HIGH STRENGTH CONCRETE AS REPAIR MATERIAL FOR HEATED CONCRETE

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Abstract— The aim of present paper is to study the effects of elevated temperature ranging from 100 to 1000ºC on the residual strength, Young's modulus and slant shear bond stress of concrete of M20 and M60 grades. In both the grades ordinary Portland cement (OPC), high alumina cement (HAC) and high strength concrete (HSC) were used as repair materials. The specimens were heated to different temperatures of 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000ºC for three hours duration. The rate of heating was maintained as per ISO-834 temperature time curve for the standard fire. After heating, the specimens were tested to compressive strength, flexural strength, modulus of elasticity and shear bond stress with OPC, HAC and HSC as repair material. The results were analyzed and the effects of temperature on the repair materials were compared for both the grades of concrete. The HSC as repair material exhibited better performance than OPC and HAC.

Keywords— High Performance concrete, Compressive Strength, Young's modulus, Slant shear test

I. INTRODUCTION

Concrete is widely used construction material in all modern concrete structures because of its high compressive strength, good durability and mould ability. Modern concrete technologists have made ultra-high-strength concrete with grades over M250 possible.

Much attention had been attached to the fundamental properties of the concrete at room temperature: research on the behavior of the concrete under elevated temperature has attracted the researchers in the recent times. These studies are very useful for the design of special concrete structures subjected to elevated temperatures such as thermal shielding for nuclear reactors, metallurgical and chemical industries, runways, etc. causes physical changes including large volume changes owing to thermal shrinkage and creep related to water loss. The changes in volume will result in large internal stress thus leading to micro cracking. Elevated temperatures also bring in some chemical and micro-structural changes such as migration of water, increase in dehydration and thermal incompatibility of the interface between cement paste and aggregate. All of these changes will have a bearing on the decrease of strength and stiffness of concrete. Many researchers working on this subject gave a general conclusion that the strength of concrete decreases with the increase in temperature and exposure duration.

II. LITERATURE REVIEW

Phan and Carino[1] carried out studies on the effect of elevated temperature on engineering properties of high strength concrete (HSC). Tests is conducted on four mixes with a water/cement (w/c) ratios ranging from 0.22 to 0.57 and room temperature strengths ranging from 51 to 98 MPa. Two mixes contained silica fume. The parameters considered are compressive strength ,flexural strength,youngs modulus of elasticity and slant shear. The authors conclude that the behavior of HSC differs from that of normal strength concrete (NSC) under the same temperature exposure. In terms of strength loss, it was shown that, for intermediate temperatures between 100 and 400ºC, the compressive strength of HSC could be reduced by close to 40% of the room temperature strength: approximately 20 to 30% more than in NSC. The HSC mix with lowest w/c of 0.22 sustained, on an average the lowest loss in relative strength.

Sarshar and Khaury[2] carried out investigations to access the compressive strength of concrete at high temperatures and found that both material and environmental factors were influencing the strength of concrete during the heat cycle and after cooling. The cement part replacements used were silica fume; ground granulated blast furnace slag and pulverized fuel ash (PFA). Eleven temperature levels ranging up to 600ºC were used. The other parameters considered were load level during the heat cycle, the rate of heating, the duration of temperature exposure, the mode of cooling and the time of exposure after cooling. It was conclude that, concrete paste containing 100% ordinary Portland cement (OPC) lost significant residual compressive strengths above 300ºC. It was further concluded that specimens containing PFA and slag performed significantly better than specimens containing 100% OPC or silica fume. The slag cement paste specimens gave the best results of all the cement pastes tested. The application of a constant uniaxial compressive load of 15% of the initial cold strength during the heat cycle resulted in residual and hot strength of the fire brick concrete tested.

Castilo and Durrani[3] carried out investigations to study the effect of transient high temperature on compressive strength and load deformation properties of the HSC under both unloaded and preloaded conditions and to compare the behavior with that of NSC. Based on the results obtained from the study, it was concluded that when exposed to temperatures in the range of 100 to 300ºC, HSC showed a 15-20% loss of compressive strength. After an initial loss of strength, the HSC recovered its strength between 300 to 400ºC, reaching a maximum value of 8-13% above the strength at room temperature. At temperatures above 400ºC, the HSC progressively lost its compressive strength, which dropped to about 30% of the room temperature at 800ºC.

Ahmed et al[4]. Investigated the residual compressive and bond strengths of limestone aggregate subjected to elevated temperatures. In their study, the influence of high temperatures (100-600ºC) on the residual compressive and bond strength of concrete made from limestone aggregates was experimentally investigated. The main test parameters involved were maximum temperature, the time of exposure at maximum temperature, the cooling, the age of concrete at the testing date and the cement content. From this study, it was reported that 7-day compressive strength of concrete increased with temperature up to 100ºC. In addition, for this temperature range, young concrete showed higher residual strength than the old concrete. It was also reported that a decrease of 15% of original strength appeared at 150ºC. It was concluded that the cooling method had no significant influence on either the residual compressive or bond strengths.

Hoff et al[5]conducted research to study the effect of elevated temperatures on residual strength of HSC. Twelve HSC mixtures were made including the three types of concrete: normal density concrete (ND), light weight (LW) concrete in which the structural light weight coarse aggregate was used and the modified normal density (MND) concrete prepared by using 45% (by volume) of NW aggregate. Each concrete was made with and without polypropylene fibers. It was conclude that all three types of concrete showed slight improvement in residual strength, at an exposure of 200ºC, but this improvement was not observed when subjected to 100ºC exposure. At a temperature of 300ºC, significant loss of strength was observed. At a temperature of 900ºC and above, all the concrete essentially had no structural integrity. Residual strengths of HSC at exposed temperatures of 300ºC or higher are significantly different from the residual strengths of NSC.

Chan et al[6] carried out an experimental programme to evaluate the mechanical properties of high performance concrete (HPC) and NSC subjected to temperature up to 800ºC. The experimental programme subjected the HPC and NSC to a temperature of 800ºC and evaluated their residual compressive strengths. It was conclude that, although the strength of HPC degenerated more sharply than that of conventional concrete, with the increase of exposed temperature, HPC had higher residual strength.

Janotka and Bagel[7] carried out an experimental investigation on the effects of temperatures up to 800ºC, on the strength characteristics of concrete, at Mochovce Nuclear Power Plant (Slovakia). The experimental programme include the casting of concrete specimens in laboratory conditions, using the materials identical with those used at the Mochovce construction site and subsequently exposing them to selected temperatures. Test results revealed no significant changes in the specimens exposed elevated temperatures up to 400ºC.

Potha Raju et al.[8] investigated the effect of elevated temperature on the flexural strength of fly ash concrete of different grades of M28, M33, and M35. Concrete specimens of 100 X 100 X 500 mm with partial replacement of cement by fly ash were heated to 100, 200 and 250ºC for 1, 2 and 3 h durations. The specimens were tested for flexural strength in the hot condition immediately after removing from the oven. It was concluded that the fly ash content up to 20% showed improved performance compared with the control specimens by retaining greater amount of its strength.

Randall Lawson et al.[9] aimed to characterize the residual mechanical properties of HPC after being exposed to elevated temperatures. The average compressive strength for the different grades of concrete adopted in the study was 40 to 100 MPa. The selected temperatures were 100, 200, 300 and 400ºC. Significant drops in the compressive strengths were reported for concrete exposed to elevated temperatures.

III. RESEARCH SIGNIFICANCE

The main focus of the present paper is to select a suitable repair material for regaining the properties of concrete. The risk of exposing of concrete to elevated temperatures has increased significantly. The strength study of various repair materials and repair techniques is quite necessary. Some of the structures in which the concrete subjected to elevated temperatures are:

a) In nuclear reactors, radiation is present in addition to heat. Therefore, concrete has to serve a dual purpose: it needs to sustain the elevated temperatures it will be subjected as well as acting as a shield to radiation.
b) In metallurgical and chemical industries, glass making industry, cement and lime industry, power industry, coke ovens, storage tanks for hot crude oil and hot water, coal gasification and liquefaction vessels etc., concrete is used, where it is subjected to elevated temperatures.
c) In take off areas of jet aircraft, localized areas of concrete are subjected to the effects of exhaust gases of the jets. The problem of heat resistance of such areas will become

increasingly acute, as the technology of vertical take-off becomes more fully developed. This is also true for rocket launching pads.

d) In chimney construction, concrete walls have replaced the usual firebrick lining where elevated temperatures are encountered.

In order to assess the structural safety of the structures exposed to elevated temperatures, it is essential to study the effect of exposure to elevated temperatures on the strength of HSC.

IV. EXPERIMENTAL PROGRAMME

Two grades of concrete M20 and M60 are designed as per IS 10262-1982 & ACI method respectively with the following materials

a) **Cement**: OPC conforming to IS 269-1989[14] adopted in this work.

b) **Fine Aggregate**: locally available river sand was used in the present work. Fineness modulus and specific gravity of the sand are 2.3 and 2.60 respectively. The sand was dried before it used in the mix to avoid problem of bulking. The fine aggregate used was conformed to zone II of IS: 386 - 1973.

c) **Coarse Aggregate**: locally available coarse aggregate with a maximum size of aggregate of 12.5mm was used. Grading of the coarse aggregate was carried out to obtain the optimum density. The fineness modulus and specific gravity of the coarse aggregate are 6.57 and 2.63 respectively.

d) **Water**: locally available portable water with pH value of 7.65 was used in the present work and it conforms to IS:3025-1986

e) **Admixture**: Owing to the low w/c ratio adopted, super plasticizer (conplast SP 430) was used to increase the workability. This super plasticizer conforms to IS 9103-1999.

The details of mix proportions are presented in Table 1.

Table 1: Estimated batch of quantities per cubic meter of concrete

Grade of Concrete	Cement (kg)	Fine Aggregate (kg)	Coarse Aggreg ate (kg)	Wate r (l)
M20	399.13	517.36	1327.66	191.6 8
M60	654	615	880	196

Batching, Casting, Vibrating and Curing of Test Specimen

The details of batching, casting, vibrating and curing are summarized below.

A tilting-type rotary drum mixer was used. All the ingredients were placed in the mixer and water was added during rotation. Initially 80% of total water was added and mixed for 75 s, then super plasticizer at the dosage of 400ml/50Kg of cement was mixed with remaining 20% of the water and this mixture was fed to the concrete and mixing was continued another 45s. All the test specimens were cast in a removable standard (cast iron) moulds conforming to IS 10086-1982[19] and vibrated on a standard vibrating table conforming to IS 7246-1974. Test specimens were demoulded after a lapse of 24h from the commencement of casting and submerged under water until the time of testing.

Testing of Specimens

1. **Compressive Strength :** The compressive strength test was conducted on 100mm cubes of each batch. Tests for 28-day compressive strength were carried out according to IS: 516-1959[21]. Specimens stored under water were taken out from the water after the 28 days of curing and sir-dried. After exposing the specimens to desired temperatures and duration, the cubes were placed in compression testing machine in such a manner that the load was applied to the opposite sides of the cubes. The axis of the specimen was carefully aligned with the center of the steel platen of the compression-testing machine. The load was applied without shock and was increased continuously at a rate of approximately 140kg/cm^2/min until resistance of the specimen to the load breaks down and no greatest load is sustained. The maximum load applied to the specimen is then recorded. The measured compressive strength of the specimen is calculated by dividing the maximum load applied on the specimen during the test by cross sectional area.

2. **Flexural Strength:** To study the flexural strength of concrete, six prisms of size 100 X 100 X 500 mm were cast for each batch. The heated prisms are cooled for room temperature and then placed under universal testing machine to find out the flexural strength of the heated specimen.

3. **Young's Modulus:** To study the Young's modulus of concrete, three cylinders were cast for each batch of standard size, diameter 150mm and 100mm height. The heated specimen are cooled and then fixed in capping mould. The specimen is placed under 200-ton compression testing machine. The maximum load is applied on the prisms was noted down. The Young's modulus of elasticity is the ratio between stress and strain expressed in **N/mm^2.**

4. **Slant Shear Bond Test:** To study the slant shear properties, two-mortar section specimen of 55 x 55 x 150 mm are placed inclined with an angle of 30. the casted specimen are heated

and cooled at room temperature. The specimens were tested for bond strength under compression testing machine

Exposing the Specimens to Temperature

A purpose built electric furnace was used to heat specimens under study. The heating arrangement in the furnace is as per international standards ISO 834[22] specifications. The furnace can be separated into two parts. The separated part can be pulled out after loosening the screws provide for tightening between the two parts. It consists of wheels at the bottom and can be moved to required location by moving on rails. It also consists of a bed of refractory bricks of 110 mm size, on which the specimen are to be placed. The chamber measures 650mm in height, 500mm in width and 1800mm in length with the slides and lined with electrical heating coils embedded in refractory bricks. Temperatures in the furnace are controlled by means of a dedicated control panel, which house the power supply and circuit switches for the furnace. The control panel has an oven temperature inside the furnace exceeds specified temperature. The maximum operating temperature of the furnace is 1000°C. Air vents are also provided in the unseparated part, at the top, to allow vapour to escape from the heating chamber and to allow any thermocouple leads if provided to be connected to a digital temperature logger.

Results Analysis and Discussions

General

The present research is aimed at studying the performance of repair materials. The repair was carried out with three types of repair materials

(i) Ordinary Portland Cement (OPC) Concrete
(ii) High Alumina Cement (HAC) Concrete
(iii) High Strength Concrete (HSC)

Effect of temperature on properties of repair materials

1 Compressive Strength: Fig .1 shows the variation of compressive strength of OPC concrete, HAC Concrete, and HSC concrete specimens with temperature. All three types of Concrete exhibited decrease in strength with increase in temperature beyond 200°C. However, a slight increase in strength was observed up to 200°C due to the effect of accelerated curing. HSC Concrete showed a greater strength almost 21% and 11% higher strength than OPC and HAC respectively. HSC Concrete maintains and exhibits better strength in the range of 27°-200°C than OPC and HAC series of specimens. It can be concluded that HSC is performing better than OPC & HAC by retaining more compressive strength.

2 Flexural strength: Fig 2 shows higher strengths for all three types of concrete at initial temperature range of 27°-100°C. But gradually decreases in strength with the increase of temperature. In the range of 100°C-700°C, all concretes showed a gradual fall in their strength and almost same strengths from 700°C-1000°C range.

3 Young's Modulus: It is evident from Fig. 3 that all the three Concretes showed higher young's modulus up to 100°C and HSC Concrete retains more young's modulus up to 600°C. The young's modulus of HSC concrete is 200% more than OPC concrete while HAC specimen show 100% more value than OPC. OPC series show the least modulus than the other two series at initial temperature range of 27°C Hence, it can be concluded that HSC Concrete exhibited higher young's modulus at elevated temperatures compared to OPC & HAC.

4 Bond Strength: It is evident from Fig. 4 that in the initial temperature range 27°C-100°C, higher slant shear was observed for HSC specimens than HAC & OPC Concrete, i.e.50%higher strength. Then the slant shear is almost more or less same for all Concretes with the temperature range of 200°C-700°C. At higher temperature range of 700°C-1000°C again HSC specimens show better strength than OPC Concrete. All the three concretes show initial higher slant shear and gradual fall at increase in temperatures.

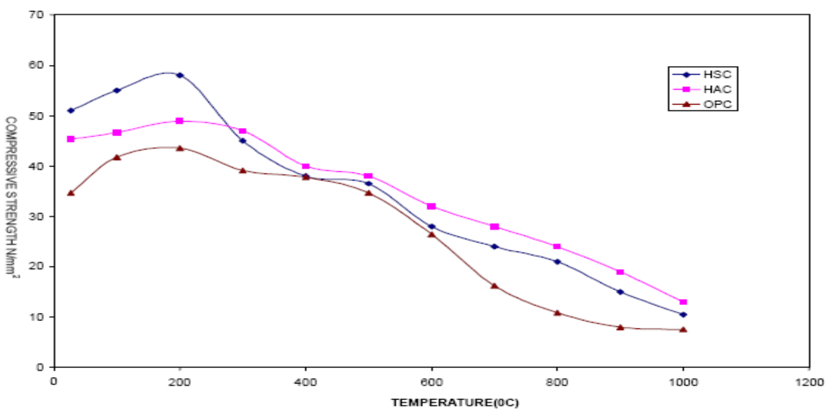

Fig.1 TEMPERATURE vs COMPRESSSIVE STRENGTH

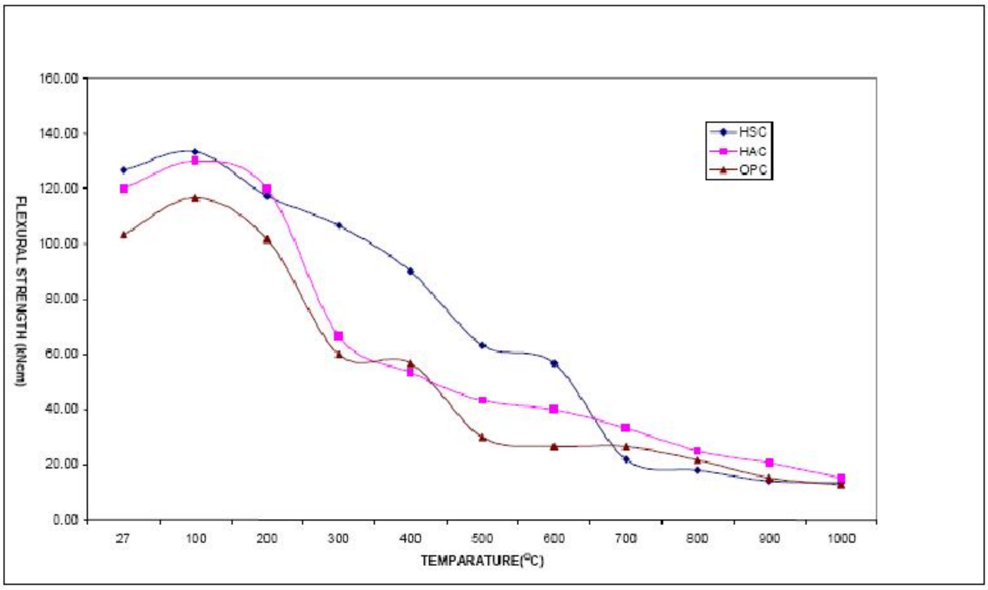

Fig.2 TEMPERATURE vs FLEXURAL STRENGTH

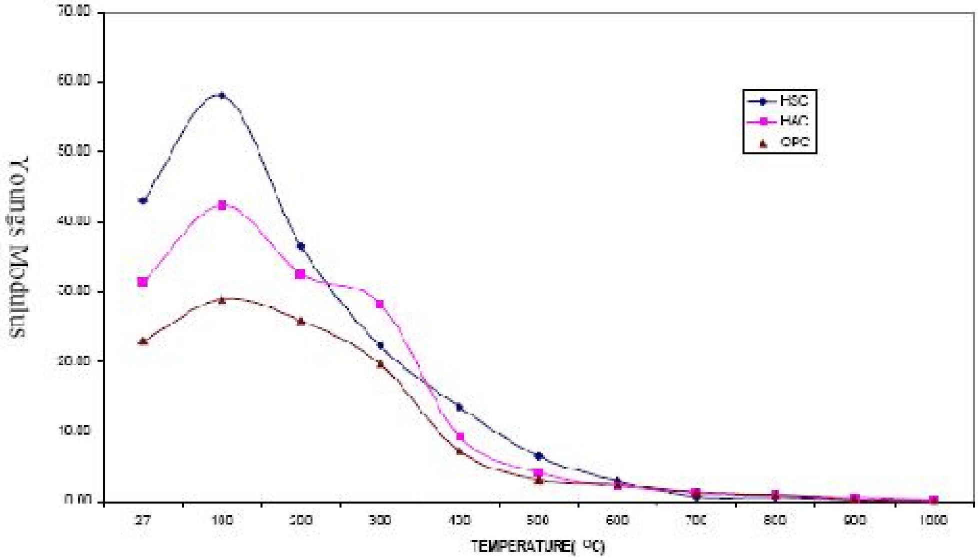

Fig.3 TEMPERATURE vs YOUNGS MODULUS OF ELASTICITY

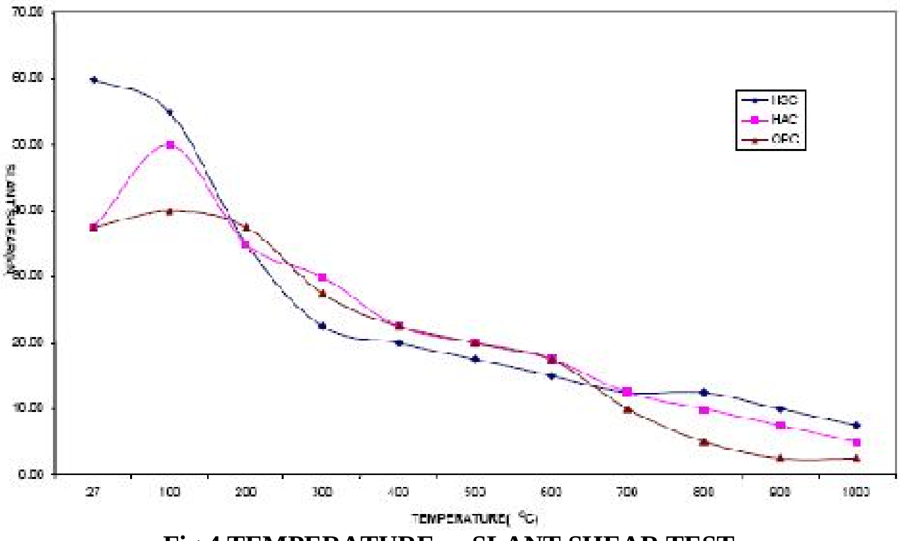

Fig.4 TEMPERATURE vs SLANT SHEAR TEST

CONCLUSIONS

The present study aimed at investigating the parameters like Compressive Strength, Flexural strength, Young's modulus and slant shear bond strength of all the repair materials i.e. Ordinary Concrete, High Alumina Cement Concrete, High Strength Concrete.

<u>After the detailed analysis of results the following Conclusion were drawn</u>

1. The Compressive Strength of all repair materials increased initially up to 200°C and decreased gradually beyond 200°C. HSC performed better than HAC & OPC by retaining more Compressive strength at all temperatures.
2. The flexural strength of all repair materials decreased with the increase in temperature. HSC exhibited more residual flexural strength than HAC &OPC at almost all temperatures.
3. The Youngs Modulus of all the repair materials was observed to be increased upto 100°C and decreased with increase in temperature beyond 100°C. HSC Concrete exhibited more youngs modulus at almost all temperatures.
4. It was in general observed that the bond strength decreased with the increase in temperature for all repair materials. HSC showed good bond strength compared to other repair material even under fire.

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