actual application of the relationship.

3.2.2 Stress-strain relationship

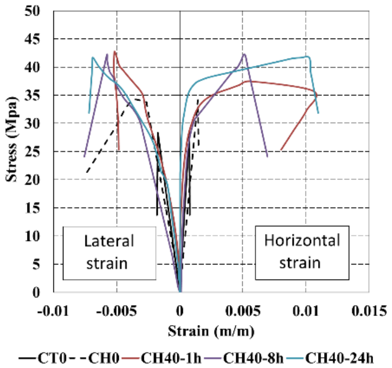
Figure 6 shows stress-strain curve relationship of horizontal and lateral strain for all unconfined and confined concrete cylinders. Overall compressive strength and ultimate horizontal strain of confined cylinders were greatly improved. Stress-strain relationship mechanism of confined concrete cylinders was expressed by bilinear pattern. Initially, stress-strain mechanism of JFRP confined concrete cylinders express similar mechanism with unconfined concrete specimen in 1st region area. Subsequently, stress-strain curve exhibits nonlinear stress-strain mechanism in the 2nd region. Compressive force starts inducing micro-cracks inside concrete specimens as lateral expansion and horizontal expansion increase, consequently JFRP confinement effect occurs in this region as increases of ductility and compressive strength of concrete. As compression stress increases, lateral tensile stress of JFRP also increases. When the lateral stress exceeds ultimate tensile strength capacity of JFRP, fracture mechanism of JFRP confinement tube was initiated.

Heat treatment effects on JFRP could be observed from stress-strain relationship graph in figure 6. Figure 6a shows stress-strain relationship of JFRP confined concrete cylinders with heat treatment of 40 °C for 1 hour, 8 hours and 24 hours. Softening mechanism could be observed when specimens reached peak strength capacity. Stress-strain relationship of JFRP confined concrete cylinders with heat treatment of 80 °C for 1 hour, 8 hours and 24 hours could be observed from figure 6b. Horizontal strain capacity has been greatly improved with increase of heating duration. Highest horizontal strain capacity could be observed on heat treatment JFRP of 80 °C for 24 hours. Figure 6c shows stress-strain relationship of JFRP confined concrete cylinders with heat treatment of 100 °C for 1 hour, 8 hours and 24 hours. As the temperature increases from 40 °C to 80 °C, specimen exhibits increase of horizontal strain capacity. In contrast, specimens with 100 °C demonstrate lower horizontal strain capacity as the duration of heating increases from 1 hour to 24 hours. There could be some damage induced to JFRP because of excessive heat condition. According to Shimazu F. and Sterling C. (1966), the heating in the absence of water caused a much greater amount of hydrolysis and dehydration, which was particularly marked at the higher temperature to cellulose with water at temperature 100 and 150 °C. Thus, the absent of aqueous condition may damage cellulose more than the aqueous one.

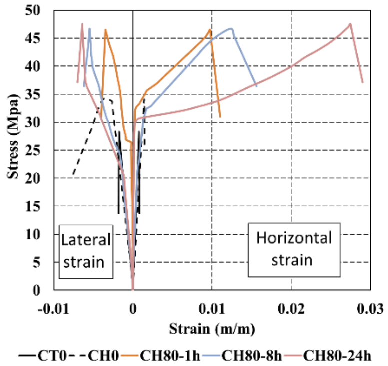
3.3 Modeling of compressive strength

Ultimate compressive strength is one of the most important parameters in concrete confined with FRP in the design stage. As stated by Dai *et al.* (2011), a compressive strength prediction model was proposed based on Lan and Teng model (2003). Dai *et al.* (2011) proposed the model based on Conventional FRPs (e.g., GFRP and CFRP) and large rupture strain FRP (LRS-FRP) such as PET-FRP and PEN-FRP, as shown below:

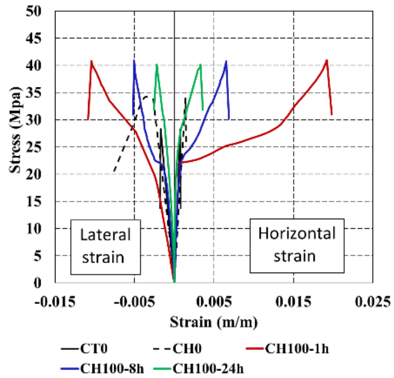
$$f'^{*}_{cc} = f'^{*}_{co} + 3.5\sigma_l \qquad (1)$$



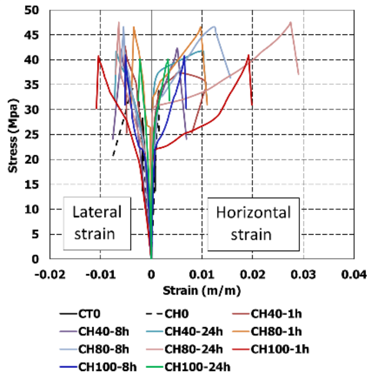
a) 40º JFRP heat treatment confined cylinders



b) 80º JFRP heat treatment confined cylinders



c) 100°C JFRP heat treatment confined cylinders



d) JFRP heat treatment confined cylinders

Figure 6. Stress-strain relationships of Jute FRP confined concrete cylinders

where f'^{*}_{cc} = compressive strength of confined concrete; f'^{*}_{co} = compressive strength of unconfined concrete and σ_l = confining pressure (or lateral stress) of FRP jacket,

$$\sigma_l = \frac{\sigma_{h,rup} t_{FRP}}{R} \quad (2)$$

where $\sigma_{h,rup}$= hoop stress of FRP jacket; t_{FRP}=nominal thickness of FRP jacket; and R = radius of concrete core,

$$\sigma_{h,rup} = E_{FRP}\varepsilon_l \quad (3)$$

where E_{FRP} = secant modulus of NFRP obtained from coupon test; and ε_l = hoop or lateral strain of NFRP at peak strength obtained from coupon test.

Using information obtained from figure 5, compressive strength prediction model Equation (1) was modified as shown below:

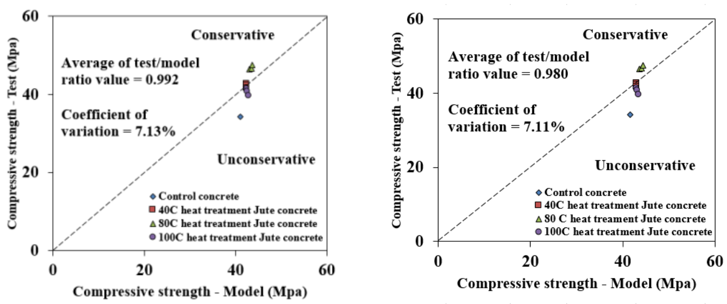
$$f'^{*}_{cc} = f'^{*}_{co} + 3.65\,\frac{\sigma_{h,rup} t_{FRP}}{R} \quad (4)$$

where $\sigma_{h,rup}$ = ultimate tensile strength of JFRP obtained from coupon test under the assumption that the tensile stress of FRP jacket is the tensile strength of coupon. Equation (4) indicates the slightly better confinement effect than Equation (1).

Table 2. Comparison table of compressive strength test and model prediction

Specimen	f'_{cc}-test (MPa)	f'_{cc}-model (MPa) Equation 1	Error (%)	f'_{cc}-model (MPa) Equation 4	Error (%)
Control	28.3	28.3	0.00	28.3	0.00
CH0	34.3	41.1	-19.82	41.6	-21.41
CH40-1h	42.7	42.5	0.52	43.1	-0.90
CH40-8h	42.3	42.5	-0.52	43.1	-1.95
CH40-24h	41.7	42.4	-1.77	43.0	-3.22
CH80-1h	46.5	43.0	7.61	43.6	6.26
CH80-8h	46.7	43.4	6.94	44.1	5.56
CH80-24h	47.5	43.7	8.13	44.3	6.74
CH100-1h	41.4	42.5	-2.52	43.1	-3.99
CH100-8h	40.7	42.5	-4.41	43.1	-5.91
CH100-24h	39.7	42.9	-7.99	43.5	-9.56

Comparison of compressive strength result between test and model prediction were demonstrated in Table 2 using prediction model as Equation 1 and 4. Figure 7a predicts ultimate compressive strength with percentage error between -19.82 to 8.13%. For Figure 7b, the model express ultimate compressive strength prediction with higher accuracy of prediction for 80 °C heat treatment JFRP specimens.



a) Comparison model using Equation (1) b) Comparison model using Equation (4)

Figure 7. Comparison graph between compressive strength result from graph and model prediction

4 CONCLUSIONS

This study experimentally investigates on heat treatment effect on jute composite in tension and JFRP confined concrete cylinders in compression (wrapped in WEFT direction). The following conclusions were drawn from this study:

1) All JFRP coupons exhibited approximately linear stress-strain relationship as terms of stress-strain relationship. Jute with heat treatment 80 °C for 24 hours has the highest percentage of tensile strength increase at 20.2% compared to untreated specimens, with the highest percentage of initial elastic modulus improvement of 20.3% compared to untreated specimen. The highest ultimate strain value is expressed as jute coupon with heat treatment 40°C for 8 hours as 9.0% ultimate strain improvement compared to untreated specimen.

2) For compression test of cylinders, heat treatment and heating duration affects enhancement properties of JFRP on confined concrete. Heat treatment provides ultimate compressive strength and ultimate horizontal strain improvements, the most under heating temperature of 80°C.

Compressive strength improvement of confined concrete increases significantly by 35%, 36% and 38% for 80°C heat treatment 1 hour, 8 hours and 24 hours, respectively.

3) Dai *et al's* model demonstrated prediction of compressive strength result of JFRP-wrapped concrete cylinders with moderate accuracy. Equation 4 model provided higher accuracy prediction of 80 °C heat treatment JFRP specimen. Due to limited study in heat treatment with JFRP, further investigation especially on hoop strain of JFRP at peak load should be conducted.

5 ACKNOWLEDGMENTS

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6 REFERENCES

Dai J.G., Bai Y., and Teng J, 2011. Behavior and Modeling of Concrete Confined with FRP Composites of Large Deformability, Journal of Composites for Construction. 15, 6. 963-973.

Horsangchai, K., T. Jirawattanasomkul and T. Ueda, 2016, Behavior of concrete confined with natural fibre reinforced polymer, International Conference on Fibre-Reinforced Polymer (FRP) Composites in Civil Engineering, 8, 1-6.

Jawaid, M. and H.P.S. Abdul Khalil, 2011. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers. 86, 1– 18.

Jirawattanasomkul, T., 2015, Compressive Behavior of Concrete Confined with Jute Natural Fiber Reinforced Polymer, Symposium on Reliability of Engineering System, 1-6.

JSCE, "Test method for tensile properties of continuous fiber sheets," JSCE Concrete Library, JSCE-E541-2000.

Lam L. and Teng J.G. 2003. Design-oriented stress–strain model for FRP-confined concrete, Construction and Building Materials, 17, 6. 471–489.

Mohammed, L., M. N. M. Ansari, P. Grace, J. Mohammad, and M. Saiful Islam, 2015, A Review on Natural Fiber Reinforced Polymer Composite and Its Applications, International Journal of Polymer Science. 696-711.

Mokhothu, T.H. and M. J. John, 2015, Review on hygroscopic aging of cellulose fibres and their biocomposites, Carbohydrate Polymers, 131, 337-354.

Sen, T., and H. N. Jagannatha Reddy, 2013, Pretreatment of Woven Jute FRP Composite and Its Use in Strengthening of Reinforced Concrete Beams in Flexure. Advances in Materials Science and Engineering, 18-32.

Shimazu F., C. Sterling, 1966. Effect of Wet and Dry Heat on Structure of Cellulose. Journal of Food Science 31: (4), 548–551

Takemura, K. 2010. Effect of surface and heat treatment on tensile properties of jute fiber reinforced composite, WIT Transactions on The Built Environment, 112, 167-175.

Thitithanasarn, S., K. Yamada, Y.W. Leong, H. Nishimura and H. Hamada, 2011, Effect of Surface Treatment on thermal and mechanical performance of Jute Fabric reinforced engineering Thermoplastics composites, International conference on composite materials, 18, 1-5.

Yan, L., B. Kasal, and L. Huang, 2016, a review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering, Composites Part B, 92, 94-132.