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Repair of heat damaged reinforced concrete slab with High Strength Fibre Reinforced Concrete materials

Nur Ain Hamiruddin[1, a)] Rafiza Abd Razak[1, b)] Khairunnisa Muhammad[1, c)] and Muhd Zulham Affendi Mohd Zahid[1, d)]

1 Department of Civil Engineering Technology. Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), P.O. Box 77, D/A Pejabat Pos Besar Kangar, Perlis,01000,Malaysia

a)Corresponding author: ainamir1404@gmail.com

b)rafizarazak@unimap.edu.my

c)khairunnisa@unimap.edu.my

d)mohdzulham@unimap.edu.my

Abstract. The purpose of this study is to investigate the flexural behaviour of heat damaged reinforced concrete (RC) slab by using High Strength Fibre Reinforced Concrete (HSFRC) as repair materials. The slab samples consist of twelve one-way columns heated at 200 ° C, 400 ° C and 600 ° C for 120 minutes. The thickness of the HSFRC layer used to heat damaged slab samples is 40 mm thick. Two distinct curing methods were implement during this study: i.e. normal curing (standard room temperature 26°C) and heat curing (temperature of 90°C for 48 hours). The center-point loading flexural strength test based on ASTM C 293 were referred to examine the flexural strength of the slab samples other than evaluated the mechanical properties of repaired samples (i.e. flexural strength, secant stiffness, toughness and ductility). The HSFRC's results showed that compressive strength at 28 days was 88.66 MPa. Whereas the flexural strength of heat damage repaired samples that exposed to 200°C (R200), 400°C (RNC400) and 400°C (RHC400) were gained by about 3.06% (34.93 MPa), 14.47% (38.79 MPa) and 30.95% (44.38 MPa) respectively, contrasted to the control sample (CS) which is 33.89 MPa. However, heat damage for non-repaired samples that exposed to 200 ° C (NR200) and 400°C (NR400) decline by about 0.77% (33.63 MPa) and 8.13% (31.14 MPa) respectively. Therefore, the utilized of HSFRC as repair materials can improve the flexural strength than control sample (CS). This is clearly indicate that HSFRC can enhance the mechanical properties of heat damaged reinforced concrete (RC) slab which can illustrate that the results of flexural behaviour reflected the superiority by using HSFRC as repair materials.

1. Introduction

A reinforced concrete building (RC) exposed to unintended fire can cause cracks and losses in the main components bearing capacity such as beam, column and slab. Cement is hydrated when the temperature reaches 700 ^{o}C and starts decomposing. Normally, the practical solution for retrieving the structure is to

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repair of heat-damaged members [1]. In previous studies, HSFRC with higher compressive strength of 55 MPa could be used as part to counter these issues however HSFRC could increase stiffness yet failed to re-establish the actual flexural strength, toughness and ductility of heat damage RC slab samples [2]. According to The Concrete Society [3], the specified characteristic of cube compressive strength for High Strength Concrete (HSC) between 60 to 100 MPa. In this study, the repair materials used for heat damaged RC slab samples was HSFRC with compressive strength of 88.66 MPa.

2. Materials and procedures

2.1 Normal concrete (NC) substrate samples

As stated by the Department of Environment (DOE) [4], the mix designed of 0.5 water-cement ratio (w/c) were used to accomplish a compressive strength of 30 MPa focused on 28 days based on BS 1881-116 (1983) [5] and slump test between the range of 150-180 mm. The compressive strength samples are used 100 mm x 100 mm x 100 mm cube. The mix proportion of normal concrete was detailed in Table 1.

Table 1. Mix proportion of normal concrete by weight.

Constituent Materials	kg/m^3
Ordinary Portland Cement (OPC)	470
Course Aggregate	590
Fine Aggregate	1090
Water	235

2.2 Repair materials

HSFRC was used as a repair materials which consists of cement Type-I CEM 52.5N, silica fume, fine sand, two various length of micro-steel fibers i.e. (6 mm and 13 mm long) and Glenium 51 superplasticizer. The average compressive strength of cube 100 mm x 100 mm x 100 mm HSFRC for 28 days is approximately 88.66 MPa with the rate of 2 kN/s used while the slump flow test results are acquired 900 mm based on ASTM C1611 [6] procedure. The detailed of HSFRC mix proportion was tabulated in Table 2.

Table 2. Mix proportion of HSFRC by weight.

Constituent Materials	Ratio to cement
Portland Cement	1.00
Silica fume	0.20
Fine Sand[a]	0.30
Superplasticizer	0.085
Water	0.20
Steel Fiber	0.121

[a] Fine aggregate size range = 600 to 1180 μm

2.3 Preparation of samples

The fresh normal concrete (NC) is poured into its mould and left for 24 hours after casting. Following 24 hours the NC substrate samples were removed, cleaned and cured in water curing tank for two days. Surface preparation was performed on NC samples at three days of age. In this study, the drill holes method was performed for substrate surface texture by having a superior bond between two different materials [7].

Furthermore, the NC samples was cured in a water curing tank up to 28 days from the date of casting. Then, the samples of the NC was transported to the curing room (standard room temperature of 26 ° C) for one month. The NC samples then placed into the mould of slab, the samples surface of the NC was wet for 10 minutes with a damp cloth before placing it with HSFRC.

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Preparation of this samples according to ASTM C 192 [8]. There are twelve samples one-way slab with six category that were prepared (i.e. two samples for every category such as control sample (CS), heat damaged for non-repaired sample at 200°C (NR200), heat damaged for non-repaired sample at 400°C (NR400), heat damaged for repaired sample at 200°C (R200), heat damaged for repaired sample at 400°C by normal curing (RNC400) and heat damaged repaired sample at 400°C by heat curing (RHC400).

2.4 Detailed geometric sample and steel reinforcement component

According Eurocode Standard 2 [9] twelve samples of one-way slab were designed and cast in slab moulds with thickness of 20 mm. The main reinforcement design calculation, f_y is 500 N / mm² with diameter of 10 mm placed in the horizontal and longitudinal direction by 30 MPa grade concrete slab. Slab dimensions are 500 mm long, 200 mm wide and 80 mm thick with nominal concrete cover is 25 mm.

2.5 Procedures of mixing, casting, and curing the slab samples

Followed by the Department of Environment (DOE) [4] the drum mixer was used in concrete mixing and the slump test was measured by ASTM C143 [10]. Prior the concrete is poured into the slab mould has been oiled and the reinforcement is placed in it. 25 times the rodding to compact each layer with round tamping rod and smoothly finished by the trowel at the top surface of slab sample. Next 24 hours casting, slab samples were removed and stored in a curing tank for 28 days prior to be transferred to curing room for the heat process. In this study, there are six categories of slab samples conducted as shown in Table 3.

Table 3. Sample of reinforced concrete (RC) slabs.

No.	Category of sample	No. of slab sample	Label
1	Control sample of slab	2	CS
2	Heat damaged for non-repaired sample at 200°C	2	NR200
3	Heat damaged for non-repaired sample at 400°C	2	NR400
4	Heat damaged for repaired sample at 200°C	2	R200
5	Heat damaged for repaired sample at 400°C through normal curing	2	RNC400
6	Heat damaged for repaired sample at 400°C through heat curing	2	RHC400

2.6 Heat process

The RC slab samples were heated at 200, 400 and 600 °C for 120 minutes by using electrical furnace except the control samples. Noticed that at 600 °C the samples suffered explosive spalling damage, therefore were not for additionally tried.

2.7 Repair methods

After heat process the samples were left for 24 hours in electrical furnace to chill off before were roughened by utilizing drill holes method. After that, the application of HSFRC by 40 mm thick as a repair materials started and the repaired samples were cured for 28 days prior tested. The slab samples between two distinct materials after repaired were depict in Figure 1.

Figure 1. Slab sample between normal concrete and HSFRC

2.8 Flexural testing

In this study, to determine the load-deflection curve the supported slabs were tested under center-point loading test with applied capacity load of 600 kN by using a universal testing machine and the load rate of 2 kN/s. The flexural strength is performed referred to ASTM C 293 [11].

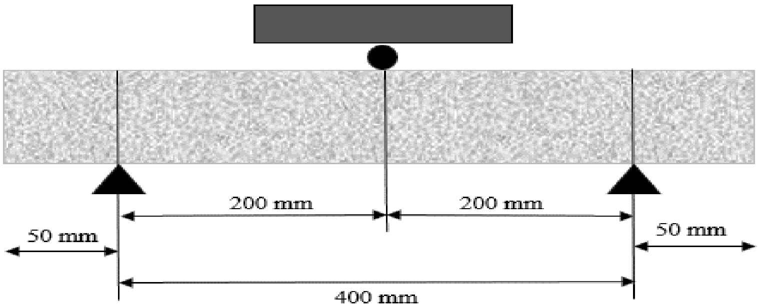

Figure 2. Details flexural strength test by center-point loading.

The loading rate then calculated by using the equation under ASTM C 293 [11] with one point load and two supporters at the bottom of the slab sample;

$$r = \frac{2Sbd^3}{3L} \quad (1)$$

Where r is the load rate, MN / min; S is the rate of extreme fibre stress increase, MPa / min; b is the average of sample width, mm; d is the average of sample depth, mm and L is the length of span, mm.

The load used is always at constant rate until the break point. For this experiment, the load rate used is 1.2 MPa / min (2.0 kN / s). Additionally, based on the flexural strength of ASTM C 293 [12] is calculated by using the equation below;

$$R = \frac{3PL}{2bd^3} \quad (2)$$

Where R is the modulus rupture, MPa; P is the maximum load shown by testing machine, N; L is the length of the span, mm; b is sample width, at the fracture, mm and d is the average of sample depth, at the fracture, mm.

3. Results and discussion

The flexural behavior of the slabs rated on the load–deflection diagram shown in Figures 3 and 4 in terms of ultimate load capacity, secant stiffness, and toughness is measured in table 4. The ratio of strength to maximum displacement of the load-deflection diagram perform the slab secant stiffness while the area under diagram shows the toughness. While structural ductility is important to appraise the performance of structural system structures that are subject to extreme loads.

This ductility is determined as a structural or member ability to support the applied load after the elastic limit without loss of load-carrying capacity before failure [7].

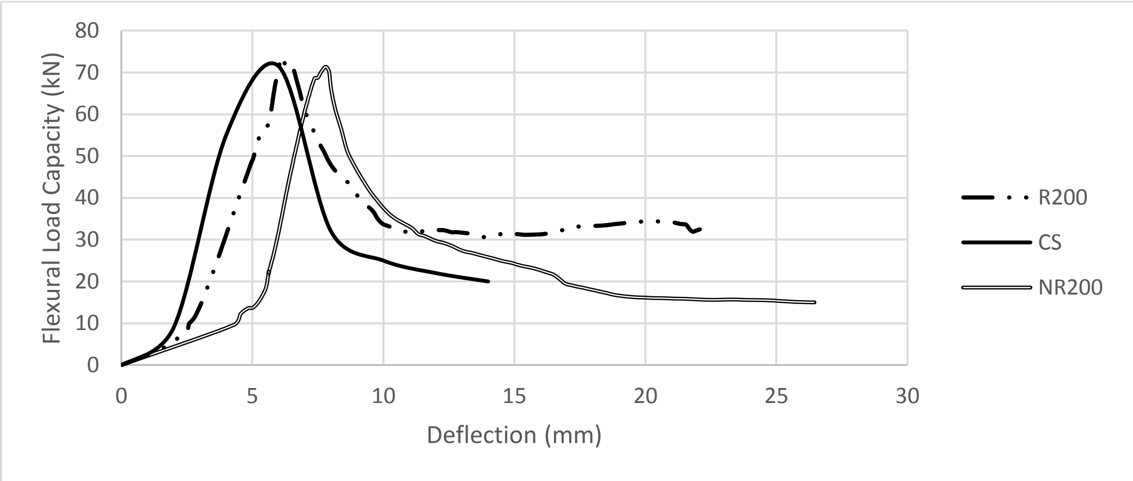

Figure 3. Load–deflection of control sample slab, heat damaged for non-repaired sample at 200°C and heat damaged for repaired sample at 200°C.

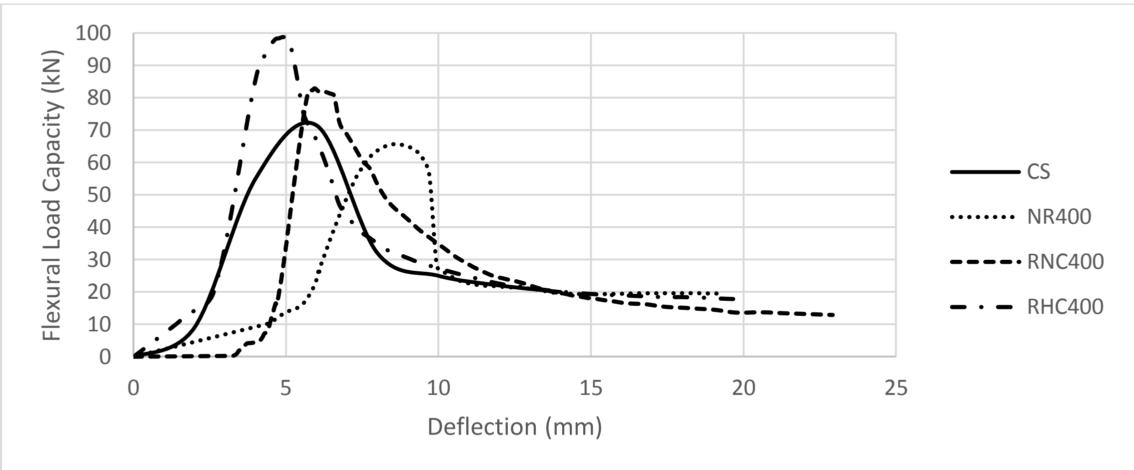

Figure 4. Load–deflection of control sample slab, heat damaged for non-repaired sample, heat damaged for repaired sample through normal curing and heat damaged for repaired sample through heat curing at 400° C.

Table 4. Results of RC slab samples P_{ult}, secant stiffness, toughness and ductility.

Slab category	P_{ult} (kN)	Secant stiffness (kN/mm)	Toughness (kNmm)	Ductility (kNmm)
CS	72.30	13.41	441.32	8.42
NR200	71.74 (-0.77%)*	10.31 (-23.11%)	535.32 (21.30%)	8.76 (4.12%)
NR400	66.42 (-8.13%)	8.62 (-35.72%)	652.32 (47.81%)	9.12 (8.31%)
R200	74.51 (3.06%)**	13.16 (-1.86%)	1198.13 (147.81%)	10.60 (25.89%)
RNC400	82.76 (14.47%)	15.11 (12.68%)	1371.32 (310.73%)	13.24 (57.24%)
RHC400	94.68 (30.95%)	21.20 (58.09%)	777.98 (76.28%)	10.15 (20.55%)

P_{ult} = ultimate load capacity at failure, *=% decreased, **=% increased, NR200= heat damaged for non-repaired sample at 200°C, NR400= heat damaged for non-repaired sample at 400°C, R200= heat damaged for repaired sample at 200°C, RNC400= heat damaged for repaired sample at 400°C through normal curing, RHC400= heat damaged for repaired sample at 400°C through heat curing.

3.1 Effect of Heating Temperature on RC slabs.

The graph of experimental load versus mid-span deflection curves for the RC control sample, heat damaged for non-repaired sample at 200°C and heat damaged for repaired sample at 200°C depicts in Figure 3. Before the samples repaired, the ultimate flexural strength of heat damaged for non-repaired sample at 200°C (NR200) and heat damaged for repaired sample at 200°C (NR400) suffered a huge losses with 0.77% and 8.13%, respectively, with an increase in the deflection when contrasted to the control sample. The Table 4 shows that the ultimate strength of the load–deflection represents the secant stiffness subjection of the heat damaged slab is larger than the subjection of ultimate flexural strength. Therefore, more considerations must be given to deformation and stress redistribution of post-fire concrete structures. For NR400 sample the secant stiffness was genuinely reduced by 35.72% which is larger than the sample of NR200 was truly reduced by about 23.11% of the control sample (CS). It can conclude that both the flexural strength and secant stiffness of the slabs was diminished for non-repaired samples. While the toughness sample of NR200 gained by 21.30% and sample of NR400 gained by 47.81%, respectively. The results show that the toughness is depends on temperature which can figure out in Table 4. Based on the load-deflection curves attained the sample of NR400 enhance the ductility of structure. Structural ductility raised significantly after NR400 heating contrasted to NR200 sample. It is important to emphasize that the toughness and ductility gained significantly, while the flexural strength and secant stiffness decline when increasing at temperature for non-repaired samples.

3.2 Effect of HSFRC on flexural strength, secant stiffness, toughness and ductility of repaired RC slabs.

The repair methods utilized as part of this study by applied of HSFRC with 40 mm thick as a bonding material on a rough sample surface. The improved method utilized in this study is to increase the ultimate flexural strength by about 3.06% for heat damaged of repaired sample at 200°C (R200), 14.47% for heat damaged of repaired sample at 400°C through normal curing (RNC400) and 30.95% for heat damaged of repaired sample at 400°C through heat curing (RHC400) which indicated that the higher obtained yield with utilizes HSFRC as a repair materials. By using of HSFRC as its viability to secant stiffness shown the sample of RNC400 gained by about 12.68% and sample of RHC gained by about 58.09% respectively, illustrated in Figure 4. Hence, the results by utilization of steel fibre as repair materials at 400 °C has a greater modulus elasticity that makes the concrete stronger and stiff [12] however, the stiffness for repaired sample of R200 loss about 1.86%. This is depends on the curing methods applied after the samples repaired. It can be seen in Table 4, the toughness shows the repaired samples of R200, RNC400 and RHC400 increased with 147.81%, 310.73% and 58.09% respectively. Theoretically, the HSFRC layer affects the toughness. It is also worth noting that the increase in the toughness is more pronounced than compared to the increase of ultimate flexural strength, such stiffness and ductility of the repaired samples. It is equivalent to ductility deformation exhibiting higher for samples of R200, RNC400 and RHC400 contrast to control sample (CS). Therefore, repaired with HSFRC is provide better ductility than control sample. It can be concluded that HSFRC has superior corrosion resistance and is very durable [13].

3.3 Effect of Curing Regimes

This study also investigates the impact of two curing regime of HSFRC on its behaviour as a repair material: i.e. normal curing and heat curing. It can simply reported that curing methods had commit to raised significantly the ultimate flexural strength, as shown in Table 4. The load versus mid-span deflection curves for control, normal curing and heat curing slabs are depicted in Figure 4 have significant implications for regaining ultimate flexural strength of heat damaged slabs. When contrast to normal curing the heat curing accomplish the ultimate flexural strength, reaching higher stiffness but the toughness and ductility is lower. The ultimate flexural strength of repaired sample at 400°C through curing (RHC400) gained about 30.95% while repaired sample at 400°C through normal curing (RNC400) gained about 14.47%. The secant stiffness was raised by 58.09% due to the increasingly significant regain on the modulus elasticity of concrete heat-damaged while curing. The normal curing toughness gained by about 310.73% for sample of RNC400 and 76.28% for sample of RHC400 therefore the normal curing recorded the higher toughness contrast to heat curing samples [14]. This clearly shows that the heat curing method of repaired sample by using HSFRC provide better enhancement on toughness then normal curing methods [15]. From two methods of curing the ductility for RNC400 sample indicated that normal curing is higher with gained of 57.24% while RHC400 sample with gained of 20.55%. Therefore, normal curing ductility is better than the heat curing sample. Consequently, the normal curing influencing ultimate flexural strength and secant stiffness as well whereas the toughness and ductility may due to the heat curing to implement significant ability.

4. Conclusions

This paper discusses the improvement of twelve one-way slab samples to investigate the flexural behaviour of heat damage reinforced concrete (RC) slab repaired with High Strength Fiber Reinforced Concrete (HSFRC).Based on the results of the experiment, the following conclusions can be made:

(1) HSFRC mix design gained a compressive strength with 88.66 MPa at 28 days and flow ability of 900 mm.

(2) The flexural strength attained for control sample is more than the heat damaged for non-repaired sample exposed to 200°C and 400°C, which are 33.63 MPa and 31.14 MPa respectively.

(3) The heat damaged for non-repaired sample at 200°C and 400°C ultimate flexural strength is reduced around 0.77% and 8.13% respectively, contrasted with control sample (CS).

(4) The secant stiffness of heat damaged for non-repaired sample at 200°C is decline larger than decline of ultimate flexural strength. Therefore, more considerations should be given to the deformation and stress redistribution of post-fire concrete structures. The secant stiffness of the NR400 sample completely reduce by about 35.72% more than the NR200 sample which actually reduce by about 23.11%.

(5) The toughness indicated that the repaired samples for R200, RNC400 and RHC400 increased 147.81%, 310.73% and 76.28% respectively. Theoretically, which indicated the HSFRC layer has affect to toughness. It is also worth noting that the increase in the toughness is more noticeable than the enhancement as compared to that flexural strength, secant stiffness and ductility of repaired sample.

(6) The curing method assumes a part on the execution of HSFRC. The flexural strength conduct acquired in this investigation of the sample cured with heat process marks as higher strength than the cured sample with normal curing. The enhancement in mechanical properties of HSFRC upon the heat curing had commit to improved performance of the repair material (HSFRC).

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References
[1] Haddad RH, Shannag MJ, Hamad RJ 2007 Repair of heat-damaged reinforced concrete T- beams using FRC jackets Volume **59** 223-31
[2] Ramadoss P, Nagamani K, Engineering S and Ceg D 2004 High Performance Fiber Reinforced Concrete under Compression and Flexure Strength
[3] Collins, Michael. 2017 Concrete Society Provides Technical Information, *Concrete.org.uk*
[4] Deparment Of Environment 1995 Preparation of Environment Statements for Planning projects that Require Environment Assessments. London HMSO
[5] BS 1881-116 1983 Testing concrete Method for determination of compressive strength of concrete cubes.
[6] ASTM C 1611/C1611M 2014 Standard Test Method for Slump Flow of Self- Consolidating Concrete
[7] Tayeh B A, Bakar B H A, Johari M A M and Lei Y 2013 Evaluation of Bond Strength between Normal Concrete Substrate and Ultra High Performance Fiber Concrete as a Repair Material *Procedia Engineering.* 554–63
[8] ASTM C 192/C192M 2016 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
[9] Eurocode Standard 2 1991 Design of Concrete Structures EN 1992-1-1
[10] ASTM C143/C143M 2015 Standard Test Method for Slump of Hydraulic Cement Concrete.
[11] ASTM C 293/C293M 2016 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)
[12] Parameswaran V S 1991 Fibre-reinforced concrete a versatile construction material Building and Environment **26** 301-05
[13] Haddad RH, Al-Mekhlafy N and Ashteyat AM 2011 Repair of heat-damaged reinforced concrete slabs using fibrous composite materials *Construction and Building Materials.* **25** 1213-21
[14] Haddad RH and Shannis LG 2004 Post-fire behavior of bond between high strength pozzolanic concrete and reinforcing steel *Constr. Build Mater.* **18** 425–35
[15] Haddad RH, Al-Saleh RJ and Al-Akhras N M 2008 Effect of elevated temperature on bond between steel reinforcement and fiber reinforced concrete *Fire Safety. J* **4** 334–43