Effect of Elevated Temperature on Mechanical Assets of Metakaolin Base Steel Fiber Reinforced Concrete

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Abstract. The fact of vast usage of concrete leads to important problems regarding its design and preparation of eco-friendly to obtain an economic cost of the product on varieties of time periods. Conventional ordinary Portland concrete may not able to meet its functional requisites as it found inconsistency in high temperature. The exposing of concrete structure to elevated temperature may be in case of rocket launching space ships, nuclear power plants. In this experiment, to enhance the high temperature resistance, pozzolanic materials and steel fibres are added to preserve the strength characteristics of concrete structure. In this analysis, the pozzolanic admixture MK is used as partial replacement of cementitious materials. The volume fraction of steel fibre is varied 0.25%, 0.5%, 0.75% and 1% by preserving MK as stationary for 10% replacement of cement. The strength parameters of concrete such as compressive strength, split tensile strength and flexural strength are studied.

1. Introduction
Concrete is characterized by quasi-brittle seizure, the nearly complete loss of loading capacity, once failure started. With spurt in modern technology and immeasurable usage of concrete and mortars, the strength workability, durability and other major characteristics of the normal concrete require modifications to make it most suitable for all circumstances. Conventional ordinary Portland cement concrete which is designed on the basis of its strength characteristics may not able to meet its functional prerequisites or demands as it found discrepancy in aggressive environment, time of constructions, energy absorption Capacity, repair and retrofitting jobs etc. As a result of which usage of admixtures became complementary solution. In recent decade, the civil concrete structures have been subjected to fire accidents or blasts which lead to significant loss of assets. As a result of unpredictable misfortunes, structures are exposed to high temperatures that will produce considerable adaptations in the physical and mechanical properties with irreversible loss of strength and toughness. The material integrity and porosity is important aspects in fire resistance of concrete, where heat and mass transfer process is concerned. Especially, the pore pressure rise and temperature gradient related to spalling or separation of surface layers, which could significantly decrease the fire resistance of concrete structures. The main illustration for exposing concrete assemblies to high temperature are concrete foundations in case of rocket launching platform, structures in nuclear power station or sometimes those exposed to fire accidents or else blasts. As a result of rendering to the high temperature, explosive spalling has been noticed by many researchers often causing in serious deterioration of concrete possessions. High heat causes various physical (e.g., evaporation, condensation, water and vapour advection, phase expansion), chemical (e.g., dehydration, thermo-chemical damage) and mechanical (e.g., thermo-mechanical damage, cracking, spalling) activities takes place resulting in worsening of concrete properties.
In order to overcome the heat impairments on concrete properties, addition of admixtures is one of finest way which increases pozzolanic activity due to the presence of finer particles upgrades concrete characteristics. The enhancement of strength and durability of concrete carried out by adding cementitious materials such as Fly Ash (FA), GGBS, Silica Fume (SF), Metakaolin (MK) during construction results in better performance even in aggressive environment due to is filler effect and pozzolanic reactions. To enrich fire resistance, addition of fibres recommended since at elevated temperature, melting of fibres will create additional networks to allow water vapour pressure generated in structure. The inclusive of fibres will dominates over plastic and drying shrinkage cracking, in addition to enlarging energy absorption capacity of the concrete sample.

2. Literature Review

A lot of work has been done and going on the use of MK as a cementitious material in enhancing different properties of FRC. Since MK reduces porosity of harden concrete in addition to densifies and reduces thickness of interfacial zone, thus optimising the adhesion between the cement and aggregates. The steel fibres (ST) boost the energy absorption capacity of unheated specimen. In the research, various variations studied; such as effect of different upraised temperature exposure, effect on duration of heating period to record the physical observations immediately after heating and during testing of specimens like colour, propagation of cracks and mode of failure [1]. The reduction in strength at 200°C (not in case of specimen tested immediately after heating for one hour). There is no definite behaviour pattern could be observed with reference to four heating periods and three modes of testing conditions considered [1].

The thermal conductivity is maximum in room temperature and is gradually decreases at higher temperature of 600°C and 800°C respectively. The reduction of thermal conductivity was accompanied by the declining of density so that magnitude of the falling of thermal diffusivity was lower, approximately twice to trice, even though it seems to be a very good result [2]. It is pronounced that rise in strength of the plain cement mixes cured adiabatically at the elevated temperatures when compared to those cured isothermally at the same temperatures. Addition of FA and slag causes better confrontation to chloride permeability at all temperatures compared to OPC sample [3].

The residual strength of concrete losses as the exposure temperature rises, and prolonging the heating time is inversely proportional to residential strength [4]. The spalling frequency upsurges with higher MK content, mainly because of its dense pore structure seems to be the reason for such spalling [5]. Results providing conclusion that cement replaced by 10% of MK as admixture achieves maximum strength at pre and post mature stages for composite fibres (ST and PPF) reinforced HPC. For generation of optimal values, 10% MK replaced by cement and 1.25% of composite fibres for accomplishing maximum benefits [6].

When specimens exposed to elevated temperature increases, the strength of concrete is retarded due to spalling effect and at same time it began to deteriorate. However, the addition of fibres into the concrete mixture minimised the cracking effects that occur in the concrete [7]. The density of concrete increases marginally with upsurges in percentage of fibre content. Density of SFRC with MK has increased a bit over normal concrete and this is due to partial replacement of cement by MK, which densifies the concrete because of its micro-filler effect since having relatively finer particle size [8]. The desirable content of MK is 10% for development of High Strength Concrete as it gives reasonable mean target strength and workability than any other proportions. The mechanical strength characteristics values will increase up to 100°C and thereafter strength values fall with higher temperature [9].

The literature survey reveals that only rare number of experimental studies are carried on combined effect of high temperature and heating time on residual strength of concrete, which needs to be more investigation that will be beneficial in engineering practices.

3. Experimental Programme

3.1 Materials

In this work the locally available JK cement of 43 grade confirming to IS: 8112-1989 has been used. The specific gravity of cement was 3.15. The coarse aggregates obtained from local crushing unit confirming the IS 2383. The aggregate of perishable through IS 12.5 mm sieve and retained on IS 6.5 mm sieve was used in experimental practice. The specific gravity of coarse aggregate was 2.7 and bulk
density was 1600 kg/m$^3$. Conventionally locally obtained river sand was used as fine aggregates in this tentative study with fineness modulus and specific gravity of 3.1 and 2.7 respectively. The MK obtained from Jitmull Manufactures located at Chennai, Tamilnadu having bulk density 0.4-0.5 kg/l. The crimped ST used in trials is obtained from Stewols India (P) Ltd. located at Nagpur, Maharashtra. The aspect ratio, specific gravity and density of 50, 7.9 and 7840 kg/m respectively.

3.2 Mix Proportion

**Table 1.** Tabulation for mix design for M40 grade concrete.

| Serial number | Components           | Mass (kg/m$^3$) |
|---------------|----------------------|-----------------|
| 1             | Cement               | 337.5           |
| 2             | Metakaoline          | 37.5            |
| 3             | Water                | 150             |
| 4             | Fine sand particles  | 758.93          |
| 5             | Coarse aggregates    | 1237.7          |
| 6             | Water – binder ratio | 0.4             |

4. Experimental Procedure

The various dimensions of moulds to be prepared are arranged as listed below.

**Table 2.** Different mould dimensions arranged.

| Sample       | Tests               | Dimensions (mm) |
|--------------|---------------------|-----------------|
| Cubes        | Compression test    | 100x100x100     |
| Cylinder     | Split tensile test  | L=300; d=100    |
| Beams        | Flexural test       | 100x100x100     |

While fraternising MK based FRC, primarily the dehydrated mixing of basic ingredients such as cementitious materials such as cement and MK, sand, dry coarse aggregates is carried out. After uniform colour of mix obtained, calculated amount of ST is spread uniformly over mixture. This process was followed by addition of water which was a mixing media. For different combinations, same casting procedure was pursued with different volume fractions namely 0.25%, 0.50%, 0.75% and 1% of Steel fibres. This wet mix is poured in predetermined dimensional moulds. After 28 days of water healing of specimens is followed by subjecting those to heavy raised temperature in muffle chamber. In current work, temperature variation is controlled to ranges of 200$^\circ$C, 400$^\circ$C, 600$^\circ$C and 800$^\circ$C for constant duration of one hour for each sample as shown below.
4.1 Remarks on exposure to elevated temperature

The alteration in color of specimen due to heating after fire exposure may give a sense of temperature of concrete element has faced. The change of color of elements mainly depends upon the constituents with which it is made up of. In addition to this, surface cracking is remarked when elements is faced a temperature above 600°C. The cracking reveals the rate of heating and duration heat faced by concrete elements and it is well known fact that rapid heating to extreme temperature cause additional internal cracks.

| Table 3. Tabulation of color changes of specimen |
|-----------------------------------------------|
| Temperature variation (°C) | Color changes   |
|-------------------------|-----------------|
| 27°C                    | White           |
| 200°C                   | Off white / buff grey |
| 400°C                   | Dusky grey      |
| 600°C                   | Dark grey       |
| 800°C                   | White           |

Figure 2. Color change and surface cracks due to exposure to elevated temperature.

The mechanical attributes of heat affected specimens are analysed by conducting compression, split tensile and flexural test.

5. Test Results and Discussion

In this experimental analysis, the pozzolanic admixture MK is used as partial replacement of cementitious materials. The volume fraction of steel fibre is varied 0.25%, 0.5%, 0.75% and 1% by preserving MK as stationary for 10% replacement of cement. The strength parameters in concrete such as compressive strength, split tensile strength and flexural strength are studied. Main intension is to
determine optimal range of volume fraction of ST providing extreme strength behavior after heated condition. The cast concrete elements for compressive strength test (100×100×100 mm cubes), split tensile test (length =300mm, diameter =100mm cylinders), flexural strength test (100×100×300 mm beams) for 28 days of water curing and are subjected to heavy heat in muffle furnace. From test results each combination are compared with each other to determine efficient volume fraction of fibres and to study the behavior of elements for variety of temperature ranges.

5.1 Compressive Strength Results
In muffle furnace these elements were exposed to pre-determined temperature levels, primary to subjection to compression test. In current analysis, cubes of dimensions 100×100×100 mm\(^3\) were tested in Compression Testing Machine (CTM) of maximum capacity of 3000KN to determine its strength and investigated accordance to IS: 516-1959. In CTM, load is applied sluggishly awaiting failure of cubes occurs.

| Temperature exposure | C1 (0.25%) | C2 (0.50%) | C3 (0.75%) | C4 (1.0%) |
|----------------------|------------|------------|------------|-----------|
| 27 °C                | 50.16      | 53.03      | 53.16      | 53.16     |
| 200 °C               | 36.53      | 37.80      | 43.23      | 38.5      |
| 400 °C               | 34.33      | 36.80      | 37.66      | 36.00     |
| 600 °C               | 26.96      | 29.26      | 33.20      | 32.03     |
| 800 °C               | 20.40      | 19.96      | 19.83      | 25.03     |

5.2 Split-tensile test results
The evaluation of tensile strength is compulsory to determine the load at which the concrete members may crack, where cracking is a form of tension failure. The experiment is conceded as per IS: 5816-1999. Cylinders of diameter 100mm and length 300mm were cast for different proportions of ST. Each element is tested in CTM of adequate capacity and applied with elevated loads at specified rate. Procedure is carried out until element develops tension cracks on surface for failure load.
5.3 Flexural Test Results

For the flexural strength test, pre-defined dimensional prismatic specimens were cast. The size of beams in current assessment as defined in previous chapters, 100×100×300 mm³ tested in Universal Testing Machine (UTM). Since its longitudinal dimension is reduced as per convenience to work with heating in muffle furnace. This experiment helps in studying modulus of rupture, bending capacity, in addition to providing flexural strength of prisms. Usually flexural strength is directly proportional to failure load and depends on aspect ratio. The test is approved as per IS: 516-1959.

6. Conclusion

The MK composite concrete will show increasing strength by 6% with adding volume fraction of steel fibres. For volume fraction of 0.75% Steel fibres is providing optimal strength for primary stage of heating up to 600°C. At extreme heat, addition of proportion of fibres will upgrades its strength characteristics even at 800°C. Thus, it is finalized that 1% of volume fraction of fibres will be optimal at extreme temperature. It is well known fact that strength attributes will decline with improve in temperature. Overall remarks conclude that combination C4 with 1% of steel fibres gives maximum residual strength and minimum strength loss at temperature 800°C.
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