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Performance of Heat Affected RC Beams after Repair

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Abstract

Exposure of reinforced concrete (RC) buildings to an accidental fire may result in cracking and loss in the bearing capacity of major components like columns, beams and slabs. It is challenging for structural engineers to develop efficient repair and rehabilitation techniques that enable RC members to restore their structural integrity after being exposed to intense temperatures for considerable period of time. Therefore, this study was carried out to generate experimental data on repair techniques and performance of heat affected RC beams after repair. Data is presented from tests conducted on RC beams. Initially RC beams were exposed to high temperatures by furnace in which rate of heating is as per standard ISO 834 furnace and repaired using two different repair materials 1 and 2. Non-destructive tests (NDT) were conducted for all the beams after a curing period of 28 days and again after temperature exposure of 100 to 700°C with increments of 100°C each for 3 h duration. After heating, the fire affected beams were repaired with repair materials 1 and 2. Thereafter, these test specimens were tested by NDT followed by flexure test. The load deflection behaviour of RC beams repaired with repair material 1 and 2 have been studied and presented.

Keywords: concrete, elevated temperatures, polypropylene fibres, RC beams, steel fibres.

1. INTRODUCTION

The most commonly applied structural supplies are reinforced concrete because of its good robustness, which has been used for many years to build a wide variety of structures from house to bridge. Subsequently little maintenance or repair work is usually required on concrete structures that have been designed and built well unless they are exposed to aggressive conditions. Inadequate design detailing, quality of construction, reinforcement congestion, maintenance, chemical attacks, fire accidents, atmospheric effects and natural disasters. All of these factors affect durability of concrete structures. Except in extreme cases, most of the structures require reinstatement to meet its serviceable requirements by suitable repair techniques. Evaluation, repair and rehabilitation of fire damaged structures have become a topical interest. This specialized field involves experts in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. With the occurrence of local damage or even complete collapse of buildings under fire, research and development efforts are carried out in these related disciplines. It has become a challenge for Civil Engineering community to make a structure functionally feasible after the damage due to fire. There are various options for repair materials and repair methods available for executing repair jobs [1]. The selection of the suitable material and method for repair is very important to achieve efficient, cost-effective and durable repair.

2. LITERATURE SIGNIFICANCE

Reviews of work done by various researchers discuss the behaviour of concrete at elevated temperatures and the rehabilitation and repair of structures. Several fire tests have been conducted on reinforced concrete beams at elevated temperatures during the past three decades as the accumulated annual loss of life and property due to fire is comparable to the loss caused by natural disasters. This necessitates development of fire resistance design and proper repair of damaged structures. A brief review of the existing literature on the behaviour of RC beam under elevated temperatures and the selection of repair materials for the composite of the fire damaged structures is presented.

Ellingwood and Lin (1991) studied the flexure and shear behaviour of reinforced concrete beams exposed to severe fire. Based on results all beams developed shear cracks as early as 90 minutes after the start of the fires. Flexural cracks formed in the positive moment region approximately 30 minutes later and extended rapidly, as a result all the beams failed in flexure rather than shear. The significant factor affecting the behaviour of a properly designed reinforced concrete flexural member is the temperature history in the reinforcement.

Kumar et al (2009) carried out an investigation to generate experimental data on residual flexural strength of heated reinforced cement concrete (RCC) beams and their strengthening using various repair techniques. The beams were heated in two stages. In the first stage, beams were kept at each temperature for 3 h between 100°C and 1000°C, in increments of 100°C. Beams exposed to temperature ranging between 100 and 500°C were repaired by applying paint. The beams exposed to temperature ranging between 600 and 1000°C were repaired for spalling. In the second stage, all repaired specimens were again heated. After allowing them to arrive at room temperature these test specimens were tested for flexural strength and conclude that up to 600ºC the application of heat-resisting paint performed better.

Naaman (2006) investigated three different lengths of polypropylene fibres; 12.7, 19.05, and 25.4 mm in his study and found that only a slight improvement in performance is achieved in specimens with longer fibres, that is, a higher aspect ratio. The proportion between length and diameter or equivalent diameter is an important fibre consideration which is defined as the fibre aspect ratio.

Milind (2015) investigated the performance of polypropylene fibre reinforced concrete for High strength concrete (M30and M40) mixes with the addition of various proportions of polypropylene fibressuch as 0%, 0.5%, 1%, 1.5% & 2%. The experimental test results concluded that the optimum Polypropylene fiber content is 0.5%.

Deepthy (2016) studied the performance of steel fiber reinforced concrete under elevated temperatures and predict the performance characteristics of steel fibers with different percentages (0%, 0.5%, 1%) on concrete with temperatures (200°C, 400°C). Steel fibres used in the study were hooked end Steel fibers of two different diameters 0.55mm with 35mm length and 0.75mm diameter with 60mm and aspect ratio of 63.63 and 80. It was observed that with 1% Steel fiber content the compressive strength is very much high compared to the control mix. Reduction in compressive strength appears to decrease in a systematic manner with increase in steel fibers.

3. OBJECTIVES OF THE PRESENT STUDY

This paper is an initialization in the repair techniques for the fire affected beams. In the present study crimped flat steel fibres with length 42mm, diameter 0.7mm and aspect ratio 60 at volume fraction 1% were used. Also polypropylene fibres with length 12mm at 0.3% by cement weight were used in the present work. Steel and polypropylene fibres are used separately in the present study.The objective of this investigation is to experimentally examine the behavior and damage of RC beams subjected to high temperatures. Also to arrive at the compatibility between the repair material and substrate and the appropriate repair procedure for heat damaged RC beams.

4. EXPERIMENTAL PROGRAM

4.1 Reinforcement details and material properties

To study the flexural strength of RC beams at higher temperatures, a total of 30 beams were cast. All the beams were 1200 mm long and 112 mm x 240 mm in cross section. Beam is reinforced with two bars at the top and three bars at the bottom. All the five main bars are 10 mm in diameter. Steel bars of 6 mm diameter were provided as stirrups. The spacing between the lateral ties is 60 mm centre to centre throughout the length of 1200 mm. The reinforcement details of the beams is shown in Fig.1.High Yield Strength Deformed bars (Fe415) conforming to IS 1786-1985 were used as longitudinal reinforcement. Mix proportions of 1: 2: 4 were used with a water cement ratio of 0.48. The cement used was Portland Pozzolona Cement (PPC) conforming to IS 1489-1991. The fine aggregate was natural river sand conforming to zone II of IS 383-1970. The coarse aggregate used was crushed hard blue granite passing IS 20 mm sieve and retaining on IS 4.75 mm sieve. Potable water of pH value 6.72 was used.

4.2 Casting of RC beams

The clear cover provided in the beam is 15 mm and was maintained using cover blocks. Cover blocks were kept inside the beam moulds at the bottom and sides. The reinforcement cage was placed in the mould. The beam moulds were filled with concrete. Each layer was compacted using a needle vibrator. The surface was levelled with trowel and was marked for identification. After the curing period of 28 days, all the beams were tested initially by Rebound hammer and ultrasonic pulse velocity tester respectively. After testing the specimens they are exposed to temperatures ranging from 100 to 700°C with increment of 100°C each for 3 h duration and allowed to cool to room temperature. A custom built electric furnace according to ISO 834 specifications was used to heat the RC beams as shown in Fig. 2(a), 2(b) and 2(c). Again the specimens were tested by Rebound hammer and ultrasonic pulse velocity tester after exposed to high temperatures.

Fig. 2 (a) RC beam specimens before heating

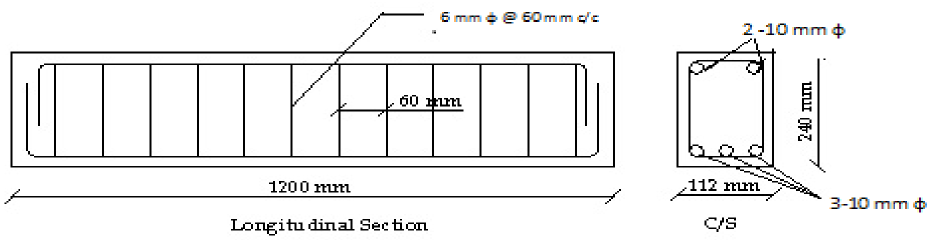

Fig.1 Reinforcement detailing of the beam

Fig. 2 (b) RC beam specimens in to the heating chamber

Fig. 2 (c) RC beam specimens after heating

4.3 Sub-surface preparation

The original concrete cover was chipped off up to 15 mm thick to expose the existing reinforcing bars. Cleaning of the reinforcing bars preceded immediately using sand blasting equipment until all the reinforcing bars were to bare white metal finish as shown in Fig.3. High pressure water spraying was used immediately before epoxy application in order to remove all loose and defective concrete and for final cleaning of reinforcing bars. This utilized a 41.3 MPa high pressure washer as shown in Fig.4. The quality of bonding surface and rough texture was assured by this final surface preparation procedure. The tight spaces and reinforcing bar cages required Nitobond SBR latex epoxy application by hand brushing shown in Fig.5. It was therefore necessary to require that the epoxy would have an adequately long "overlay time" of at least six hours to allow application, erection of forms and pouring of concrete.

Fig. 3 Sand blasting of chipped beam

Fig. 4 High water pressure spraying

Fig.5 Applying epoxy resin

4.4 Casting of RC chipped beams

Nominal mix of 1:2:4 mix proportions were used with water cement ratio of 0.48. The cement used was Portland Pozzolana cement (PPC). The coarse aggregate used was crushed stone passing IS 10 mm sieve and retained on IS 4.75 mm. The fine aggregate used was river sand conforming to zone-II of IS 383-1970. For repairing the beams two materials were used.

1. Repair material 1(RM 1): The crimped flat steel fibres with length 42mm, diameter 0.7mm and aspect ratio 60 at volume fraction 1% were used.
2. Repair material 2(RM 2): The polypropylenes with length 12mm at 0.35% of cement weight were used.

The 15 mm clear cover that is removed is again maintained using cover blocks inside the beam moulds at the bottom. Concrete layer of 15 mm thickness was laid on the bottom of the mould. After the primer is applied, the specimen is placed in the mould again as shown in Fig.6. Then the gap between the chipped beam and the mould was filled with concrete and repair material. Each layer was compacted using tampering rod. The surface was levelled with trowel and was marked for identification. The beam specimens were demould after 24 h of casting. The demoulded specimens were cured in a water tank for a period of 28 days and there after tested by rebound hammer and ultrasonic pulse velocity tester. Then the repaired beams are tested for ultimate failure load on a100 ton Universal Testing Machine (UTM) with two point loading as shown in Fig.7.

Fig. 6 Specimen placed in the mould

Fig. 7 RC repaired beam in UTM under two point loading

5. RESULTS & DISCUSSION

5.1 Visual appearence

There is no significant color change in the beams subjected to temperatures up to 200ºC. The beams subjected to temperature 300ºC and 400ºC turned light yellow in color after cooling them to room temperature.There a significant colour change in the beams subjected to 400 to 700ºC which turned to light brown from red hot in colour after cooling them to room temperature.

5.2 Non destructive tests

5.2.1 Compressive strength through Rebound hammer

Fig.8 shows the variation of average compressive strength of repaired beam specimens with temperature. Referring to Fig.8 it was observed that the beams which are repaired with repair material 1exhibit more compressive strength than the beams repaired with repair material 2after temperature exposure. After 300ºC exposure bothrepair materials performed better than heat affected beams.

5.2.2 Pulse velocity through ultrasonic pulse velocity

Fig.9 shows the variation of average pulse velocity of beam specimens with temperature. Referring to Fig.9, it was observed that the beams heated up to 700ºC and repaired with both repair materials exhibit less average pulse velocity than the beams at room temperature. However, these values are better than the values of heat affected beams.

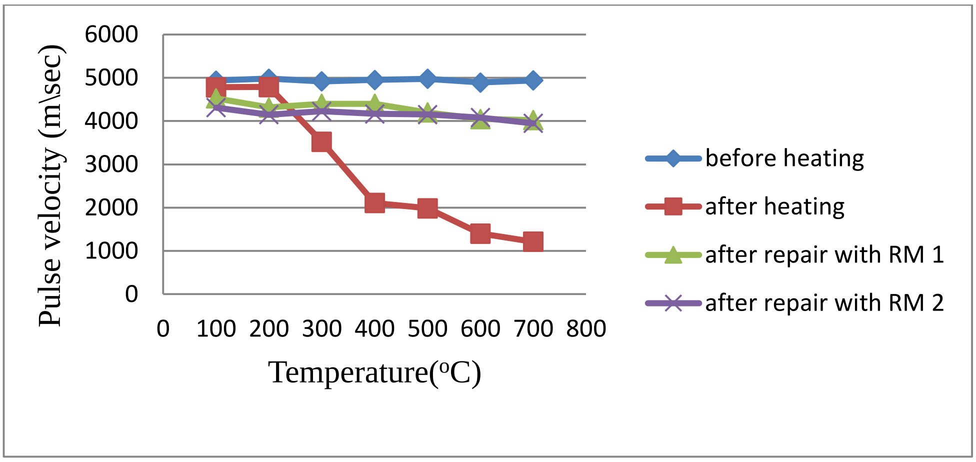

Fig.9 Variation of average pulse velocity with temperature

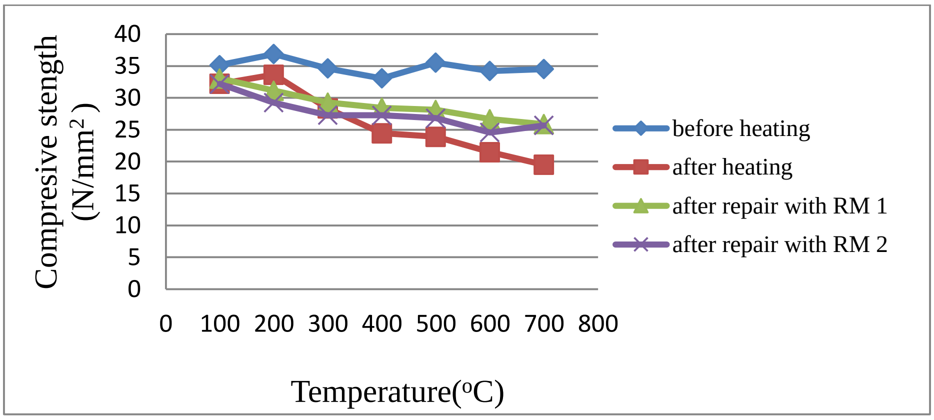

Fig.8 Variation of compressive strength (by Rebound hammer) with temperature

5.2.3 Load- deflection behavior of repaired RC beams

The rate of deflection gradually increases as the temperature to which the beams are exposed increases. Due to the increase in the temperature, the beam looses its strength proportionally. Therefore the load bearing capacity decreases which leads to the rise in deflection. At all temperatures, the stiffness of the beams repaired with steel fibres has been observed to be more than the beams repaired with polypropylene fibres. The area covered by the load-deflection curve is an index for toughness of the material. It is observed that in majority of the cases, the toughness of beams repaired with steel fibres has been observed to be more than that of beams repaired with polypropylene fibres.

Fig.10 to Fig.16 show the load-deflection behavior of beams exposed to temperatures 100, 200, 300, 400, 500, 600 and 700ºC respectively.Fig.17, shows the variation of percentage flexural strength with temperature. It was observed thatat all temperatures, the flexural strength of the beams repaired with steel fibres has been observed to be more than that of beam repaired with polypropylene fibres. Up to 400ºC beams repaired with steel fibres has a marginal increase in flexural strength compared to that of heat exposed beams but for 500 to 700ºC range it performs better than heat exposed beams.

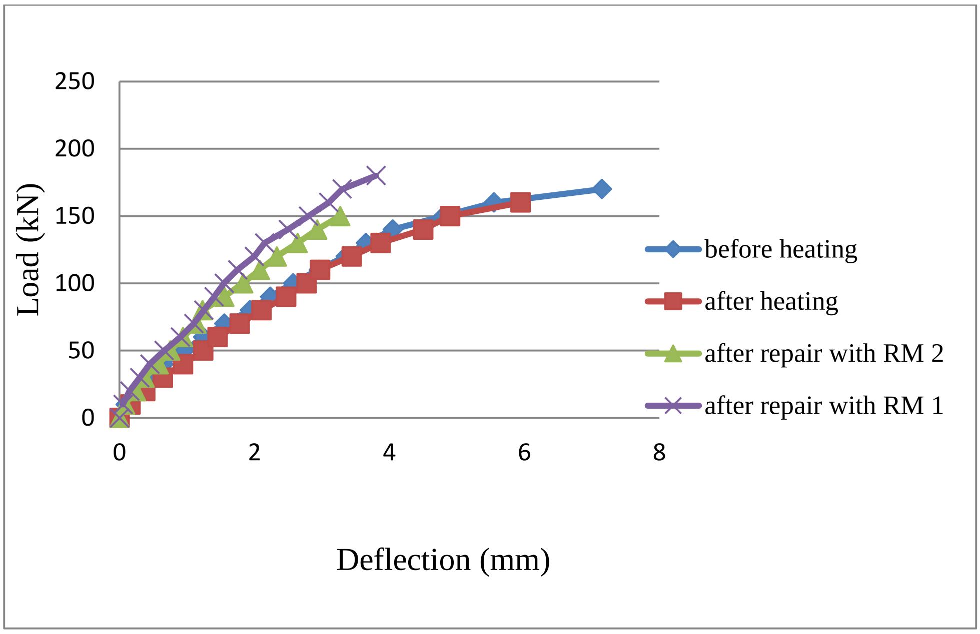

Fig.10 Load – Deflection behaviour of RC beam exposed to 100 ^{0}C

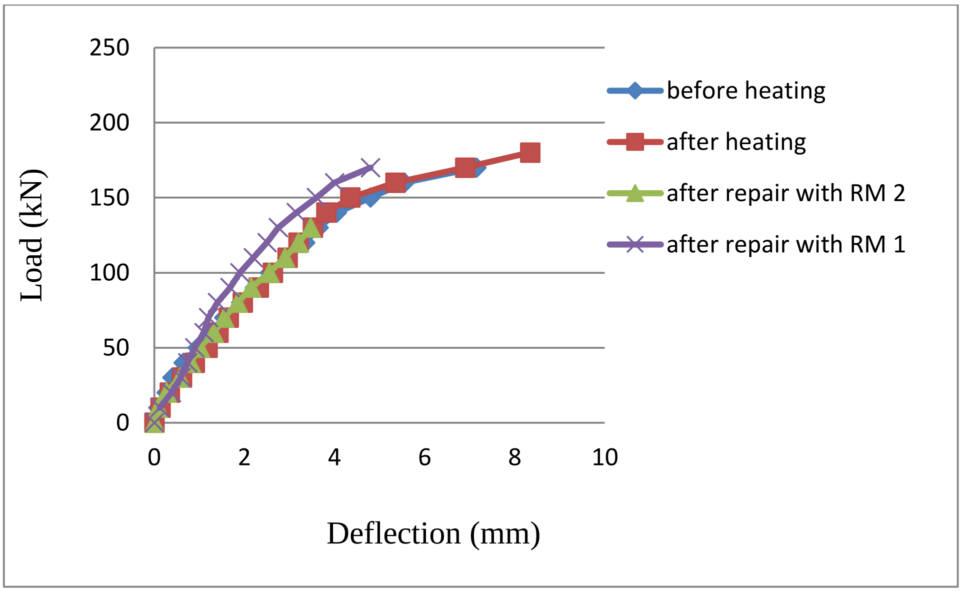

Fig.11 Load – Deflection behaviour of RC beam exposed to 200 ^{0}C

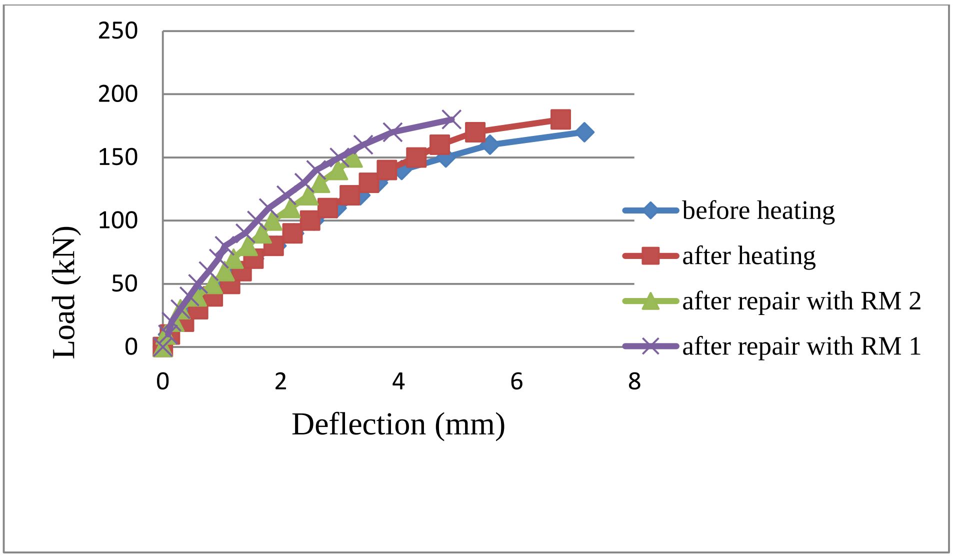

Fig.12 Load – Deflection behaviour of RC beam exposed to 300 ^{0}C

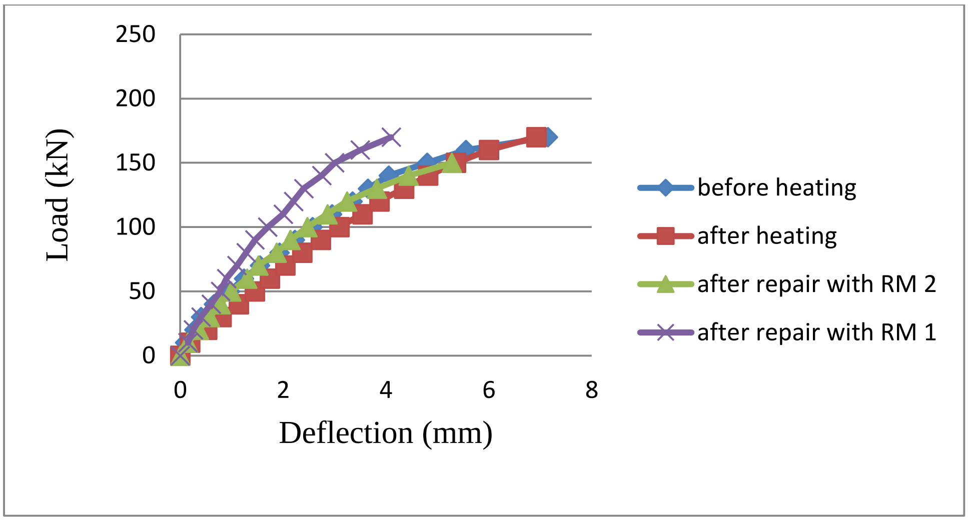

Fig.13 Load – Deflection behaviour of RC beam exposed to 400 ^{0}C

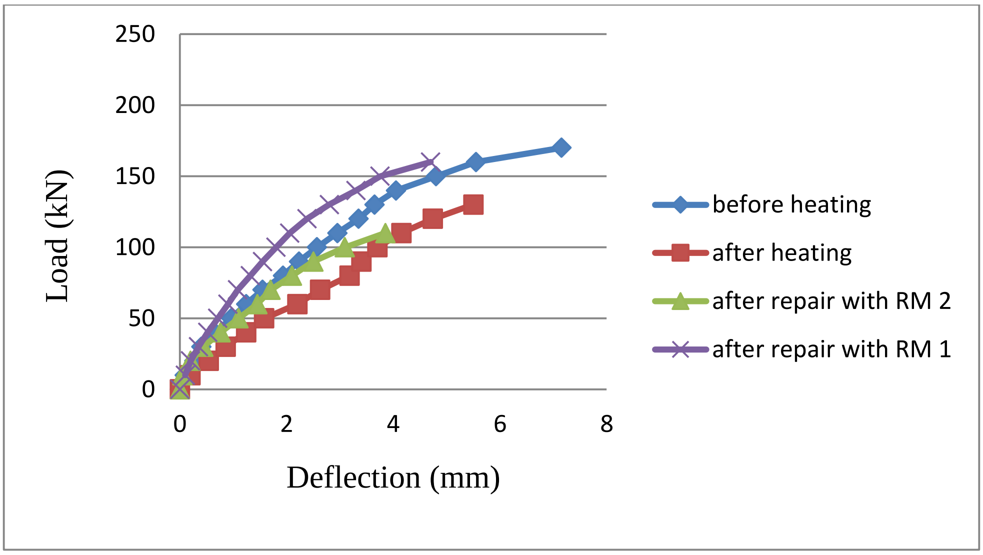

Fig.14 Load – Deflection behaviour of RC beam exposed to 500^{0}C

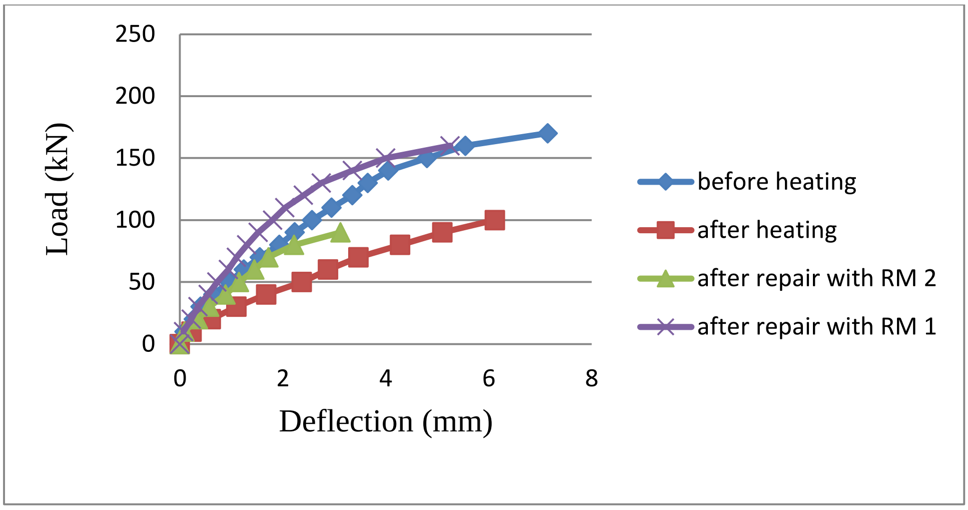

Fig.15 Load – Deflection behaviour of RC beam exposed to 600 ^{0}C

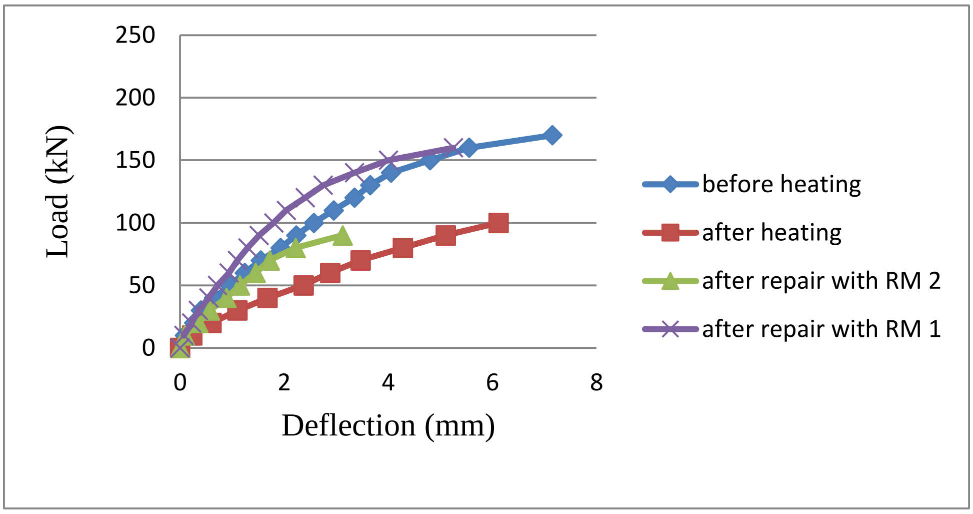

Fig.16 Load – Deflection behaviour of RC beam exposed to 700^{0}C

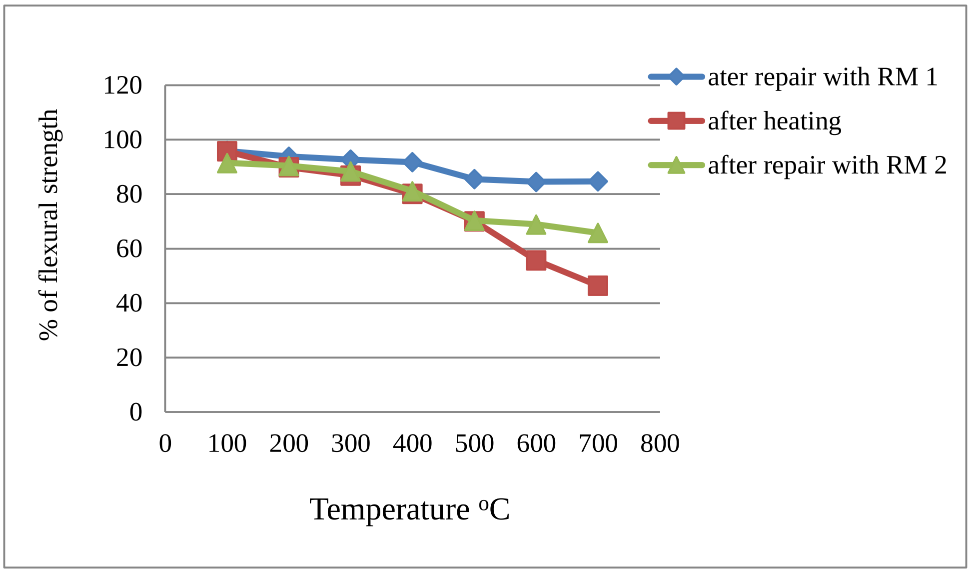

Fig. 17 Variation of % flexural strength with temperature

6. CONCLUSIONS

Based on experimental results of RC beams subjected to high temperatures before and after repair, the following conclusions are drawn.

- Based on Rebound hammer test results, beams repaired using steel fibres performed better than the beams repaired using polypropylene fibres.
- The addition of steel and polypropylene fibres to the cover concrete of heat affected beams enhanced the compressive strength by about 24%.
- The ultrasonic pulse velocity test results show that RC beams repaired with steel fibres and polypropylene fibres exhibited lower pulse velocities than that of companion beam. However, these pulse velocity results show a good concrete quality grading according to concrete quality grading specified by IS 13311 (Part1):1992.
- RCbeams repaired using steel and polypropylene fibres recorded a mximum drop in UPV by about 13% of pulse velocity upto 200°C, while beyond 200°C the pulse velocity of repaired beams was much greater by about 60% than the heat affected beams.
- Up to 300°C, beams repaired using steel fibres and polypropylene fibres performed better than heat affected beams as well as companion beam at room temperature with respect to stiffness.
- In majority of the cases, the toughness of beams repaired with steel fibres has been observed to be more than that of beams repaired with polypropylene fibres.

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