Vol.6 No.1 January-June 2018

Journal of Thailand Concrete Association
วารสารวิชาการสมาคมคอนกรีตแห่งประเทศไทย

BEHAVIOR OF CONCRETE CONFINED WITH NATURAL FIBER REINFORCED POLYMER SUBJECTED TO ELEVATED TEMPERATURE

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ARTICLE INFO:

Received:March 30, 2018
Received Revised Form:
June 5, 2018
Accepted: June 21, 2018

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ABSTRACT:

This study investigates the behavior of concrete confined with Natural Fiber Reinforced Polymer (NFRP) under elevated temperature. Jute Natural Fiber Reinforced Polymer (JNFRP) is used in this research. The compression test of a total of 27 JNFRP-confined concrete cylinder with 1 and 2 layers were conducted at room temperature and 50°C. The results show that the elevated temperature causes reduction in compressive strength of concrete. With same amount of JNFRP layers, the compressive strength of confined concrete under room temperature is higher than those under elevated temperature about 12.9 – 29.6%. In addition, the tensile test for a JNFRP and epoxy-resin coupons was performed with the same temperature variation. It is found that the JNFRP-coupons under elevated temperature developed higher tensile strength and modulus.

KEYWORDS: Concrete, Compressive strength, Natural fiber, Jute fiber, Elevated temperature

1. Introduction

During the Mae Lao earthquake at Chiang Rai (M_w = 6.1), many Reinforced Concrete (RC) buildings were severely damaged and failed [1], as shown in Figure 1. Repairing of damage structures and restoration are required and many effective concrete repair methods have been proposed such as shotcrete or sprayed mortar [2]. Moreover, not only the concrete repair is necessary, since those RC buildings (especially local houses) were designed and constructed without seismic design and engineering standards, it is imperative to strengthening such non-seismic resistant buildings to prevent possible further damages and ensure safety. Fiber Reinforced Polymer (FRP) such as Carbon, Glass, Aramid FRPs is widely used in civil engineering applications because of its resistance to corrosion, light weight and simple installation [3]-[4]. In addition, FRP jacketing can also enhance the confinement of concrete, leading to higher strength [5]-[9]. In recent year, natural fiber is becoming more used in civil engineering owing to its environmental friendly and low cost [10]-[14]. The natural fiber is known to be sensitive to elevated temperature so a study on concrete confined with natural fiber reinforced polymer subjected to elevated temperature is necessary.

Thailand is located close to the equator, causing the country to have hot climate. With high temperature during day time reaching up to 50 °C, concrete may lost its compressive strength. Under elevated temperature, performance of concrete

Figure 1 Failure of RC columns during Mae Lao earthquake [1]

Table 1 Details of JNFRP coupons and epoxy-resin coupons

Temperature	JNFRP coupon's label	Epoxy matrix's label	Heating time (hour)
Room temperature (37 °C)	JU	EPU	-
50 °C	JH50	EP50	4

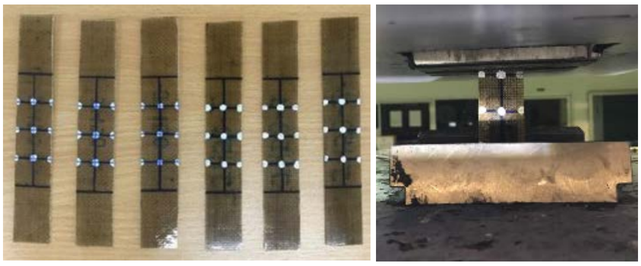
strengthened with JNFRP may not be effective. Therefore, such temperature condition should be taken into account in JNFRP strengthening of concrete.

This study, therefore, aims to investigate the behavior of concrete confined with JNFRP under elevated temperature. The compression test of a total of 27 JNFRP-confined concrete cylinder with 1 and 2 layers were conducted at room temperature and 50°C. The results show that the elevated temperature causes reduction in compressive strength of concrete. With same amount of JNFRP layers, the compressive strength of confined concrete under room temperature is higher than those under elevated temperature about 12.9 – 29.6%. In addition, the tensile test for a JNFRP and epoxy-resin coupons was performed with the same temperature variation. It is found that the JNFRP-coupons under elevated temperature developed higher tensile strength and modulus.

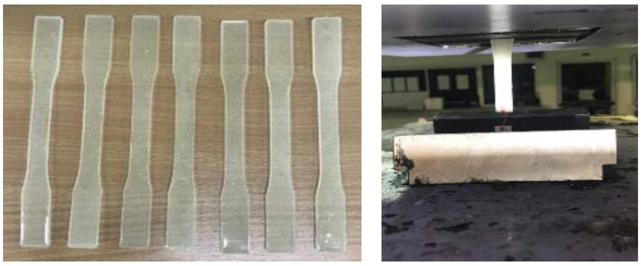
2. Experimental Program

2.1 Tensile tests of JNFRP coupon and epoxy matrix

To obtain tensile properties of JNFRP and epoxy resin, tensile tests of JNFRP and epoxy-resin coupons were conducted according to ASTM D3039-M08 [15] and ASTM D638-08 [16]. Jute fiber sheets in a transverse direction, so called WEFT, were prepared and applied epoxy resin onto the fiber to make JNFRP coupons, as shown in Figures 2 (a) and (b). Then, bubbles on the coupons were removed with a roller and they were cured for 7 days. Epoxy-resin coupons were prepared using the dog bone mold and they were smoothen at the top surface. Prior to tensile tests, JNFRP and epoxy-resin coupons were heated in the dried oven at 50 °C for 4 hours, denoted as JH50 and EP50, as shown in Table 1. At room temperature, JNFRP and epoxy-resin coupons are denoted as JU and EPU, respectively. The tensile test with a speed of 2 mm/min was setup as shown in Figure 2.



a) JNFRP Coupon and test setup



b) Epoxy resin and test setup

Figure 2 JNFRP and epoxy coupons

2.2 Compression tests of concrete cylinders

To investigate the confinement and temperature effects on concrete cylinders wrapped with JNFRP, a total of 18 concrete cylinders (including 3 control specimens) were subjected to the compression loads. The concrete cylinders with a diameter of 100 mm and a height of 200 mm were wrapped with 1 and 2 layers of JNFRP in WEFT direction. On their top and bottom, CFRP sheets with a dimension of 20 x 40 mm were wrapped to prevent premature fracture of JNFRP due to stress concentration.

Table 2 Details of concrete cylinders

Temperature	Heating time (hour)	Unconfined	Confined with 1 layer	Confined with 2 layers
Room temperature	-	CU - J0 (control)	CU – J1	CU – J2
50 °C	4	CH50 - J0	CH50 – J1	CH50 – J2

Prior to the test, concrete cylinders were heated in the dried oven with 50 °C (denoted as CH50) for 4 hours. The concrete without heating is denoted as CU (see Table 2). The labels of unconfined concrete cylinders are suffixed with J0, whereas labels concrete confined with 1 and 2 layers are suffixed with J1 and J2, respectively. Table 2 shows details of concrete cylinders.

Figure 3 shows the compression tests of concrete cylinders confined with JNFRP. The loading speed was 1 mm/min. The strain gauges were attached on the JNFRP's surfaces, whereas Linear Variable Displacement Transducers (LVDT) were set up at the left and right sides of the specimens to measure the displacement during testing

3. Experimental results

3.1 Tensile properties of JNFRP and epoxy-resin coupons

From tensile tests of JNFRP coupons, JNFRP coupons at a room temperatures and heated at 50 °C have an average tensile strength of 203 and 208 MPa, respectively, whereas their average elastic moduli are 15,927 and 15,767 MPa, respectively. For epoxy-resin coupons subjected to a room temperatures and 50 °C, their average tensile strengths are 19 and 17 MPa, respectively, while their average elastic moduli are 1,060 and 1,043 MPa (see Table 3). Compared to specimens at room temperature, JNFRP and epoxy-resin coupons heated with 50 °C show more or less similar tensile strength as well as elastic modulus.

Stress-strain relationships of JNFRP and epoxy-resin coupons are shown in Figures 4 and 5. The stress-strain curves of both JNFRP and epoxy-resin coupons

Figure 3 Compression test and instrumentation

Table 3 Tensile properties of JNFRP and epoxy-resin coupons

Specimen	Average Tensile Strength (MPa)	Average Elastic Modulus (MPa)	Average Ultimate Strain (%)
JU	203	15,927	1.32
JH50	208	15,767	1.66
EPU	19	1,060	5.41
EP50	17	1,043	5.28*

* average result of 2 samples as there was error during testing of sample EP50-3

show non-linear behavior. The maximum and the average tensile strength and ultimate strain of JNFRP coupons subjected to 50 °C is relatively higher than that in JNFRP coupons at room temperature. On the contrary, tensile strength of epoxy-resin coupons subjected to 50 °C is slightly smaller than that in epoxy-resin coupons at room temperature, whereas ultimate strain is more or less similar in both temperature (see Figure 5). This is because the temperature of 50 °C is slightly higher than the epoxy resin's glass temperature of 44 °C, changing properties of the epoxy resin. Noted that, in figure 5, the sample EP50-3 shows the results of about 50% ultimate strain compared to other samples. This is because there was error during testing, the EP50-3 test has been stopped in the middle and its results shall be neglected.

3.2 Compressive properties of concrete cylinders

3.2.1 Failure modes of unconfined and confined concrete cylinders

At both room temperature and 50 °C, all control specimens (CU-J0 and CH50-J0) failed in a very brittle manner with a very loud noise and their crack

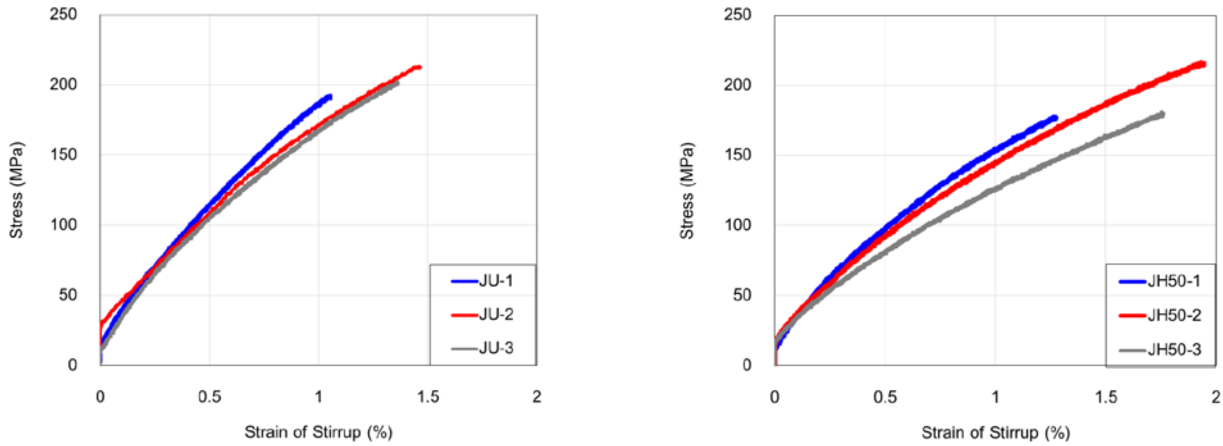


Figure 4 Stress-strain relationships of JNFRP coupons subjected to a room temperature and 50 °C

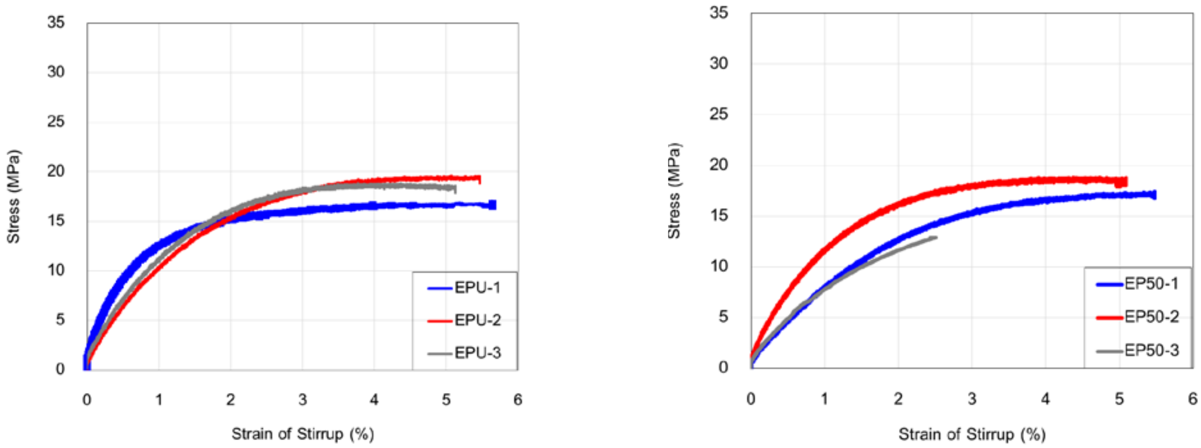


Figure 5 Stress-strain relationships of epoxy-resin coupons subjected to a room temperature and 50 °C

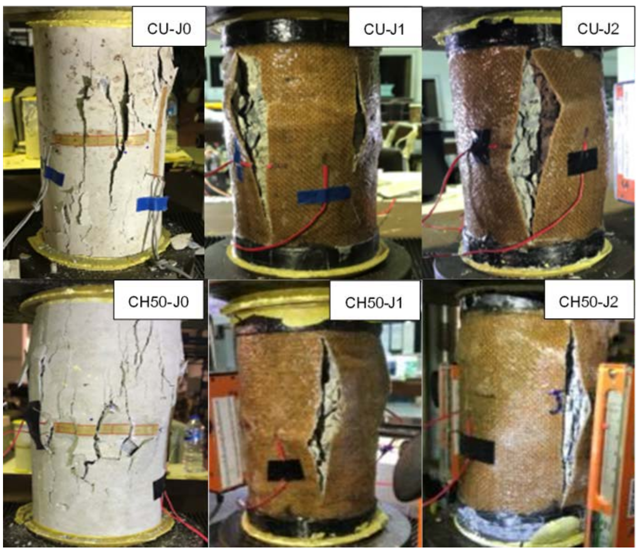


Figure 6 Failure modes of unconfined and confined concrete cylinders

patterns are as shown in Figure 6. All JNFRP confined concrete failed in tensile rupture of JNFRP starting from top to bottom of specimens. In specimens subjected to 50 °C (CH50-J1 and CH50-J2), a very limited noise was observed when JNFRP ruptured owing to higher ductility of JNFRP after heating. Bulging of both concrete and JNFRP can be observed at the end of the test (see Figure 6). This indicates that an elevated temperature has an influence on the failure mode of the bonding between Jute fiber sheet and epoxy resin. At elevated temperatures, ductile behaviors such as crack growth and rupture can be seen [17].

3.2.2 Compressive strength of unconfined and confined concrete cylinders

Compressive strength of concrete cylinders with same amount of JNFRP decreases when

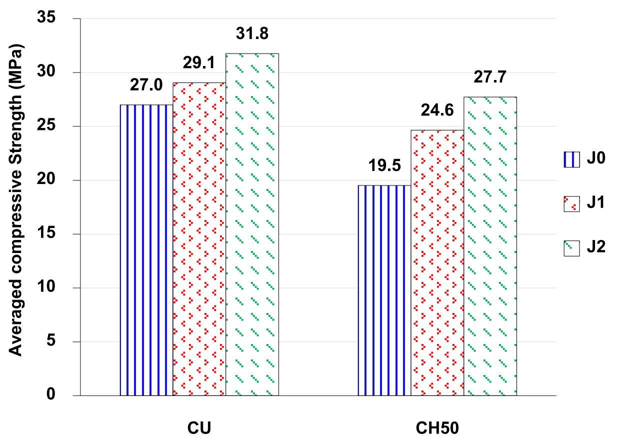


Figure 7 Effect of temperature on compressive strength of concrete cylinders subjected to a room temperature and 50 °C

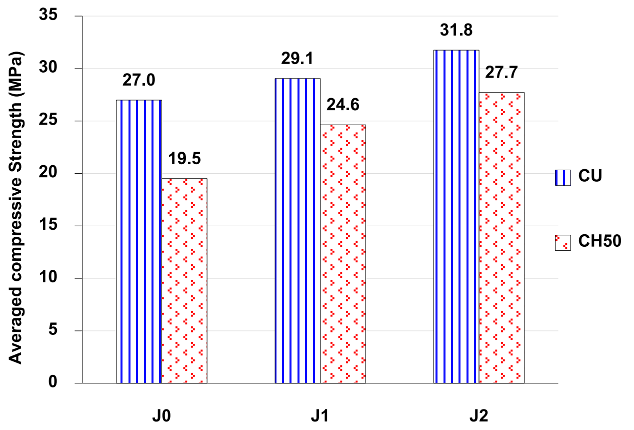


Figure 8 Effect of JNFRP's layers on compressive strength of concrete cylinders subjected to a room temperature and 50 °C

temperature increases, as shown in Figures 7 and 8. Concrete cylinders with 1 layer of JNFRP (CU-J1) has strength of 29.1 MPa at a room temperature, but it is decreased to 24.6 MPa at 50 °C in CH50-J1. This reduction of compressive strength in CH50-J1 is approximately 15.5% of the compressive strength at a room temperature (CU-J1), which is thought to be owing to reduction of bond interface between concrete and JNFRP as temperature significantly influences on fracture behavior of composite bonded joints [17]. Similarly, in concrete with 2 layers of JNFRP, compressive strength of concrete at 50 °C is 27.7 MPa reducing from compressive strength at room temperature (31.8 MPa) approximately 12.9% (see Figures 7 and 8).

4. Conclusions

This study on compressive behavior of concrete confined with JNFRP subjected to elevated temperature can be summarized as follows:

1) Tensile strength and ultimate strain of Epoxy-resin coupons subjected to elevated temperature (50 °C) is relatively slightly smaller than that in Epoxy-resin coupons at room temperature. This is because elevated temperature is greater than the epoxy resin's glass temperature of 44 °C, leading to changing of its properties. Anyhow, the effect of high temperature on the properties of JNFRP and Epoxy-resin should be considered in further study.

2) All JNFRP confined concrete failed in tensile rupture of JNFRP starting from top to bottom of specimens. At elevated temperatures, ductile behaviors can be seen. In heated specimens, a very limited noise was observed when JNFRP ruptured owing to higher ductility of JNFRP after heating. This indicates that temperature has an influence on the failure mode of the bonding between Jute fiber sheet and epoxy resin.

3) Compressive strength of concrete cylinders with same amount of JNFRP decreases when temperature increases. The reduction of compressive strength due to elevated temperature is approximately 12.9 – 29.6%.

5. Acknowledgements

The authors would like to acknowledge Kasetsart University Research and Development Institute (KURDI) as well as Faculty of Engineering, Kasetsart University for a research funding in 2016 and 2017.

6. References

[1] A. Pimanmas (2014, May 20). *Lesson learned, Chiang Rai Earthquake (1): Cause of damages* (in Thai) [Online]. Available: https://mgronline.com/science/detail/ 9570000055667

[2] S. Thongjaeng and T. Pheeraphan, "An experimental study of sprayed mortar for repairing application", *J. of Thailand Concrete Association*, vol.3, no.2, pp.24-29, Jul-Dec, 2015.

[3] Y. Xiao and H. Wu, “Compressive Behavior of Concrete Confined By Carborn Fiber Composite Jackets”, *J. Materials in Civil Eng.*, vol. 12(2), pp. 139-146, 2000.

[4] D. N. Saheb and J. P. Jog., “Natural Fiber Polymer Composites: A Review”, *Advances in Polymer Technology*, vol. 18(4), pp. 351-363, 1999.

[5] L. Lam and J. G. Teng, “Design-oriented stress-strain model for FRP-confined concrete”, *Construction and Building Materials*, vol. 17 (6&7), pp. 471-489, 2003.

[6] J. G. Teng and L. Lam, “Behavior and Modeling of Fiber Reinforced Polymer-Confined Concrete”, *J. Structural Eng.*, vol. 130(11), pp. 1713-1723, 2004.

[7] T. Jiang and J. G. Teng, “Analysis-oriented stress–strain models for FRP–confined concrete”, *Engineering Structures*, vol. 29(11), pp. 2968-2986, 2007.

[8] J. G. Teng et al., “Theoretical Model for Fiber-Reinforced Polymer-Confined Concrete”, *J. Composites for Construction*, vol. 11(2), pp. 201-210, 2007.

[9] J. G. Dai et al., “Behavior and Modeling of Concrete Confined with FRP Composites of Large Deformability”, *J. Composites for Construction*, vol. 15(6), pp. 963-973, 2011.

[10] K. Horsangchai et al., “Behavior of concrete confined with natural fiber reinforced polymer”, in *Int. Conf. Fiber-Reinforced Polymer (FRP) Composites in Civil Eng.*, vol. 8, pp. 1-6, 2016.

[11] K. Takasaki et al., “Experimental Study on Shear Behavior of RC Beams Jacketed by Flax Fiber Sheet”, *Concrete Research and Technology Tech. Paper*, Japan Concrete Inst., vol. 36(2), pp. 1189-1194, 2013.

[12] T. Sen and H. N. Jagannatha Reddy, “Application of Sisal, Bamboo, Coir and Jute Natural Composites in Structural Upgradation”, *Int. J. Innovation, Management and Technology*, vol. 2(3), pp. 186-191, 2011.

[13] D. Gon et al. “Jute Composites as Wood Substitude”, *Int. J. Textile Science*, vol. 1(6), pp. 84-93, 2012.

[14] S. Yaman et al., “Compresive Strength of Concrete Damaged by Elevated Temperature and Confined by CFRP Fabrics”, *Int. J. Civil Eng, and Technology (IJCIET)*, vol. 5(8), pp. 148-162, 2013.

[15] *Standard test method for tensile properties of plastics*, ASTM Standard D638-08, West Conshohocken, PA, 2008.

[16] *Standard test method for tensile properties of polymer matrix composite materials*, ASTM Standard D3039M-08, West Conshohoken, PA, 2008.

[17] R. L. Fernandes et al., “Effect of temperature on pure modes I and II fracture behavior of composite bonded joints”, *Composites Part B: Engineering*, vol. 96, pp. 35-44, 2016.