STRENGTHENING OF HEAT DAMAGED REINFORCED CONCRETE CYLINDERS

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Abstract

The purpose of this study is to investigate the effectiveness of various strengthening techniques in restoring heat damaged reinforced concrete. A series of 40 reinforced concrete cylinders were tested under concentric compression after being jacketed externally with high strength fiber reinforced concrete (HSFRC), Ferrocement (FC) and Glass fiber reinforced polymer (GFRP) jackets. Concrete specimens were exposed to elevated temperatures ranging from room temperature to 900 ºC. The overall response of strengthened specimens was investigated vis-à-vis un-strengthened specimens in terms of axial compression, axial displacement and axial stress strain behaviour. The results indicate that important gains in strength and ductility can be achieved by strengthening heat – damaged R.C cylinders by HSFRC, FC and GFRP external Jacketing. GFRP jacketing was found to be the most effective method of strengthening fire or heat damaged concrete structures.

Keywords: concrete cylinders, strengthening, GFRP, Ferrocement, HSFRC

INTRODUCTION

Reinforced Concrete structures (RCC) may require strengthening for a various reasons. Heating or fire accidents in buildings demands repair and rehabilitation. Many experimental techniques have been used in recent years to strengthen RCC columns under ambient condition using suitable retrofitting and strengthening techniques. Materials of strengthening include FRP wrapping, FC jacketing, HSFRC, Steel plate bonding etc. Apart from low maintenance cost and improvement in the service life of buildings, Fibre Reinforced polymer (FRP) wrapping have several benefits like high strength, light weight, resistance to corrosion, low cost, and versatility (Ehsani et al, 1998). Also the interaction between concrete and fiber enhances concrete strength and ultimate strain (Luca et al, 2011). Effectiveness of FRP jacketing is significant in columns with circular cross section (Lam et al, 2003). Many researchers have emphasized the potential usage of FC laminates in repair and rehabilitation of concrete structures. Increased strength and ductility were observed in FC encased short circular and square concrete columns with unreinforced and reinforced cores for both axial and eccentric loading conditions (Kaushik et al, 1990). Apparent stiffness and ultimate load carrying capacity has been increased due to FC retrofit coating in new structures, repair and rehabilitation of existing structures and marine environment (Nedwell et al, 1990, Mourad et al, 2012). HSFRC provides a better alternative to normal concrete, with high strength/weight ratio, high toughness, excellent durability, and moreover cost effective than conventional materials. Utilization of composite materials in rehabilitating structures can greatly reduce maintenance, improved life safety and service life (Haddad et al, 2011). Literature review on HSFRC exhibits the possibility of designing structures with new geometries and shapes with great improvement in strength (Martinola et al, 2010). However, literature indicates that the

repair of heat damaged reinforced concrete elements with these strengthening techniques have not been investigated in detail (Haddad et al, 2011, Yaqub et al, 2011, 2012).
The main aims of this research are to investigate the effectiveness of applying HSFRC, FC and GFRP jackets on heated one-sixth-scale reinforced concrete cylinder; and to study the behavior of damaged and repaired elements in terms of strength gain, ductility and failure modes.

1 EXPERIMENTAL PROGRAMS

The experimental program consists of testing one-sixth- scale cylinder (150 mm dia) specimens with a height of 450 mm in three phases as follows; Level 1: Control specimens without any damage and without jackets, Level 2: Specimens were induced with heat damage and without jackeing, and Phase 3: Heat damaged specimens strengthened with HSFRC, FC, and GFRP jackets. The RC cylinders numbers and details are given in Table 1. The dimension and reinforcement details are shown in Fig.1.

Tab. 1 Specimen Details

Temperature	300	600	900
Designation & Wrapping Methods	CC3 CC3 HSFRC CC3 FC CC3 GFRP	CC6 CC6 HSFRC CC6 FC CC6 GFRP	CC9 CC9 HSFRC CC9 FC CC9 GFRP CC9MC

1.1 Materials properties

Concrete was prepared with ordinary Portland cement, Natural River sand, and crushed limestone aggregate of maximum size 12.5 mm with tap water. Cylinder compressive strength of 37.19 MPa was obtained after 28 days. The concrete mix consisted of 450 kg/m^3 Portland cement, 658 kg/m^3 washed sand, 1034 kg/m^{3}crushed limestone, and 202.5 kg/m^3 tap water. The steel used for longitudinal reinforcement was 10 mm diameter with 520 MPa yield strength and while that used for lateral ties 6 mm diameter bars of 590 MPa. Hook end steel fibers were used in preparing the HSFRC jacket. The fibers were used at volumetric fraction of 2%. The steel fiber used in the jacket was 0.60mm diameter, 30mm length with yield strength of 1120 MPa. It was planned to use locally available weld mesh as a low cost material in rehabilitation and upgrading of RC Cylinders. The weld mesh used in the jackets had square openings of (13*13 mm) and wire diameter of 0.96 mm, tensile tests was performed on three coupons and the average yield strength was 385 MPa. The properties of GFRP used for the investigation was unidirectional with nonstructural weaves in the secondary direction to hold the fabrics together, which was glued using epoxy resin, with thickness of about 0.324mm, average tensile strength of 3400 N/mm^2, and an ultimate elongation of 4.33%. The materials used in preparing slurry specimens included ordinary Portland cement, natural sand which was less than 600 micron and silica fume. The slurry mix proportions were 1:0.6:0.15:0.35:0.01 by weight of cement, sand, silica fume, water and super plasticizer correspondingly. Prepared slurry mix had a high compressive strength of about 68.06 MPa and a high flow as measured by a standard ASTM C939 flow cone (about 32 seconds).

1.2 Casting, Curing and Thermal Testing

A concrete cover of 12.5 mm was provided at side in all the cylinders. A cover of 15 mm was also provided between the ends of the longitudinal bars at the top and bottom surfaces of the specimens to prevent direct loading. The water curing period lasted for 28 days after which

the specimens were kept in the laboratory at ambient temperature and humidity conditions for another 122 days.
A programmable electrical furnace intended for a maximum temperature of 1200°C was used for heating the specimens. The temperature inside the furnace was measured and recorded with specially installed thermocouples. After 150 days, the specimens are heated in the furnace to different target temperatures ranging from ambient temperature to 900°C. Rate of heating was set at 10°C/min and each target temperature was maintained for 3 hrs to achieve a thermal steady state (Fig. 2). After exposing the specimens (CC3, CC3CY, CC6, and CC9 NA) to target temperatures for the desired time duration, the specimens were allowed in the furnace for natural cooling till room temperature.

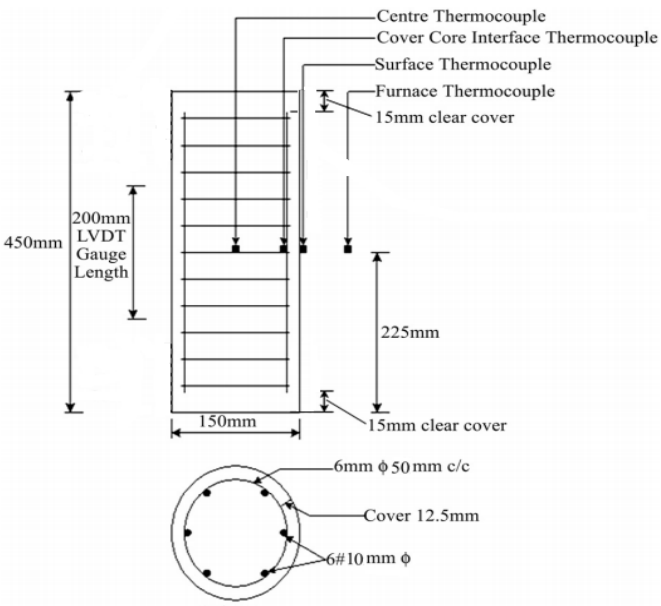

Fig. 1 Reinforcement details and position of thermocouple

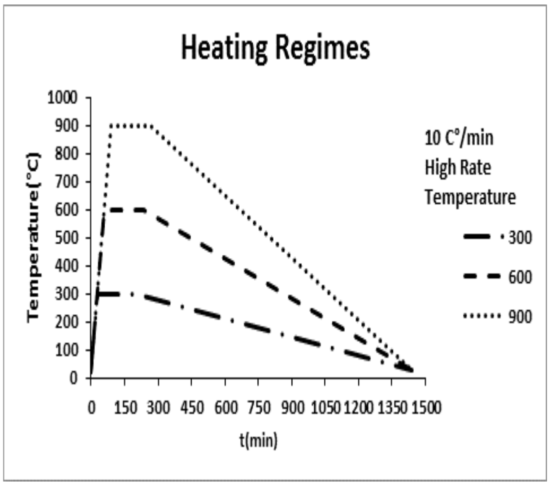

Fig. 2 Heating Regimes

1.3 Observation during heating

Assessment of fire damaged concrete usually starts with visual observation of colour change, cracking and spalling of concrete surface. The colour of concrete cylinder changed to pink when the specimens were exposed to 300°C temperature and became light greyish at 600°C. However, the specimen's changed to ash white colour when exposed to 900°C.There was no visible crack on the surface of the specimens heated up to 300°C. However while insignificant hairline cracks were observed at 600°C. The number of crack became relatively pronounced at 900°C. No spalling was observed in 300°C and 600°C temperatures. On exposure to temperature of 900°C no instant spalling was recorded in any of the specimens and spalling occurs after few days.

1.4 Installation of Strengthening Schemes

The heat damaged cylinders were strengthened with 1) HSFRC, 2) FC and 3) GFRP jacketing. The columns which were heated to 900°C temperature were repaired before wrapping. The loose concrete was removed with steel wire brush and the surfaces of specimens were cleaned thoroughly to remove dust or oil stains and a primer coat of bonding was applied over the surface to achieve good bonding between the old concrete and new micro concrete (MC) (BS EN1504, Technical report no. 69). Also, for the specimens exposed

to 300°C and 600°C, a primer epoxy bonding was applied after the surface was cleaned in order to provide good bonding between the substrata and the new strengthening material.
Dr.fixit Epoxy bonding agent was applied on the surfaces of cylinder specimens to provide good bond between the heat damaged specimens and the HSFRC jacket. The specimens were placed in the mould containing 25 mm thick HSFRC slurry. A gap of 20 mm was left at the ends of concrete cylinders to prevent HSFRC jacket from direct loading condition while testing. FC jacketing was similar as in HSFRC jacketing in cleaning, bonding and curing process. The specimens were wrapped with two layers of welded wire mesh. At several places, the first and the second layers of the wire mesh were tied together with the same diameter of steel wire. An overlap of 100 mm was provided in the lateral direction of the wire mesh. The slurry was forced into the mesh by hand to form 25mm thick FC jacket. Before GFRP jacketing, the surface of the specimens were scraped lightly to remove surface contaminants. Firstly the surface of the concrete was coated with a layer of epoxy primer on the external surfaces of the concrete to fill air voids and provide high bond strength. Secondly, a thin layer of the two part saturant solution consisting of resin was applied over the specimens. Later first layer of GFRP sheets were wrapped around the specimens carefully with a lap of 100 mm in length. A roller was used to remove the entrapped air between the fiber and excess saturant so as to allow better impregnation of the saturant. After the application of the first wrap, a second layer of saturant solution was applied on the surface of the first layer.

1.5 Instrumentation and test setup

Instrumentations were put in place to measure the axial and transverse displacements during concentric loading. A special kind of steel-frame was used to mount the LVDTs away from the surface of the specimens at the central zone to monitor the axial contraction and lateral displacements of the cylindrical specimens. Monotonic concentric compression was applied at a very slow rate (0.1 mm/min) to capture the complete post peak behavior of the measured load deformation curves.

2 RESULTS AND DISCUSSION

Heat damaged columns and heat damaged strengthened columns are subjected to axial compression and the axial load versus displacement behavior has been studied.

2.1 Failure modes of Control Specimens and Heat Damaged specimens

In the unheated control specimens shear failure was observed. Cracks formed near to the top and bottom ends due to batten effect (Kumutha et al, 2007), and as the displacement increased, the flexural cracks perpendicular to the cylinder axis widened with a sudden separation failure. In case of heat damaged cylinders, as reported in previous studies (Yaqub et al, 2011) the failure was gradual and exhibited ductility with increase in load and the lateral ties opened because of the spalling produced due to high temperature. The vertical cracks formed at the top and bottom ends of the cylinders, which eventually propagated and lead to crushing.

2.2 Failure modes of Heat damaged Strengthened specimens

Failure of the HSFRC specimens was mainly due to the vertical and diagonal cracks in the jacket. The vertical cracks got widened with increase in load as shown in (Fig. 3). Further increase in load created noise due to breaking of steel fibers, thereby indicating the stress transfer from the dilated concrete to the jacket. In FC Strengthened cylinders the initial cracks formed at the ends, while the number of cracks increased with loading. Beyond peak loading the mesh wires started bulging out with breaking noise in all the specimens. The failure mode of repaired FC jacketed specimens is shown in (Fig. 3). The steel wires of the welded mesh in the vertical direction bulged, while wires in horizontal direction got broken in entire length of the specimen. The failure of specimens occurred due to the cracks in the core concrete and the yielding of transverse wires. The failure mode clearly indicates that the transverse wires were subjected to hoop tension and thereby produced passive confinement pressure. In the specimens repaired with GFRP, the column failure was due to rupture. Clicking sounds were heard during the loading stage, and failure occurs at top and bottom of the specimens as shown in (Fig. 3). In this region, the stress attentiveness is attributed to high energy release, in the form of sudden failure of GFRP sheets. The damaged specimens exhibited good contact between the jackets and the concrete indicating no de-bonding.

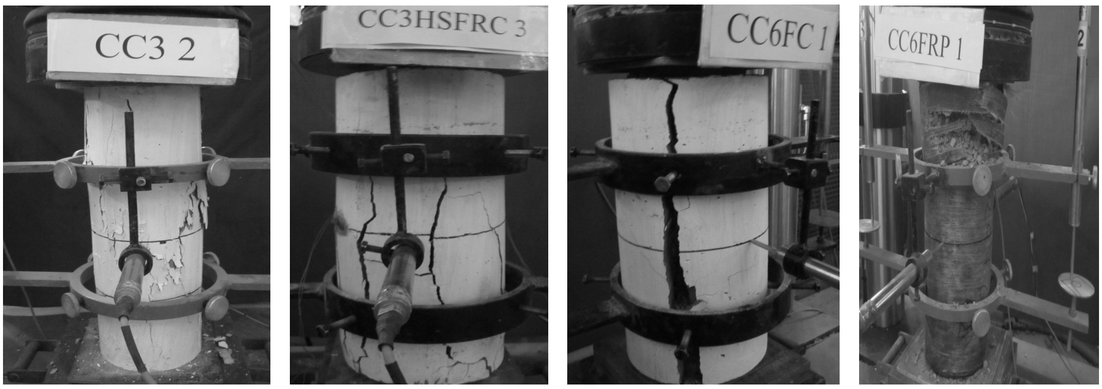

Fig. 3 Failure pattern of heat damaged cylinder and strengthened specimens

2.3 Strength of Heat damaged Strengthened Specimens

In this study heat damaged cylinders are repaired using number of methods comprising of HSFRC, FC and GFRP. Specimens were tested under axial compression & strength & deformability of repaired specimens were evaluated. Fig. 4 shows the effect of these methods on axial compressive strength. It shows that the post heating effect causes drastic reduction in strength of cylinders (Fig. 4) .The strength was restored considerably by the various strengthening techniques (Fig. 5, 6, 7).

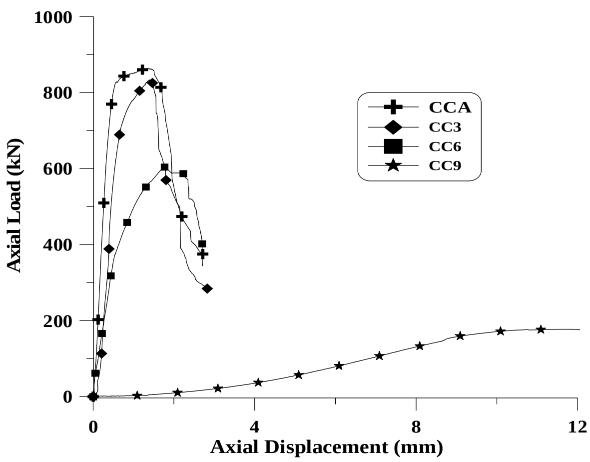

Fig. 4 Axial load- displacement comparison of control and heat damaged cylinders

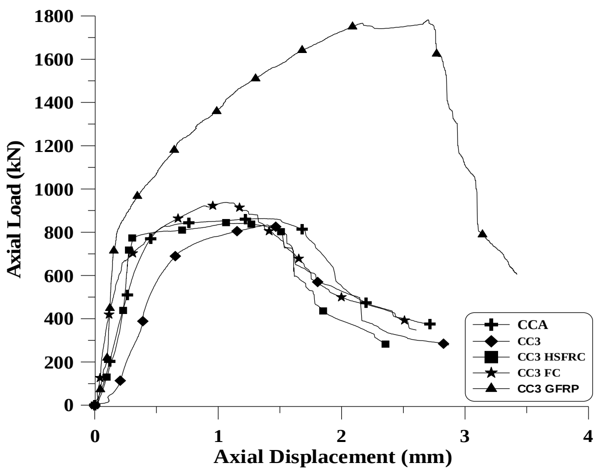

Fig. 5 Comparison of control and heat damaged specimens with 600°C strengthened cylinders

HSFRC jackets provide confinement effect to heat damaged specimens. Such confining effect is produced due to the fact that the heat damaged concrete dilates more under axial compression due to micro crack and porosity. HSFRC jackets restrain the heat damaged concrete, from radial bulging. When the heat damaged concrete reaches its ultimate unconfined compressive strength, the activation of jackets confines the columns in a three – dimensional state of stress, and consequently, increase the load carrying capacity of cylinder till the failure at its confined compressive strength. It can be seen that the strength of the heat damaged and HSFRC jacketed specimens are higher than the unstrengthen heat damaged specimens, but still remains less than the control specimen.

FC jacketing introduced hoop tension in the heat damaged cylinders, which eventually caused passive confinement. The effects of FC jacketing in strength enhancement is almost similar with HSFRC jacketing method, but the volume of variation is more prevalent in FC jacketing (Fig. 5-7). In GFRP Strength specimens the core concrete failed due to the compressive forces on the concrete. GFRP wrapping became active after this point. Expansion of the concrete core in the lateral direction made the GFRP more and more active in resisting the axial compressive force. Considerable strengthening was introduced due to double layer GFRP wrapping. The strength of the jacketed cylinder was greater than the control specimen.

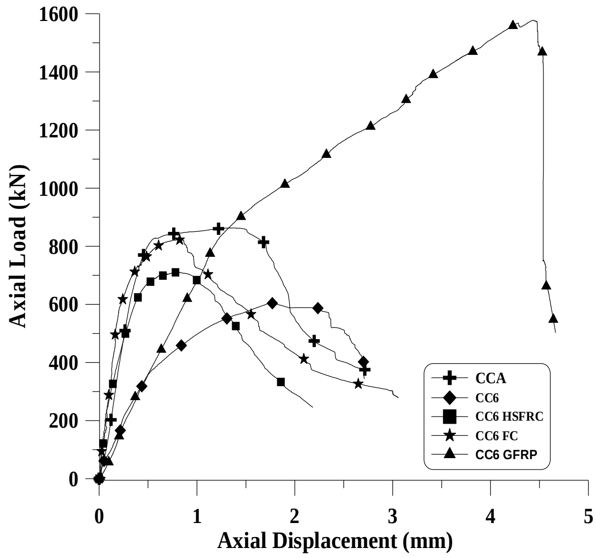

Fig. 6 Comparison of control and heat damaged specimens with 600°C strengthened cylinders

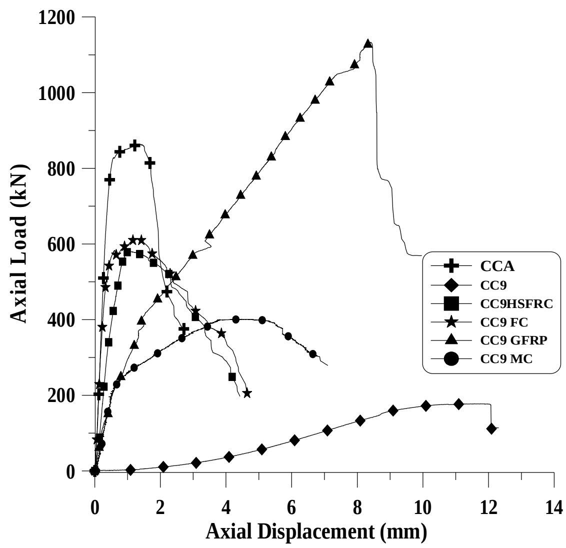

Fig. 7 Comparison of control and heat damaged specimens with 900°C strengthened cylinders

2.4 Ductility of heat damaged & strengthened Specimens

HSFRC and FC jacket repairing exhibits less amount of deformation ability in comparison to heat damaged columns. Above effect is due to the increase in cross section area in these methods. Increase in load carrying capacity and deformation by GFRP wrapping improves ductility of the specimen. Relative column load versus displacement is shown in Fig. 5-7. It can be seen that the enhancement of ductility of heat damaged columns wrapped with GFRP jacket was more noticeable than other jacketing methods. The Ultimate axial and lateral strains increased manifold, representing the ductility enhancement. This enhancement in the ductility is due to significant confinement to micro cracked heat damaged columns.

3 CONCLUSIONS

Following conclusions can be made based on the study. HSFRC, FC and GFRP composites can be utilized as strengthening technique for increasing the axial load carrying capacity of heat damaged reinforced concrete columns. The axial compressive strength of heat damaged cylinders increased significantly with GFRP when compared to other two strengthening techniques. Specimens repaired with HSFRC and FC jacketing exhibit less amount of deformation ability than the heat damaged specimens. Ductility of heat damaged specimens wrapped with GFRP jacket was more noticeable than other jacketing methods. Increase in ductility and strength of GFRP jacketed specimens is higher than the HSFRC and FC strengthened specimens

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