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GFRP Retrofitting of Reinforced Concrete Beam Exposed to Elevated Temperature

[1]N.H. Mahamad Marop, [2]C. Petrus, [2]L.D. Goh and [2]N.A. Marzuki
[1]Faculty of Civil Engineering, Universiti Teknologi MARA,
40450 Shah Alam, Selangor Darul Ehsan, Malaysia
[2]Department of Civil Engineering, University Teknologi MARA,
13500 Permatang Pauh, Pulau Pinang, Malaysia

Abstract: This study presents the results of an experimental study aimed at investigating the flexural behavior of Reinforced Concrete (RC) beam retrofitted with Glass Fibre Reinforced Polymer (GFRP) by using Near Surface Mounted Method (NSM) when exposed to an elevated temperature. A total of 7 numbers of 150×150×750 mm RC beams were tested under a three-point bending test. The experiments results show that the flexural strength of all the control specimens decreased with increasing temperature. However, the GFRP retrofitted specimens improves the flexural strength of the beam specimens by 50, 44 and 43% for specimens burned at 200, 600 and 800°C, respectively as compared to the control specimen. Therefore, NSM retrofitting method with GFRP is proven to be effective to maintain a beam structure that was exposed to the elevated temperature.

Key words: GFRP, elevated temperature, retrofitted beam, flexural strength, high strength concrete

INTRODUCTION

The structural design of buildings should be carried out such that a structure is able to maintain its stability and strength throughout its service life including design consideration on fire resistance. There is a different range of losses between normal strength concrete and high strength concrete when the structure is exposed to elevated temperature. High strength concrete loses 40% from its original strength and this is only applicable for temperature <450°C (Benmokrane *et al*., 1995). Besides that, high strength concrete has been observed to experience some deterioration and a high risk explosive spalling when exposed to fire because of its high density (Watanabe *et al*., 2013). When a structure is exposed to elevated temperature, engineer needs to evaluate the degree of the problem and come out with a solution; either to retrofit the building or to demolish and construct a new building. Retrofitting a damaged structures is sometimes more economical compared to demolishing them.

In the future, it is expected that new retrofitting method will be developed and new views will be proposed for the existing method as well (Hassanen and Raoof, 2004). There are many retrofitting methods that can be used to enhance and strengthen the deteriorated structures thus making it useful again. Few examples of the available methods are external bonded, steel plate jacketing method and also Near Surface Mounted (NSM) method. The NSM Fibre Reinforced Polymer (FRP) seems capable in solving a number of aspects. The first one is full Fibre Reinforced Polymer (FRP) tension strength encountered in the case of externally bonded FRP reinforcements. The second one is their susceptibility in damaging deriving from the collision, high temperature and fire (Capozucca, 2014). NSM techniques gives many advantages over external bonded of FRP reinforcement, such an example is increased in bond capacity due to a larger bonded surface and protection from external impacts since the bar is been covered by the concrete cover (Kalupahana *et al*., 2013). NSM method can be used together with FRP or mild steel.

FRP is being known for their excellent mechanical properties that been utilized in construction in various ways. As compared to steel, FRP has the higher ultimate strength and lower density than steel (Obaidat, 2011). In the usage of FRP, GFRP is the most common of all reinforcing fibres. GFRP composed of glass-fibre elements and a resin matrix. Besides that, GFRP is the most usable fibres due to their relatively lower cost (Bhise, 2002). Previous research (Al-Salloum and Almusallam, 2007; Karmoty, 2012; Feng *et al*., 2014; Nigro *et al*., 2011) reported that GFRP are of low cost, high tensile strength and also have an excellent insulating property. However, the performance of GFRP as a retrofitting material on damage structures due to high

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Corresponding Author: N.H. Mahamad Marop, Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

temperature has yet to be reported. Therefore, the potential of GFRP to be used as a retrofitting material to a damaged RC beam exposed to elevated temperature is investigated in this study.

MATERIALS AND METHODS

The experiment programs were conducted to investigate the effectiveness of GFRP as a retrofitting materials using NSM method by determining the flexural strength of RC beam after they were exposed to elevated temperature.

Sample preparation: A total of (7) beam specimens were prepared and tested. The beam's size is 150×150×750 mm with a concrete characteristic strength of grade 50. The main reinforcement provided is $2H_{10}$ with shear link of R6 spaced at 75 mm centre to centre designed according to B. Standard, "structural use of concrete" (13). One beam is used as a control specimen without temperature exposure and labeled as specimen A1. Two specimens were burned for one hour, at 200, 600 and 800°C and labeled as B1 and B2; C1 and C2 and D1 and D2, respectively. All beam specimens labeled as number '2' were retrofitted with GFRP while specimens labeled as '1' are used as a control specimen. Two GFRP bars of 10 mm diameter were used to retrofit the beam. Sikadur 30 is used as a filler material and sealant to attach the GFRP with the beam. All the retrofitted beam specimens were tested under three-point bending and the flexural strength was determined. The details of the specimens are tabulated in Table 1.

Concrete casting and burning process: Concrete casting took place after all the materials and formworks were prepared. Figure 1 shows the concrete casting work of the RC beams. The compressive strength of the concrete was determined at the age of 7, 14 and 28 days. All specimens are left in room temperature and covered with wet gunny sacks for 28 days for curing purpose. After 28 days, 6 numbers of beams specimens were burned according to the designated temperature for one hour. High cautions need to be observed throughout the burning process of the beam specimens to ensure safety.

Retrofitting process: After the burning process is completed, the specimens are prepared for the retrofitting procedure. Prior to the GFRP installment, the groove was prepared in accordance to the NSM procedures introduced by Lorenz and Teng (2007). Figure 2 shows the details of the specified grooves sizes and their positions.

Sizes of the grooves used in this study is 20 mm for both b_g and h_g. Meanwhile, the spacing between the groove, a_g is 30 mm.

Once the groove details were finalized, the position was marked, followed by the hacking work. The grooves were then dusted to ensure that the grooves were clean. After the grooves wee ready, GFRP reinforcement bars were then installed. Figure 3 shows beam specimens with complete grooves ready for GFRP installation. Half of the groove was filled with epoxy and GFRP was placed on top

Fig. 1: Concrete casting of RC beam

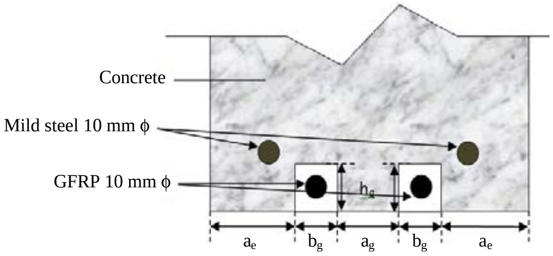

Fig. 2: Groove details; B_g and h_g = 20 mm a_g = 30 mm a_e = 40 mm

Table 1: Details of all RC beams specimen

Specimen	Temperature (°C)	Retrofitting	Compression	Max load (N/mm^2) test	Flexural strength (kN)	Decrease after (N/mm^2) (%)	Increase after burning retrofit (%)
A1	Room	No		72.07	19.22		
B1	200	No	46.59	59.85	15.96	17	
B2	200	Yes		118.70	31.65		50
C1	600	No	50.61	61.35	16.36	15	
C2	600	Yes		108.73	28.99		44
D1	800	No	50.16	45.64	12.17	37	
D2	800	Yes		79.79	21.27		43

Fig. 3: Beam specimens with complete grooves ready for GFRP installation

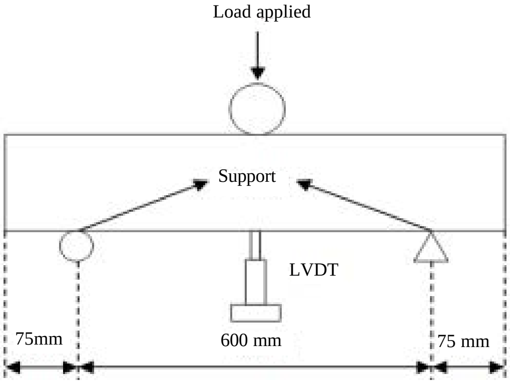

Fig. 4: Schematic diagram of the 3-point bending test

of it. The GFRP needed to be gently pressed to ensure that it was very much in touch with the epoxy. Then the groove had to be filled with the epoxy until it was fully covered. The retrofitted specimens were then left at room temperature to cure for 14 days.

Experimental set up: All the beam specimens were tested under a three point bending test. The diameter of the roller supports used in this test was 70 mm thus the clear span between each support is 600 mm. A Linear Variable Differential Transducer (LVDT) was placed at the mid span to determine the displacement at the mid-span of the beam (Fig. 4).

RESULTS AND DISCUSSION

The results collected from flexural test is analysed and presented in terms of the maximum load and flexural strength of retrofitted beam after they were exposed to high temperature. The effectiveness of the retrofitting method used is evaluated by comparing the results obtained to that of control specimens. The detail of the experimental results is tabulated in Table 1.

Maximum load: Maximum load was obtained from the three-point bending test. The results indicated that the maximum load decreases with increasing temperature. Figure 5 shows the maximum load for the control specimens and the GFRP retrofitted specimens. It was observed that the maximum load for all the control specimens decreased with increasing temperature. It was also noticed that there is no significant decrement of maximum load for temperature exposure below 600°C. However, the percentage load decrement was more than double for the temperature above 600°C. This trend is expected because when the specimen was exposed to elevated temperature some deteriorations and cracks occurred in the concrete matrices. At temperature >600°C, the matrices were weakened further and suspected to have spoiled and cracked. This observation confirmed the conclusion reported by other researchers (Cavdar, 2012; Bastami *et al.*, 2011). Nevertheless, the maximum load for the GFRP retrofitted beam specimens increased significantly. The maximum load increment recorded as 50, 44 and 43% as compared to specimens without GFRP at, at temperature exposure of 200, 600 and 800°C, respectively.

Flexural strength: The flexural strength is a mechanical parameter also known as modulus of rupture defined as a material's ability to resist deformation under bending. It is determined by using Eq. 1 as:

$$\text{Flexural strength, } f_b = \frac{3PL}{2bd^2} \tag{1}$$

Where:

b = Width of specimen (mm)
d = Depth of specimen (mm)
L = Supported length (mm)
P = Maximum load (N)

The flexural strength of all the beam specimens is shown in Table 1. From the result analysis, it was observed that the flexural strength of all specimens decreases with increasing temperature. This trend is similar to the behavior observed for the maximum load discussed in sub-chapter 3.1 together with previous research reported that shows reduction trend when specimen is exposed to elevated temperature. Figure 6 shows the comparison of flexural strength for beam specimens without retrofitting and with GFRP retrofitted

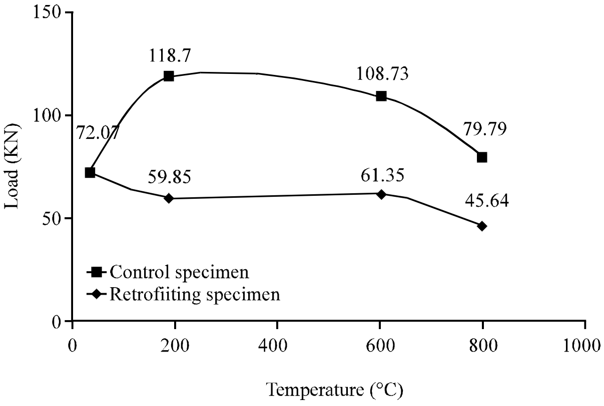

Fig. 5: Comparison of maximum loading for all RC beams

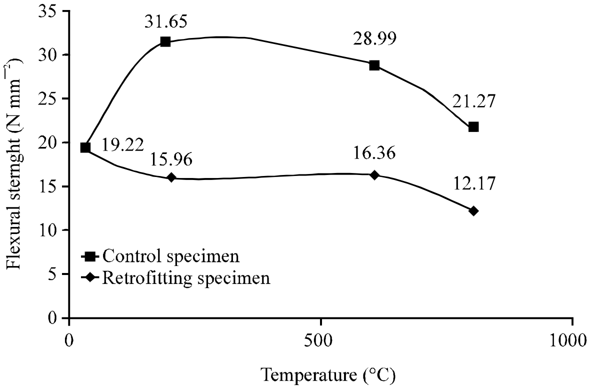

Fig. 6: Comparison of flexural strength for all RC beams

specimens. The result indicated that the flexural strength of beam B2 increased by 50% compared to B1 while beam C2 increased by 44% compared to C1 and beam D2 increased by 43% compared to D1. It was also observed from the comparison between the specimens B2, C2 and D2 to the control specimen, A1 that the GFRP strengthened the specimens by 39, 34 and 10%, respectively.

This observation proved that the usage of GFRP as a retrofitting material increased almost half of the flexural strength after being exposed to the elevated temperature. The results also indicated that the GFRP is effective both in retrofitting the damaged beam and strengthening it, especially for specimens exposed to temperature <600°C. Generally, when the beam is exposed to a higher temperature, the percentage for the beam to regain its flexural strength is lower compared to the beam that is exposed to lower temperature. Nevertheless, the observed increment of flexural strength in this study is higher than that reported by Phan and Carino which indicated that high strength concrete loses 40% from its original strength for temperature <450°C.

Fig. 7: Mode of failure for control sample

Fig. 8: Mode of failure for retrofitted sample

Crack observation: There are several modes of failures occurr in this study which is the bending and shear failure. The behaviors of the beams were different for control specimens and retrofitted specimens. It was observed that the control specimens A1, B1, C1 and D1 failed in bending while retrofitted sample B2, C2 and D2 failed in shear. The additions of GFRP increased the flexural strength thus causing the beam to fail in shear. The failure occurred by the crushing of concrete when GFRP was not present thus leading to bending failure for control specimens. On the other hand, the presence of the GFRP bar helped in transferring the load to GFRP thus producing shear failure (Fig. 7 and 8).

CONCLUSION

The flexural strength of beams that were retrofitted with GFRP using NSM method increased by 50, 44 and 43% for the temperature of 200, 600 and 800°C, respectively. Therefore, it is proven that GFRP is effective in improving the flexural strength of beam after being exposed to the elevated temperature. The increment of flexural strength was contributed by the additional loads carried by the GFRP bars despite, the concrete core deterioration due to high temperature exposure. However, the study was limited to a temperature range between 200-800°C only. Therefore, a wider range of temperature should be explored. Besides that, the potential of the different types of materials as a retrofitting material apart from GFRP should be discovered.

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