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Compressive Strength of Post Fire Exposed Concrete Column Wrapped with Fiber Reinforced Polymer Wardaya,

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Abstract: In this study, behaviour of reinforced concrete columns strengthened using fiber reinforced polymer (FRP; glass fiber and carbon fiber) after fire exposure are discussed. After being exposed to fire

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as high as 720°C for 180 minutes, the specimens showed concrete and reinforcement strength degradation, even though there was no carbonation. It was found that specimens wrapped by carbon fiber showed better compressive strength but less ductility compared to specimens wrapped by glass fiber. It was also found that the low initial compressive strength did not decrease FRP confinement effectiveness. Increase of wrapped concrete compressive strength was evident despite the low initial strength (<17 MPa). Strength estimation using ACI 440.2R-08 formula, which is originally for wrapped plain concrete without fire heat exposure, underestimated the compressive strength. In the proposed formula, the initial compressive strength (f'_{co}) should be adjusted by considering the modulus elasticity and strain limitation to have more precise estimation. **Keywords: Curing; fire exposed concrete column; fiber reinforced polymer.**

Introduction Research on the empirical formula for compressive strength estimation and behaviour of column confined using Fiber Reinforced Polymer (FRP) has been looked into extensively over the past two decades by many researchers. However most FRP confinement models [1-3] had been developed for FRP wrapped on concrete specimens with no exposure to fire. In Saafi's et al. model [1], variables which influence the FRP wrapped compressive strength are unconfined compressive strength, failure strains, and FRP stress-strain relationship. Saafi's et al. [1] research was conducted on

concrete-filled FRP tubes, tested under uniaxial compressive load with **test variables include type of fiber, thickness of tube, and concrete compressive strength.**

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Lam and Teng [2] proposed simplified formula for concrete compressive strength with circular and square cross-section reinforced with FRP. The behavior of square concrete column wrapped with FRP is influenced by corner radius of the specimen [3]. There are different strains on the sides and the corners of the square cross-section [3]. 1 Graduate Student,

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17 August 2017. Column size does not affect the strengthening behavior [3]. Lam and Teng [2] model was adopted by American Concrete Institute [4] as an empirical formula for FRP reinforcement design code. FRP has also been used to strengthen post fire exposed concrete specimen [5]. Bisby et al. [5] suggested that the use of FRP in post fire exposed specimens would significantly increase (above 100 %)

the compressive strength of the specimens. The model to estimate the

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compressive strength applies two assumptions:

(1) the total increase in the ultimate stress is the same for the fire

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exposed and non-fire exposed concrete; and

(2) the total increase in the ultimate axial strain between the strain at peak unconfined stress

4

and the strain at peak FRP- confined stress is the same for the fire

4

exposed and non-fire exposed concrete [5]. In this study, both concrete and reinforced concrete columns strengthened by FRP (glass fiber and carbon fiber) with two conditions (fire exposed and non-fire exposed) are presented. The effects of curing after exposure of fire were also investigated. An empirical formula for predicting FRP confined compressive strength of post fire exposure concrete column is proposed. Experimental Work Materials The concrete mix proportion used for the research was composed of 410 kg/m³ Portland Pozzolana Cement (PPC), 673.6 kg/m³ sand, 1012.4 kg/m³ crush stones, and 250 kg/m³ water. The target compressive strength was f'_c 20 MPa. Concrete uniformity was controlled by w/c ratio of 0.6, slump value with a range of 8-12cm, and also by Ultrasonic Pulse Velocity (UPV) test for 28 days concrete which resulted in deviation \leq 5% [6].

Mild steel reinforcing bars with 4.4 mm diameter were used, both as

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longitudinal and transverse reinforcements. The tensile strength of reinforcements before (NF) and after fire exposure (F) of the specimen was tested and presented in Table 1. The mechanical properties of FRP used in the experiment is shown in Table 2. Standard epoxy adhesive was used for FRP application. For fire heat exposed specimens, should there were any spalled concrete covers, repair work was done by using patching material. Table 1. Reinforcement Tensile Test Code Dia. (mm) Yield (MPa) Ultimate (MPa) NF 4.4 466.37 526.24 F 4.4 295.87 327.43 Table 2. FRP Specification Property Carbon Fiber Glass Fiber Tensile

Strength Tensile Modulus Elongation at Break Laminate Thickness 834 MPa 82 GPa 1% 1 mm 460 MPa 20.9 GPa 2.2% 1.3 mm Design and Test of Specimens The specimens used in this research were 100 x 100 x 300 mm³ columns (classified as short column with slenderness ratio of $10.39 \leq 22$ according to SNI 03- 2847-2002 [7]). The longitudinal and transverse reinforcement used were 4 – Ø4.4 mm and Ø4.4 mm – 50 mm, respectively (in accordance with SNI 03- 2847-2002 [7]). The column detail is shown in Figure 1. The uniformity and quality of FRP application was done according to standards by TYFO (FRP applicator). To decrease ineffective area, the specimen corner was rounded ($r = 10\text{mm}$). FRP was applied fully to lateral area of the specimen. FRP application process is shown in Figure 2. Figure 1. Column Dimensions and Detail Figure 2. FRP Application Process The specimen variables were reinforcement, fire exposure, curing after fire exposure, and wrapping material. The specimens were casted with and without reinforcement. Half of the specimens were exposed to fire at 720°C for 180 minutes in accordance to SNI 03-1736-2000 [8]. The fire exposure process uniformity was checked by carbonation test result. All fire heat exposed specimens showed the same color after tested by 1% phenolphthalein (PP), which means that all specimens experienced uniform combustion temperatures [6]. Some of the fire exposed specimens were cured using water for 3 days. Glass and carbon fibers were used for strengthening. With the mentioned variations, for easiness of identification, specimens' codes are listed as shown in Table 3. Universal testing machine (UTM) was used to conduct the concentric compressive test. From the recorded specimen load resistance and displacement during the test, the axial stress-strain curve could be generated for each specimen. Test Result Effect of Transverse Reinforcement and Fire Heat Exposure The test results show that concrete specimens (C- NF) and reinforced concrete specimens (RC-NF) have the same compressive strength. The compressive strength is shown in Figure 3. The same compressive strength showed that the transverse reinforcement had no effect. The distance between transverse reinforcement was 50 mm ($H/2$), so there was a concrete core that had no lateral confining pressure [7]. Figure 4 shows that concrete specimens exposed to high temperature at 720°C experienced

strength degradation even though there was no carbonation

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process [6]. Curing treatment using water increased the compressive strength of fire exposed concrete [6]. Wardaya, D.A.S.

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105–110 Table 3. Specimens Code, Variation and Quantity No Code 1 A (C-NF) 2 C (RC-NF) 3 E (C-NF-G) 4 G (RC-NF-G) 5 I (C-NF-C) 6 K (RC-NF-C) 7 B (C-Fc) 8 D (RC-Fc) 9 F (C-Fc-G) 10 H (RC-Fc-G) 11 J (C-Fc-C) 12 L (RC-Fc-C) 13 M (C-Fnc) 14 N (RC-Fnc) 15 O (C-Fnc-G) 16 P (RC-Fnc-G) 17 Q (C-Fnc-C) 18 R (RC-Fnc-C) Type Condition Treatment FRP Quantity Concrete Non- Fire Exposed 6 Reinforced Concrete Non- Fire Exposed 6 Concrete Non- Fire Exposed Glass 6 Reinforced Concrete Non- Fire Exposed Glass 6 Concrete Non- Fire Exposed Carbon 6 Reinforced Concrete Non- Fire Exposed Carbon 6 Concrete Fire Exposed cured 3 Reinforced Concrete Fire Exposed cured 3 Concrete Fire Exposed cured Glass 3 Reinforced Concrete Fire Exposed cured Glass 3 Concrete Fire Exposed cured Carbon 3 Reinforced Concrete Fire Exposed cured Carbon 3 Concrete Fire Exposed non-cured 3 Reinforced Concrete Fire Exposed non-cured 3 Concrete Fire Exposed non-cured Glass 3 Reinforced Concrete Fire Exposed non-

cured Glass 3 Concrete Fire Exposed non-cured Carbon 3 Reinforced Concrete Fire Exposed non-cured Carbon 3 Non-Fire Exposed condition is

shown in Figure 5. The stress-strain curve of reinforced concrete

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specimens strengthen with FRP (glass fiber–carbon fiber) in non-fire exposed condition is shown in Figure 6. Figure 3.

Stress-Strain Curve of Plain Concrete and Reinforced Concrete in

2

Non-Fire Exposed Condition Figure 5.

Stress-Strain Curve of Concrete Specimens Strengthen with

2

FRP in Non-Fire Exposed Condition Figure 4.

Stress-Strain Curve of Plain Concrete specimens in

2

Non-Fire Exposed, Fire Exposed- Cured, and Fire Exposed Non-

1

cured Conditions Figure 6.

Stress-Strain Curve of Reinforced Concrete Specimens Strengthen with

2

FRP in Non-fire Exposed Condition Specimens Confined by Fiber Reinforced Poly- mer

The stress-strain curve of concrete specimens streng- then with

2

FRP (glass fiber – carbon fiber) in fire

The stress-strain curve of concrete specimens exposed condition with

2

curing treatment is shown in strengthen with FRP (glass fiber–carbon fiber) in Figure 7.

The stress-strain curve of reinforced concrete specimens strengthen with

2

FRP (glass fiber – carbon fiber) in fire exposed condition with curing treatment is shown in Figure 8. Figure 7.

Stress-Strain Curve of Concrete Specimens Reinforced with

2

FRP in Fire Exposed-cured Condition Figure 8.

Stress-Strain Curve of Reinforced Concrete Specimens Reinforced with

2

FRP in Fire Exposed-cured Condition

The stress-strain curve of concrete specimens strengthen with

2

FRP (glass fiber and carbon fiber) in fire exposed condition without curing treatment is

shown in Figure 9. The stress-strain curve of rein- forced concrete

5

specimens strengthen with FRP (glass fiber and carbon fiber) in fire exposed condi- tion without curing treatment is shown in Figure 10. Figure 9.

Stress-Strain Curve of Concrete Specimens Reinforced with

2

FRP in Fire Exposed Non-Cured Condition Figure 10.

Stress-Strain Curve of Reinforced Concrete Specimens Reinforced with

2

FRP in Fire Exposed Non- Cured Condition Based on

the stress-strain curve of all specimens

2

variation, specimens strengthened by carbon fiber showed better compressive strength than specimens strengthened by glass fiber, but had more brittle failure mechanism. The low initial strength of speci- mens did not reduce the effectiveness of FRP con- finement. Stress-Strain Model Lam and Teng [2] empirical model was used as reference in this study, because the model is used in ACI 440.2R-08 [4] for FRP design. In this study, it was found that stress strain curve of plain concrete strengthen with FRP (glass fiber–carbon fiber) in non-fire exposed condition was well predicted by the model. The model of plain concrete in non-fire

exposed condition is shown by the straight dashed line and the experimental result is shown by the curve dotted line in Figure 11. Figure 11. Stress-Strain Curve of Plain Concrete in Non- Fire Exposed Condition Reinforced with FRP However, the ACI 440.2R-08 model cannot directly be applied

to predict the stress-strain curve of reinforced concrete

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specimens and stress-strain curve of specimens in fire exposed condition with or without curing treatment. It was found that a slight modification

in the model is necessary for stress- strain prediction of specimens

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with such conditions. The difference between ACI 400.2R-08 model and

stress-strain experimental curve is shown in Figure 12. The gap of

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f'_{cc} was caused by different f'_{co} . Wardaya, D.A.S.

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105–110 For reinforced concrete specimens and specimens in fire exposed condition had difference elastic modulus with plain concrete in non-fire exposed

condition. The difference of elastic modulus caused a “gap” between the

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initial specimen's compressive strength and the stress before the transition point. The gap caused the calculation based on ACI 440.2R-08 underestimate the compressive strength. The proposed model adjusted the f'_{co} and is shown in Figure 13. Figure 14. Fire exposed-Cured Plain Concrete Elastic Modulus Curve To reduce the gap, modification on the f'_{co} become f'_c modification is needed. f'_c modification is obtained from considering specimen's elastic modulus and the strain limitation. Specimen's elastic modulus was different for each variation. Example of Specimen's Figure 12. ACI Stress-Strain Curve Model for Reinforced elastic modulus graph is shown in Figure 14. Concrete Specimens and Specimens in Fire Exposed Condition Specimen's elastic modulus and strain limitation for each variation are shown in Table 4. Table 4. Strain Limitation of Reinforced Concrete Specimens and Fire Exposed Specimens

Specimen	f'_{co} (MPa)	f'_c (MPa)	ϵ_c (MPa)	Code
E	3714	22.16	0.0082	K (RC-NF-G)
F	2608	17.16	0.0071	H (RC-Fc-G)
J	2608	17.16	0.0071	L (RC-Fc-C)
P	1751	11.84	0.0125	Figure 13. Proposed Stress-Strain Curve Model for Reinforced
Q	1195	5.79	0.0131	ed Concrete Specimens and Specimens in Fire Exposed
R	1751	11.84	0.0095	Table 5. Comparison between ACI Model Estimation and

Proposed Model Estimation No SpCecoidmeen Age Experimental Strength ACI Model Error Proposed Model Error (days) Strength (MPa) Enhancement (%) Estimation (MPa) (%) Estimation (Mpa) (%) 1 A (C-NF) 2 C (RC-NF) 3 E (C-NF-G) 4 G (RC-NF-G) 5 I (C-NF-C) 6 K (RC-NF-C) 7 B (C-Fc) 8 D (RC-Fc) 9 F (C-Fc-G) 10 H (RC-Fc-G) 11 J (C-Fc-C) 12 L (RC-Fc-C) 13 M (C-Fnc) 14 N (RC-Fnc) 15 O (C-Fnc-G) 16 P (RC-Fnc-G) 17 Q (C-Fnc-C) 18 R (RC-Fnc-C) 51 22.04 52 22.16 Control Specimen 48 30.76 40% 31.42 2.16% 30.95 0.62% 49 39.14 77% 33.60 -14.16% 39.58 1.12% 45 36.02 63% 36.35 0.93% 34.26 -4.89% 43 39.14 77% 38.49 -1.65% 39.80 1.69% 61 17.16 62 17.78 Control Specimen 60 26.81 56% 22.59 -15.72% 27.06 0.94% 56 31.27 76% 23.96 -23.38% 31.07 -0.64% 57 30.33 77% 28.81 -5.02% 30.13 -0.66% 54 33.75 90% 30.12 -10.74% 33.98 0.70% 61 5.79 62 11.84 Control Specimen 60 24.24 319% 11.13 -54.10% 24.81 2.33% 56 30.85 161% 12.55 -59.32% 31.08 0.74% 57 29.22 404% 17.34 -40.66% 28.15 -3.65% 54 28.88 144% 18.71 -35.20% 29.08 0.71% - - - - The proposed model is more precise than the ACI 440.2R-08 model. In other word, the estimation is more efficient. The comparison between the ACI model estimation and proposed model estimation is shown in Table 5. Proposed flow chart calculations of column streng- then by FRP various conditions are shown in Figure 15. For axial capacity design, shear strength safety factor (0.65) needs to be used because the increased compressive strength was the effect of FRP confine- ment. Define Material Specification: Specimen Dimension : b (mm), h (mm), (mm) Rebar : (buah), (mm) Concrete : (MPa) FRP : , n (buah), (mm), (MPa) For Plain Concrete: , , dan : - - - = 0.586 (Lam and Teng, 2003) - - ACI committee: 0.95 Proposed : -Non-Fire Exposed= 0.96 FRP Confinement: - Fire Exposed-cured = 0.89 -Fire Exposed non-cured = 0.97 - The minimum confinement ratio: - - - - For plain concrete in non-fire exposedcondition follow ACI 440.2R- Compression Strength 08 Plain Concrete non-Fire exposed: - For reinforced concrete or fire exposedspecimen follow proposed (MPa) model: Reinforced Concrete or Fire EposedSpecimen: (MPa) Figure 15. Compression Strength Calculation Flow Chart forFigRureec1t5.aCnomgpurelsasironCStroelnugtmmhCnalcuClaotionnffFiRInoPweCdhabrttyforFRRectPangular Column Confined by Conclusion In this paper, ACI 440.2R-08 model has been eva- luated and reviewed, using test on plain concrete specimens and reinforced concrete specimens in various condition

(non-fire exposed, fire exposed- cured, and fire exposed non-

1

cured).

Based on the test results of the study, the following conclusions can be drawn: 1.

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Specimens strengthen by carbon fiber showed better compressive strength than specimens strengthen by glass fiber but had more brittle pattern. 2. Specimens in fire exposed condition with or with- out curing process has low initial compressive strength (<17 MPa) and various collapse pattern, but it did not reduce FRP confinement effec- tiveness. The compressive strength of specimens with low initial compressive strength strengthens by FRP was significantly increased (Figures 7-10). 3. Estimation of compressive strength

using ACI 440.2R-08 model is appropriate for plain concrete specimens in non -fire

1

exposed condition (Figure 11). 4. Reinforced concrete, fire exposed concrete, and fire exposed reinforced concrete had different elastic modulus with non fire exposed concrete. Gap between specimen's initial strength and the transition point was caused by the difference elastic modulus. The compressive strength was underestimated by ACI 440.2R-08 model (Figure 12). 5. For efficiency, modification (Figure 13) on the f'_{co} become f'_c modification is needed. f'_c modification is obtained by considering specimen's elastic modulus and the strain limitation (ϵ_c modification). 6. Proposed model generates closer compressive strength estimation to the compressive test result, with maximum error -4.89% for all specimens (Table 5).

References 1. Saafi, M., Toutanji H., and Li, Z., Behavior of Concrete Columns Confined with Fiber Reinforced Polymer Tubes, *ACI Materials Journal*, 96(4), 1999, pp. 500-509. 2. Lam, L. and Teng, J.G., Design-oriented Stress– Strain Model, *Journal of Reinforced Plastics and Composites*, 22(13), 2003, pp. 1149–1186. 3. Lee, C.S., Hegemier, G.A., and Phillippi, D.J., Analytical Model for Fiber-Reinforced Polymer-Jacketed Square Concrete Columns in Axial Compression, *ACI Structural Journal*, 107(2), 2010, pp. 208–217. 4. ACI 440.2R-08, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures, American Concrete Institute, 2008. 5. Bisby, L.A., Chen, J.F., Li, S.Q., Stratford, T.J., Cueva, N., and Crossling, K., Strengthening Fire-Damaged Concrete by Confinement with Fiber-Reinforced Polymer Wraps, *Engineering Structures*, 33(12), 2011, pp. 3381–3391. 6. Wardaya, D.A.S., Analisa Rumus Empiris Kuat Tekan Kolom dengan Penggunaan Fiber Reinforced Polymer pada Kondisi: Non-Fire exposed, Fire exposed-Curing, dan Fire exposed Non-Curing, Unpublished Graduate Theses, Petra Christian University, 2016. 7. Badan Standarisasi Nasional, SNI 03-2847-2002: Tata Cara Perhitungan Struktur Beton Untuk Bangunan Gedung, 2002. 8. Badan Standarisasi Nasional, SNI 03-1736-2000: Tata Cara Perencanaan Sistem Proteksi Pasif Untuk Pencegahan Bahaya Kebakaran pada Bangunan Rumah dan Gedung, 2000. Wardaya, D.A.S.

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