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Performance Evaluation of Pre-Damaged Fire Effected Deep Beams

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ABSTRACT

Deep beam's behaviour is complex as it is dependent upon several factors, such as supporting area beneath support and load, depth, concrete strength, quantity of flexural and shear reinforcements, and the ratio of shear span to depth, in addition these beams could be vernal able to high temperatures, which has to be strengthened but hasn't been thoroughly researched. This work investigates experimentally load bearing capability of deep beams reinforced with carbon fiber-reinforced polymer (CFRP) sheet to increase the deep beam's flexural strength following exposure to high temperatures. Total two specimens were cast. The first beam was examined to collapse at room temperature, whereas the second beam underwent testing following exposure to 550° C. Then these two deep beams were retrofitted using CFRP sheets by wrapping them in U shape and then tested to failure. The test results show that there is almost 6% drop in strength of deep beam after being exposed to high temperature, but the failure mood remains same i.e. flexure before strengthening and shear after strengthening. Furthermore, the experimental findings showed that retrofitting method performed exceptionally well in increasing the flexure strength up to 38% and hence improved the post-cracking behaviour of CFRP retrofitted deep beams. Heat exposed retrofitted beam is more ductile than ambient temperature retrofitted beam because of CFRP U-wrap shredding due to weakening of surface concrete thus resulting in increase of peak load deflection up to 13%.

KEYWORDS: Deep beam, deep beam at elevated temperature, CFRP retrofitting of deep beam

1 INTRODUCTION

A beam with depth larger as compared to the span is known as deep beam or the structural elements loaded as a simple beam transfer load to the supports by as compressive force [1]. Deep beams are supported on one face and loaded on the other face such that in between the supports and loads the compressive struts can be develop, for ACI 318-14 should satisfy following two perimeters, Force act at a distance 2h from support and Clear span is not more than four-time depth of beam [2]. It is due to the geometric proportions that the strength of deep beams is normally governed by the shear rather than flexure and dependent upon several factors, such as supporting area beneath support and load, depth, concrete strength, quantity of flexural and shear reinforcements, and the ratio of shear span to depth [3,4]. Different members of structure behave differently on heating. In deep beam modes of failure are significantly influenced by compressive strength of concrete, shear span-to-depth ratio, percentage of tension and web (shear) reinforcement [5].
Numerous studies on the characteristics of regular concrete at temperatures between 100°C and 800°C have been conducted [6]. Concrete that has been exposed to high temperatures often loses its mechanical properties because of changes in the matrix, a decrease in porosity and the aggregate's water release. The strength of concrete, reinforcement yield strength, and elastic

modulus all decrease at high temperature, further weakening the shear resistance mechanism [5,7]. Previous research investigated modulus of elasticity, stress–strain characteristics, compressive, flexural, and tensile strengths [8]. The load capacity of RC members is negatively impacted by microcrack development, hydration product breakdown, and resulting porosity increase by exposure to high temperatures. Nonetheless, it was found that the reinforced concrete beams' flexural strength was significantly reduced when the temperature was raised over 900°C [9]. There is a touchable strength drops, and deflection increase in deep beam with the increase of temperature and higher rate of cooling [10]. Previous research [11,12] has demonstrated that with externally bonded CFRP and near-surface mounted rebars, the structural capability of the fire-damaged beams may be restored. Studies in the literature currently under publication are restricted to using different techniques for strengthening and concrete mixtures to improve the deep beams strength against shear. Furthermore, whereas prior studies have investigated the shear response of deep beams, no experimental studies have explored the flexural behaviour of deep beams following exposure to extreme temperatures. The purpose of this study is to fill in the gaps in the literature about the effects of externally bonded CFRP sheets on the restoration of flexural strength in deep beams exposed to extreme temperatures. These were addressed by comparing the deep beam assessed at room temperature with the deep beam evaluated at an enhanced temperature of 550 °C. Furthermore, an experimental assessment was carried out to determine the extent to which heat-damaged beams' strength may be recovered by externally bonded CFRP sheets. These goals were met by testing two deep beams using three-point flexural loading, after examining crack trends, load-displacement graph characteristics, structural ductility, and failure mode the experimental findings were concluded.

2 EXPERIMENTAL PROGRAM

2.1 Methodology

The experimental work consisted of three-point load tests of two simply supported reinforced concrete deep beams, both beams were cast with same materials. One beam DB-NS is kept at normal conditions, other beam DB-T is exposed to an elevated temperature of 550°C, then both beams were tested and cracked till failure, their failure mood, maximum deflection and load deflection curves were noted then these two beams were repaired by same method using CFRP strips and named as DB-NSR for normal beam and DB-TR for exposed beam and then tested by same process to study same perimeters. Details of every step are as follows.

2.2 Material

A concrete mix was prepared using ordinary portland cement. The ASTM specification C136 was satisfied for gradation of course and fine particles. The ACI method 211 was used in design of concrete mix, for 50 mm slump and 28-day cylinder compressive strength of 28 MPa. The average 28-day compressive strength was 28.3 MPa and concrete density was 150 lb/ft3. The yield strength of reinforcing steel is 420 MPA. The average elastic modulus was 210 GPA.

2.3 Test Specimen

The test samples composed of two deep beams, that were prepared for flexure testing under three-point loading. Spam to depth ratio 1.52. Detail of beam dimension and reinforcement is given in figure 1. The details of test specimens are presented in Table 1. Longitudinal and shear reinforcement was designed to fail in flexure. The beams were cured for 28 days in compliance with ACI-308R-01-R08.

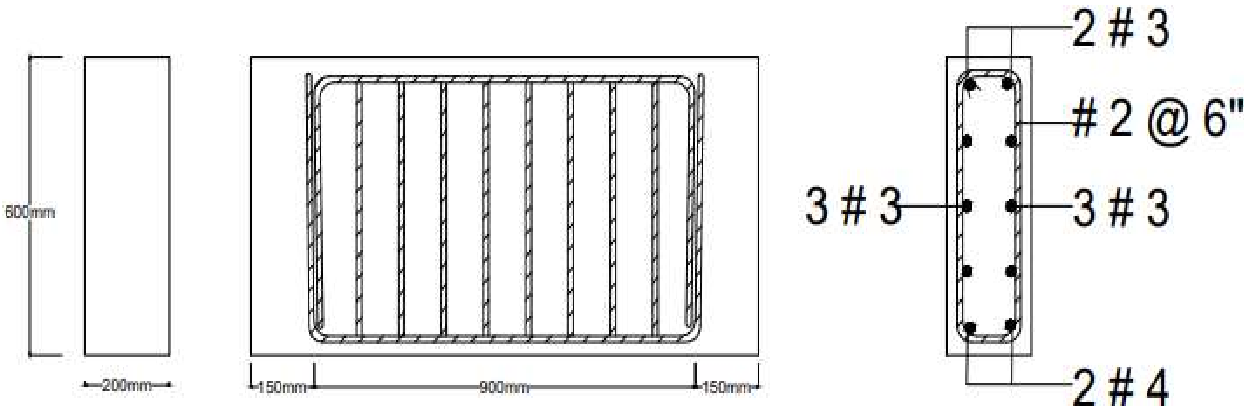

Figure 1: Detail Dimension of Deep Beams

Table 1: Detail of Specimens

Specimen ID	Bottom Rebars	Exposure Temperature	Retrofitted
DB-NS	2 #4 Bars	Ambient	No
DB-T	2 #4 Bars	Exposed to 550 ◦C	No
DB-NSR	2 #4 Bars	Ambient	Yes
DB-TR	2 #4 Bars	Exposed to 550 ◦C	Yes

2.4 Temperature Exposure

The sample DB-T with thermocouple was set at the heating Chamber. Specimen Beam was heated at high temperature for 24 hours on each side and the internal temperature of beam was noted at data logger attached with the thermocouple after every one hour. The beam was heated for 48 hours, and the maximum temperature achieved was 550°C and maintained the temperature at 542°C. Fire intensity was maintained to keep the temperature constant.

2.5 Test Setup

As shown in Figure 2, the simply supported deep beams underwent a three-point load test. The load is applied in the centre of beam at 530 mm from support by a 140 mm wide load plate. The support is arranged such that the centre of assembly aligns at a distance 150mm from both the supports so that edges of beam may not be crushed under the loading. A 2000-tone jeck was used to apply gradual load under displacement control.

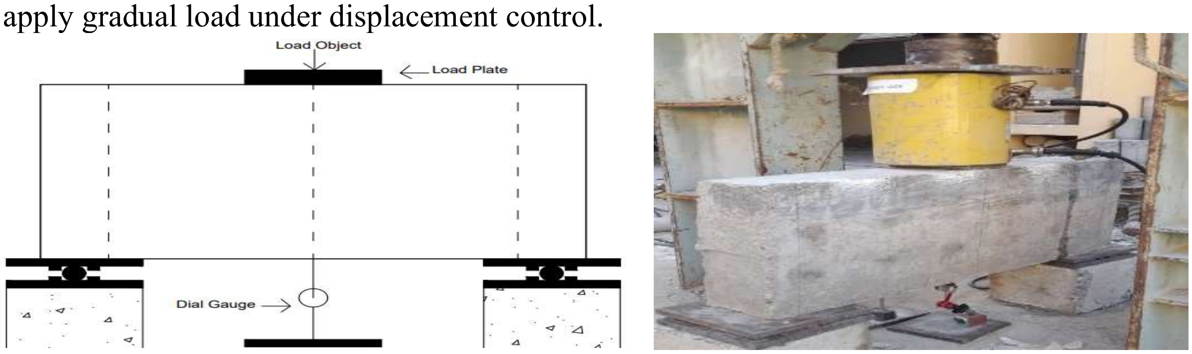

Figure 2: Testing Setup

2.6 Retrofitting Schemes

After testing DB-NS and DB-T a retrofitting scheme was employed as shown in figure 3. The beams were inverted for ease in work. Wider cracks of sample were cleaning the with wire brush and then filling them with bounding mortar after setting of mortar packers were installed in cracks to fill the crack with low Viscosity with the help of pressure pump.

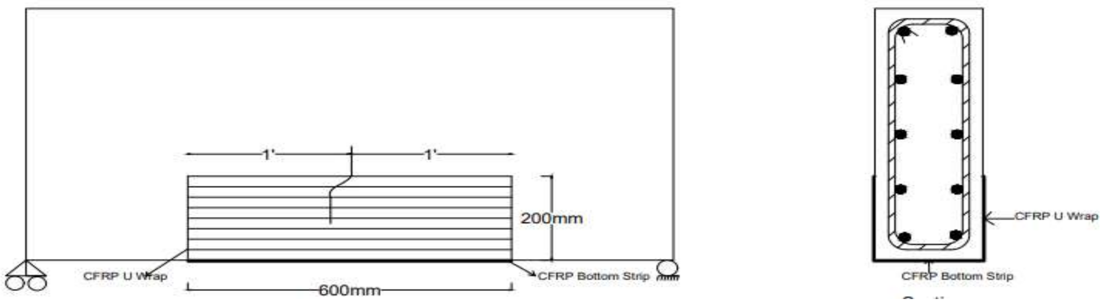

Figure 3: Retrofitting Scheme of deep beams

Wire brush and sandpaper with grander was used to roughen the beam surfaces. The properties of retrofitting material are depicted in table 2.

Table 2: Properties of retrofitting material

Material	Properties	Value
CFRP Strip/Sheet (CFW-600)	Tensile strength (N/mm2)	2,800
	Tensile modulus of elasticity (N/mm2)	165,000
	Thickness (mm)	0.60
	Percentage Elongation (%)	1.71
Adhesive Epoxy (Chemdar 300)	Tensile strength (Mpa)	71.48
	Tensile Strain at Breaking (%)	5.24
	Tensile Modulus of elasticity (Gpa)	1.87
Low Viscosity Epoxy (Chamdar 52)	Compressive Strength (N/mm2)	55
	Flexural Strength (N/mm2)	50
	Tensile Strength (N/mm2)	25
	Bound Strength to Concrete (N/mm2)	4
	Bound Strength to Steel(N/mm2)	12
Epoxy repair or Bounding Mortar (Chamdar 31)	Compressive Strength (N/mm2)	60-70
	Tensile Strength (N/mm2)	15-20
	Bound Strength to Concrete (N/mm2)	3.5
	Bound Strength to Steel(N/mm2)	15
	Modulus of elasticity(N/mm2)	4300

The surfaces were then cleaned to get rid of any dust or contaminants. A unidirectional CFRP longitudinal strip was added on deep beam's soffit in spans to increase the beam's flexural capacity and prevent flexural failure. A U-wrap consisting of a single layer of a unidirectional CFRP sheet was placed, with the fibers oriented longitudinally. The exterior surface of the concrete was coated with an epoxy primer coating to seal any gaps in the surface and establish a robust connection between the concrete and CFRP strip. The strengthening process is shown in figure 4.

Figure 4: Retrofitting Process

3 TEST RESULTS AND DISCUSSION

The crack patterns and failure mode of test samples is depicted by Table 3.

Table 3: Description of cracking pattern and failure mode of specimens

Sample	Failure	Shere Cracks	Flexural Cracks	Crushing
DB-NS	Flexure	No	Flexural crack	No
DB-T	Flexure	No	Major three flexural cracks	Slightly crushing near support
DB-NSR	Shere	Major diagonal cracks at left support to load plate	No	Yes
DB-TR	Shere	Diagonal cracks – Both support toward load plate	Peeling failure at top of CFRP Wrap and minor cracking of concrete	Crushing at load plate, web of section and upper top corner of support

Figure 5 shows compression of peak load in KN for all tested beams and Figure 6 shows maximum deflection in mm of beam at their peak load.

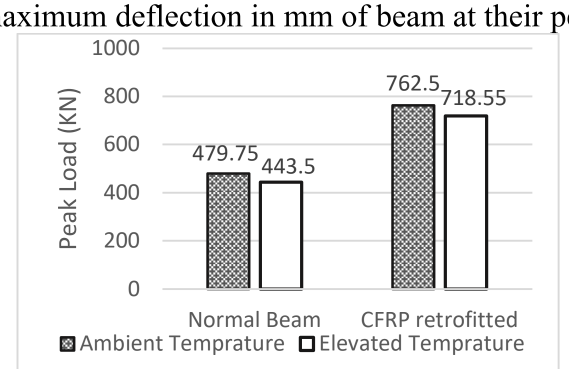

Figure 5: Peak Load

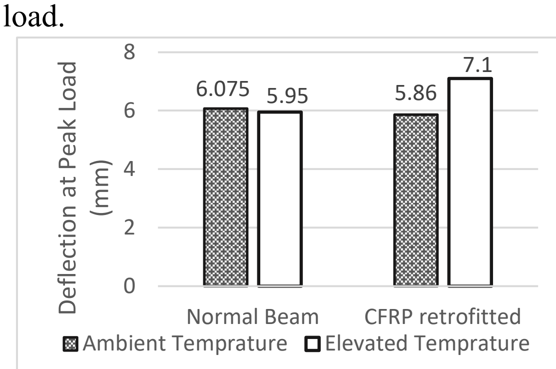

Figure 6: Maximum Deflection at Peak Load

3.1 Beam DB-NS

For beam DB-NS first flexural crack was detected at the bottom centre of the beam at the load of 374.23 KN. During loading crack open which grew and propagated straight toward the load plate on increasing the load. After that beam starts to decrease the load by increasing the deflection at mid span. Flexural crack was widened significantly at failure, no crushing of concrete was detected in the compression zone or at support. The flexural crack continued to spread and widen at peak load of 467.12 KN with a crack width of more than 5 mm, after that beam start yielding. The failure mode was pure flexural as shown in figure 7

3.2 Beam DB-T

In flexure zone, with the increase in load, vertical flexural cracks appeared, first flexural crack from the bottom at centre of span was detected at 351 KN that is 6.2% less than DB-NS. This crack spread toward the load plate as the applied load increased. When the load reaches 420 KN cracks width increase to 3.5 mm, upon reaching the ultimate load of 443 KN, diagonal cracks of 2 to 3 mm appear at one third of both supports and width of first crack reaches up to 5mm as shown in figure 8. This flexural crack opens notably after the peak load and both new propagated cracks meet the former crack at mid depth of beam. Concrete crushing was observed at the left support. Flexural cracks widen with an increase in the applied load. When the load is further increased yielding was observed without increase in further load. Crushing was not observed in the compressive zone. The mode of failure was like DB-NS. However, shear cracks were observed in DB-T. The observed shear cracks did not widen considerably compared with flexure cracks. 5 % reduction in ultimate load as compared to DB-NS was observed.

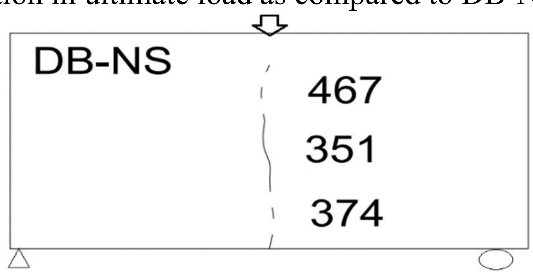

Figure 7: Crack Pattern of DB-NS

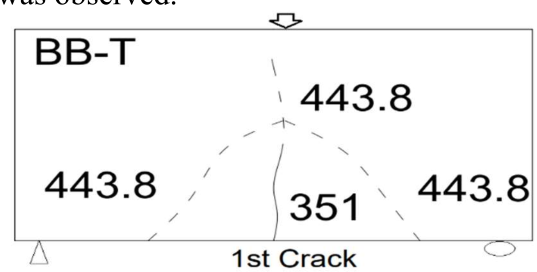

Figure 8: Crack Pattern of DB-T

3.3 Beam DB-NSR

DB-NSR is retrofitted beam of DB-NS. With the increase in load, increase in the deflection was observed in a liner manner, at a load of 339 KN and deflection of 2.29 mm the load starts to retrieve by increasing the deflection under sustained load. No cracking was observed, and no shedding of strip was observed until 520 KN. The first shear crack was noticed at 610 KN at the left support that is 42% more DB-NS's first flexural crack. As the load was increased, sudden failure in shear was observed at an ultimate load of 762 KN which is 38% greater than DB-NS and 42 % grater then DB-T with a deflection of 5.86 mm which is 3.5% less than DB-NS and 1.5 % lesser than DB-T. The crack that was propagated from left support at 520 KN as shown in figure 9 reaches the load point at ultimate load and beam deflects without taking more load thus a pure shear failure occurred. Sudden shear failure appears with notable shear deformation.

3.4 Beam DB-TR

DB-TR beam is retrofitted beam of DB-T. The load deflection curve is almost linear in the start till 253 KN, after that beam starts to revert the load by increasing the deflection. further increase in the load till 351 KN small hair line cracks appear on top corner of beam. At 443 KN, 2 mm cracks appear at bottom of beam on both side of CFRP U-wrap and a hairline crack appears from left support propagating towards load point. At 490 KN minor pealing of CFRP strips was observed by a knocking sound. At 513 KN right side 2 mm crack extends further and reaches up to two third portion of beam. At 560 KN this crack expands up to 3 mm width. When the load reaches 571 KN a proper visible pealing of CFRP U wrap was observed from top corner and crack width increase. At 606 KN another crack appears from the bottom span of the beam and meets the already propagating crack near the U wrap and reaches to load point. At 700 KN crack width further increases to a width of 5 mm and finally failure occurs at 713 KN with the deflection 7.1 mm. DB-TR shows larger deflection at the peak load that is 17 % more than DB-NSR,16 % more than DB-T and 14 % more than DB-NS. Apart from the ultimate load dropping as an indication of failure, peeling failure of CFRP U-wrap was observed. The behaviour of DB-TR is more ductile than DB-NSR due to pealing of CFRP wrap. Although failure crack shows a shere failure. The ultimate load is 5% less than DB-NS while 38% high than DB-T and 34% more than DB-NS. The crack pattern of DB-TR is depicted by figure 10.

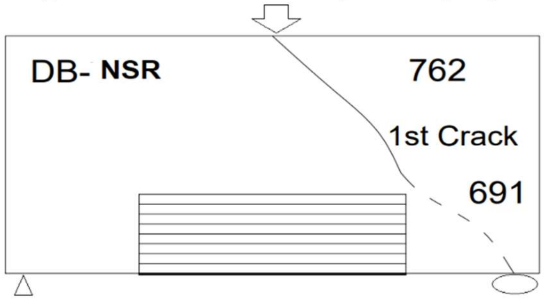

Figure 9: Crack Pattern of DB-NSR

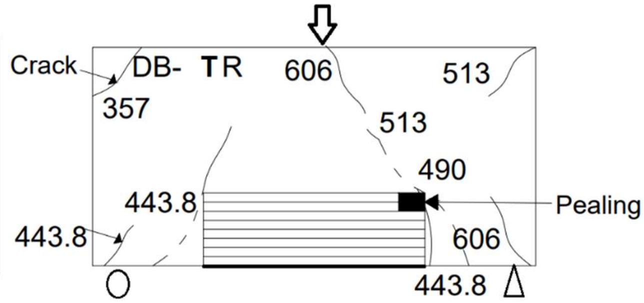

Figure 10: Crack Pattern of DB-TR

4 CONCLUSIONS

A 550° C temperature exposure does not alter the failure mood of a flexural controlled deep beams. Mood of failure can be shifted from flexure to shear by retrofitting a flexural cracked deep beam. The flexure retrofitting scheme by U-wraps CFRP strip was found efficacious in increasing the deep beam's load carrying capacity. The retrofitted deep beams exhibited a 38 % increase in load carrying capacity. The encountering to a temperature of 550 °C lessen the load carrying capacity up to 6 % in uncracked deep beam and 5.8 % in flexural retrofitted deep beam. There is increase in ductility of heat exposed retrofitted beam then ambient temperature retrofitted deep beam, this is because shredding of CFRP strips was observed in heated retrofitted deep beam due to loss of strength of skin concrete. This shredding of CFRP wrap increases the deflection of deep beam. 13 % more deflection was observed in heated retrofitted deep beam as compared to normal retrofitted deep beam. Exposure to high temperature also affects the failure mood of retrofitted beam in normal retrofitted beam pure and sudden shear failure was observed while in heated retrofitted beam although failure was in shear but diagonal flexural fracks also appears.

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