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A Study on Repair Materials for Fire Affected Reinforecd Concrete Beams

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Abstract: Exposure of reinforced concrete RC building to an accidental fire may result in cracking and loss in the bearing capacity of their major components like columns, beams and slabs. It is challenge for structural engineers to develop efficient rehabilitation techniques that enable RC beams to restore their structural integrity, after being exposed to intense fires for long period of time. Relatively few studies have been under taken on repair techniques for structural elements. Therefore, this study was carried out to generate experimental data on repair techniques for fire affected RC beams. A total of fourteen RC beams were cast with similar cross-sectional details, length and grade of concrete and clear cover provided to reinforcement. Fourteen beams were meant for fire exposure and the remaining one beam is used as companion beam. After the curing period of 28 days, all the 14 beams were tested initially by rebound hammer and ultrasonic pulse velocity meter. After testing the specimens individually meant for temperature exposure of 100 to 600^{o} C with increments of 100^{o}C each for 2 h duration and allowed to cool to room temperature. Again the specimens were tested for rebound hammer and ultrasonic pulse velocity tester after exposed to elevated temperatures. After heating, the fire affected beams were repaired with repair technique 1 and 2. Again specimens were tested for rebound hammer and ultrasonic pulse velocity tester. Thereafter, these test specimens were tested, for flexure. The percentage variations of average compressive strength by rebound hammer test and percentage variation of average pulse velocity by ultrasonic pulse velocity test have been studied. The load deflection behaviour of repair technique 1 and 2 of repaired beams have been studied and presented.

Key words: Reinforced concrete, structural integrity and rebound hammer.

1. INTRODUCTION

Reinforced concrete is the most frequently applied structural materials because of its good durability, which has been used for many years to build a wide variety of structures from house to bridge. Consequently little maintenance or repair work is usually required on concrete structures that have been designed and built well, with materials of quality, unless they are exposed to particularly aggressive conditions. A period of dynamic growth in its use came during the 1960s as a result of chronic shortage of housing. The commonly held view, that concrete is a durable, maintenance material has been changed recent years. Several examples can be shown as well as it was expected. Although hundreds of thousands of successful reinforced concrete structures that annually constructed worldwide, there are large number of concrete structures are deteriorate, or become unsafe due to inadequacy of design detailing, construction and quality of maintenance, overloading, chemical attacks, fire accidents, atmospheric effects, abnormal floods and natural disasters. All of these factors affecting durability of concrete structures. Except in extreme cases, most of the structures require restoration to meet its functional requirements by appropriate repair techniques. Concrete is generally considered to have good fire resistance since it has non- combustible and does not give off toxic fumes or smoke.(1)

The common changes in concrete properties associated with various speak temperatures are as follows:

Up to 120°C: Oven-drying temperature has negligible effect or damage on the pore system or microstructure of concrete. There is no change in colour properties of concrete up to these temperatures. Only free moisture is lost from within the concrete microstructure For temperatures lower than 120°C, concrete porosity varies very little and the shape and pore size distribution curves shows no significant modification.

Up to 250°C: Characterized by localized cracks and dehydration of the cementitious paste with complete loss of free moisture and a reduction in paste volume. Commencement of strength reduction.

300 - 600°C: Significant cracking of both the cementitious paste and aggregates due to expansion. Colour of concrete changes to pink.

At 400°C: Decomposition of calcium hydroxide.

Greater than 600°C: Complete dehydration of the cementitious paste with considerable shrinkage cracking, honeycombing and generally concrete become friable, very porous and easily broken down. Colour of concrete changes to grey. Strength lost.

Greater than 900°C: Colour of concrete changes to buff.

Greater than 1200°C: The various components of Concrete start to melt.

Greater than 1400°C: Concrete melts completely.

1.1 Spalling

Spalling of the concrete will occur when the intensity of the fire is such that moisture trapped within the concrete microstructure, achieves bursting pressures, due to the generation of superheated steam, sufficient to crack and spall the concrete.

1.2 Strength of Concrete

A significant loss of strength in the order of 30% - 40% takes place once the temperature of concrete has reached 300°C. Above about 500°C - 600°C more than 70% to 80% strength reduction takes place due to the resultant friable and porous microstructure which lies in the grey to buff colour range. In the temperature range of 150°C 300°C the loss of strength ranges between 5% and 30%.

1.3 Modulus of Elasticity: In the temperature range of up to 300°C the loss in modulus of elasticity of concrete is similar to the loss in strength and in the order of 40%. At around 550°C the loss in modulus of elasticity is in the order of 50%.

1.4 Steel reinforcement: Steel reinforcement (depending on the type) can lose up to50% of its yield strength while at elevated temperatures of the order of 600°C. However, it can fully recover its yield strength on cooling from temperatures of up to 450°C for cold worked steel and up to 600°C for hot rolled steel.

1. 5Bond between steel and concrete: The bond between steel and concrete can be adversely affected at temperatures higher than 300°C because of the greater thermal conductivity of steel compared to the cover concrete and differences in thermal expansion properties.

2 SELECTION OF REPAIR MATERIALS

There are a number of methods to repair and rehabilitate a structure but the selection of one particular procedure is finalized by enumerated reasons

- Ease of application
- Cost
- Available labor skills and equipment.
- Shelf life of the material
- Pot life of the material.

3 SCOPE OF THE WORK

Scope of present study is the repair techniques for RCC beams at elevated temperatures up to 700°C. Nominal mix of mix proportions 1:2:4 is carried out. RC beams of size 1200 mm×112 mm×240 mm were cast and cured for 28 days.(2)After 28 days of curing, beams were initially tested by rebound hammer and ultrasonic pulse velocity tester. After testing, the specimens were individually subjected to temperature exposure up to 700°C with increment of 100°C each for 3 hours duration and were allowed to cool down at room temperature. Again specimens were tested by rebound hammer and ultrasonic pulse velocity tester. Then remove 15 mm thick concrete cover on all sides of the beam by using hand-held breaker or chipping hammer.(3) Prepare substrata by removing surface contaminants by abrading methods. Then apply repairing materials to the beam by using epoxy bonding agents and cure for 28 days. After 28 days again specimens were tested by rebound hammer and ultrasonic pulse velocity tester. Then beams were tested in flexure.

4. FIRE TEST METHODS ACCORDING TO CODES AND COMMITTEE REPORTS

1. International Standard ISO 834 (1975)
2. ASTM E 119 (1988)
3. Japanese Industrial Standard JIS A 1304 (1994)

4.1 Ultrasonic Pulse Velocity:

In ultrasonic testing (UT), very short ultrasonic pulse-waves with centre frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are transmitted into materials to detect internal flaws or to characterize materials. A common example is ultrasonic thickness measurement, which tests the thickness of the test object, for example, to monitor pipe work corrosion (4&5).

The ultrasonic pulse velocity method could be used to establish:

- the homogeneity of the concrete
- the presence of cracks, voids and other imperfections
- change in the structure of the concrete which may occur with time
- the quality of concrete in relation to standard requirement
- the quality of one element of concrete in relation to another
- the values of dynamic elastic modulus of the concrete

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4.2 Schmidt Hammer Test:

A Schmidt hammer, also known as a Swiss hammer or a rebound hammer, is a device to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance. It was invented by Ernst Schmidt, a Swiss engineer. The Schmidt hammer is distributed by process worldwide.

4.3 UTM Testing: A universal testing machine (UTM), also known as a universal tester, materials testing machine or materials test frame is used to test the tensile stress and compressive strength of materials. It is named after the fact that it can perform many standard tensile and compression tests on materials, components, and structures.

5. Experimental Program:

During the life time of a structure, the possibility of accidental loading is always present**.** Fire is one of the most destructive accidental loads that an RC structure can be subjected to. The structure may also be exposed to fire even as a consequence of earthquake, due to presence of highly inflammable materials in modern furnishings, which causes major damage to the structure. The structural properties of concrete are modified by high temperature during fire. Concrete is believed to lose 25% of its room temperature compressive strength when heated to 300ºC and 75% at 600ºC. The elastic modulus is believed to be reduced in the same fashion.(6) Spalling may occur at the elevated temperatures. In this context, this research is aimed at studying the performance of different materials used for repairing fire affected beams.

Materials:

The materials used in the experimental work are

- Cement
- Coarse aggregate
- Fine aggregate
- Steel
- Water
- Steel fibers
- Polypropylene fibers
- Epoxy bonding material

Casting of test specimen:

Ingredients for nominal mix of 1:2:4 were mixed with water cement ratio of 0.48. The cement used was Portland Pozzolana Cement (PPC). The coarse aggregate used was crushed stone passing IS 20 mm sieve and retained on IS 10 mm sieve. The fine aggregate used was river sand conforming to zone-2 of IS 383-1970. The slump was found to be 30 mm.

Mixing:

Concrete was mixed in a tilting type concrete mixer (as shown in Fig.1.1). The mixer was hand loaded with coarse aggregate first, then with fine aggregate and with cement. During the rotation of the mixer, water was added to the ingredients inside. The rotation was continued up to 3 minutes. The mixer was tilted and the concrete was unloaded on a clean platform.

Casting of cubes

To study the compressive strength of concrete, 3 cubes of (150 mm x 150 mm x 150 mm) size were cast for each batch of concrete mix for each beam. Oil was applied to the cube moulds and is filled with concrete. The concrete filled cube moulds were placed on table vibrator and are vibrated for 1 minute. After the compaction was completed, excess concrete was removed with trowel and the top surface is levelled.

Casting of RCC beams:

To study the compressive strength of RCC beams at higher temperatures, a total of 15 beams were cast, out of which one beam is used as a companion beam and the remaining fourteen beams were meant for temperature exposure. 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 8 mm diameter were provided as stirrups. The spacing between the lateral ties is 60 mm centre to centre throughout the length of 1200mm.(7)

The reinforcement cage is shown in the Fig.1.3. The clear cover provided in the columns is 15 mm and the clear 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 leveled with trowel and was marked for identification.

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Fig.1 Beams after casting

Curing of specimens:
The cube and beam specimens were de-mould after 24 hours of casting. The de-mould specimens were cured in a water tank for a period of 28 days (as shown in the Fig.1.5).

Fig.1.2 Curing of specimens

Exposing the specimens to higher temperatures:
The specimens were exposed to temperatures ranging from 100 to 700^{0}C with increments of 100^{0}C for duration of three hours. The beam and cubes were placed on the platform of the separated part of the furnace and pushed into the heating chamber and was locked with the screws provided. Each of the target temperatures was set in the control panel after the beam was placed inside the furnace. Initially the temperature inside the furnace was 27^{0}C. It took some time for the furnace to reach the required temperature depending upon the set temperature i.e. more time for higher temperatures.

Repairing stages

Sub surface preparation: The original concrete cover was chipped off up to 15 mm thick to expose the existing reinforcing bars.

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-2 of IS 383-1970. For repairing the beams two materials were used.

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

RESULTS AND DISCUSSION

In the present study the behaviour of fire effected RCC beams after repairing is studied. A total of 15 beams of M20 grade were cast with similar cross-sectional details, length, rienforcement, grade of concrete and clear cover. Out of those beams, 14 beams were meant for temperature exposure and remaining one beam is used as companiagn beam. Beams are exposed to temperatures ranging from 100-700^{0}C with increments of 100^{0}C for duration of 3 h. The specimens after exposure to high temperatures were cooled down to room temperature by air cooling method. The specimens were tested for UPV and rebound hammer test for both before heating and after heating.

After heating, 14 beams were chipped off up to 15 mm thick clear cover by chipping hammer. Loose and residual materials on the chipping beam were cleaned by high pressure water jet spray and sand blasting techniques. The tight spaces and reinforcing bars cages required Nit bond SBR latex epoxy application by hand brushing.

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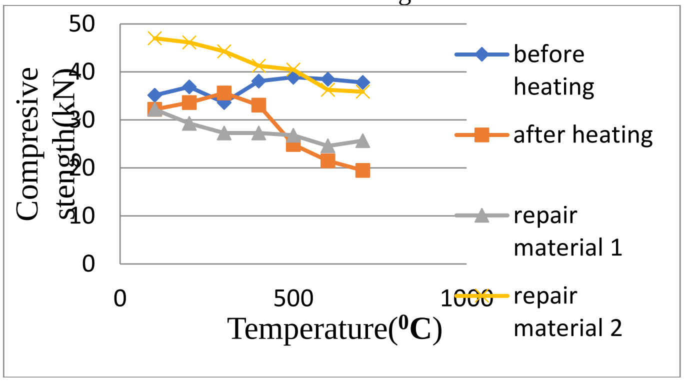
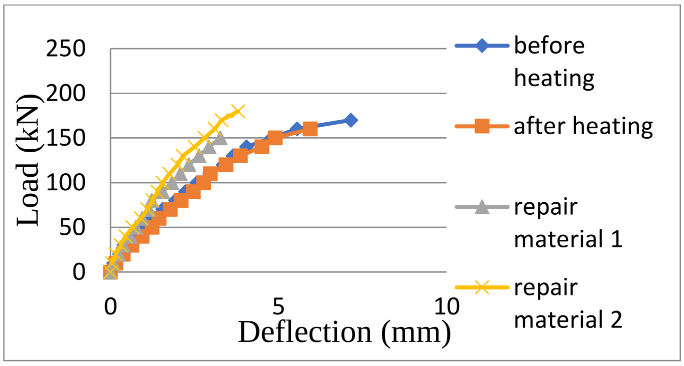
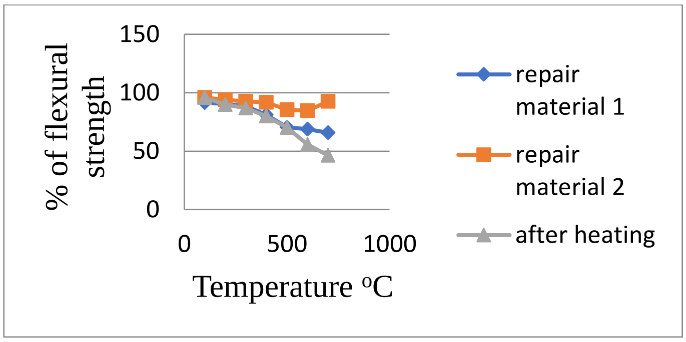
1) Repair material 1: Out of those beams, 7 beams were cast with crimped flat steel fibers. These fibers having length 42mm, diameter 0.7 mm and aspect ratio 60 at volume fraction 1% were used.
2) Repair material 2: Remaining 7 beams were repaired by polypropylene fibers. These fibers having length 12mm at 0.35% cement weight is used.



Variation of compressive strength by Rebound hammer with temperature



Load – Deflection behaviour of RC beam exposed to 100 ⁰C



Variation of % of flexural strength with temperature

Crack Patterns: Overloading a concrete member may cause several types of cracks. Depending on the direction and location of the crack (vertical, diagonal, top, bottom, etc.), the type of loading stress can be identified.

Fig.2.6 Beam crack pattern at 400°c after repair with repair material 1

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CONCLUSIONS

1 Up to 300^{0}C, repaired beams using steel fibers (repair material1) and polypropylene (repair material 2) fibers performed better than fire affected beam as well as companion beam at room temperature with respect to stiffness.
2 At 400 to 600^{0}C, repaired beams using polypropylene fibers performed better than fire affected beam as well as companion beam at room temperature with respect to stiffness.
3 At 700^{0}C, repaired beams using polypropylene fibers performed nearly same as fire affected beam as well as companion beam at room temperature with respect to stiffness.
4 Repaired beams using steel fibers performed poor at 700^{0}C as compared with companion beam.
5 Based on Rebound hammer test results, repaired beams using polypropylene fibers performed better than companion beam and fire exposed beam in compression.
6 Repaired beams using steel fibers performed poorly in compression as compared to repaired beams using polypropylene fibers and companion beam.
7 At all temperatures, the flexural strength of the repaired beam with polypropylene fibres has been observed to be more than that of repaired beam with steel fibres.
8 At all temperatures, the stiffness of the repaired beam with polypropylene fibres has been observed to be more than that of repaired beam with steel fibres.

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