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Performance of Steel Fiber Reinforced Concrete under Elevated Temperature

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Abstract: *Concrete has been well known as a low cost building material with high compressive strength and versatility. Exposure of reinforced concrete buildings to an accidental fire may result in cracking and loss in the bearing capacity of their major components, columns, beams, and slabs,producing extensive surface cracks that penetrate across depth,possible spalling,upward cambering of surface and plastic deformation of reinforcing steel.*
Keywords: *Concrete,Temperature, Steel fiber, Compressive strength*

I. Introduction

Concrete is a composite material whose constituents have different properties and also depends on moisture and porosity.Exposure of concrete to elevated temperature affects its mechanical and physical properties. Elements could distort and displace under certain conditions. Temperature affects produce dimensional changes, loss of structural integrity, release of moisture and gases resulting from the migration of free water could adversely affect plant operations and safety. The properties of concrete changes with respect to time and the environment to which it is exposed, an assessment of the effects of concrete is also important in performing safety evaluations.

Effect of temperature on concrete

The effect of temperature on different properties of concrete is considerable. Increase in temperature cause increases initial strength and reduces the long term strength. Fire represents one of the most severe risks to buildings and structures. Exposure to fire is undoubtedly the most destructive process that a concrete structure can be subjected to during its service life. Under high temperature effect, chemical composition, physical structure and moisture content of concrete changes. These changes are primarily observed at the cement paste and then at the aggregates as well. Heating to high temperatures causes the dehydration of hardened cement paste and conversion of calcium hydroxide into calcium oxide in which chemically bound water is gradually released to become free water. As a result the bond become weak and sudden crack occurs and affect the concrete to fail.

Characteristics of steel fiber

Fibers are added to concrete in order to improve the characteristics in hardening or the hardened state. The principle reason for incorporating fibres into a cement matrixis to increase the toughness and tensile strength and improve the cracking deformation characteristics of the resultant composite. When concrete subjected to high temperature Steel fibers are effective in reducing plastic shrinkage cracking and reduce the spalling.

III. Literature Review

Lau and Anson [1] studied on effect of high temperatures on high performance steel fibre reinforced concrete. After being subjected to different elevated heating temperatures ranging between 105°C and 1200°C the compressive strength, flexural strength, elastic modulus and porosity of concrete reinforced with 1% steel fibre increases. *Haddad et al*.[2] studied the effect of elevated temperature on bond between steel reinforcement and fiber reinforced concrete. Steel fibers like hooked steel fiber attained the highest bond resistance against elevated temperatures ranging 400 to 600°C. *Peng et al.* [3] studied effect of thermal shock due to rapid cooling on residual mechanical properties of fiber concrete exposed to high temperatures. The results prove that the rapid cooling regimes such as quenching in water, or water spraying for 30 min or more, caused an action of 'thermal shock' to concrete under elevated temperature. It results a sudden decrease in compressive strength. They conclude that natural cooling facilitates a relatively higher value of compressive strength compared to the cooling by quenching in water. *Bangi and Horiguchi* [4] investigated on effect of fibre type and geometry on maximum pore pressures in fibre-reinforced high strength concrete at elevated temperatures.Fibre type and geometry,significantly contributes towards pore pressure reduction while heating. . It is found that addition of steel fibres in high strength concrete also contributes in pore pressure reduction when exposed to elevated temperatures and decreases the spalling.

Literature survey reveals that there exists a gap area in using hybridlength steel fibers in the concrete when they are subjected to the high temperature.

The scope of the study includes to evaluate the effect of varying Percentage of hybridlength steel fibers in the concrete mixture subjected to different temperatures shows a potential area of study. For this making workable, high strength and durable concrete containing hybridlength steel fibers and study the variation in its compressive strength and split tensile strength when they are subjected to different temperatures.

The objectives of the study are:

- Study the effect of steel fibers on compressive strength of concrete
- To predict the performance characteristics of steel fibers with different percentages (0%,0.5%,1%) on concrete with temperatures(200°C,400°C)
- To minimize the experimental procedure according to Box-Behnken Design for optimization.

II. Materials And Methodology

The materials selected for this experimental study includes normal natural coarse aggregate, Manufactured sand as fine aggregate, cement, superplasticizer, both end hooked steel fiber and portable drinking water. The physical and chemical properties of each ingredient has considerable role in the desirable properties of concrete like strength and workability. The cement used for this project work is ordinary portland cement of Zuari 53 grade. Manufacturer's sand has been used for the present investigation ,it is also called M sand. Coarse Aggregate used are of two sizes 20 mm maximum size and 12.5 mm maximum size. The several tests were conducted on both fine and coarse aggregates as per relevant Indian Standared codes [5]. Potable clean drinking water available in the water supply system was used for casting as well as for curing of the test specimens. 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 were used. The manufracturer is Stewols private limited,Nagpur. The super plasticizer used was MASTER RHEOBUILD 918 a product of BASF India Pvt. Ltd, Ernakulam.

Mix design

The mix design is carried out as per relevant Indian standard Code[6]. The proportioning is carried out to achieve workability of fresh concrete and durability requirements. Relationship between strength and free water cement ratio should be preferably be established for the materials actually to be used. Mix designing is carried out to arrive at the quantities required for 1 m^3 of concrete and mix designation as shown in Table I.

Table. I Quantity Required For 1 M^3 Mix

W/C	Proportion Of Steel Fiber	Water (Kg)	Cement (Kg)	F_a (Kg)	C_a (Kg)	Steel Fiber (Kg)
0.35	0	160	460	660	1240	0
	0.5	159	457	656	1233	39
	1	158	455	653	1237	78
0.4	0	160	400	700	1260	0
	0.5	159	398	696	1253	39
	1	158	396	693	124	78
0.45	0	160	360	730	1260	0
	0.5	159	358.2	726	1253	39
	1	158	356.4	722	1247	78

Box -Benhken Design

Box– Behnken designs are experimental designs for Response Surface Methodology, devised by George E.P.Box and Donald Behnken in 1960 [7]. Response surface methodology (RSM) is a collection of statistical and mathematical methods that are useful for the modelling and analyzing engineering poblems introduced by George E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Response Surface Methodology (RSM) is an empirical optimization technique for evaluating the relationship between experimental outputs (or responses) and factors called x_1, x_2, and x_3. Box–Behnken is a spherical, revolving design. In this study Box-Behnken design with three variable and three-level factor to reduce the numbers of experiment adopted. Three control factors, namely, water-cement ratio, steel fiber percentage, and temperature are used in this experimental work. In the present investigation 3 set of factors are involved and hence we require a 3^3 set ie; requiring 27 replications and a 3^3 full factorial design. But according to Box–Behnken designs it can be reduced to 13 sets and the design points reside in the middle of the sides and at the corner points of a cube.Figure II. Shows the model for Box–Behnken design. The model is designed using the equation:

$$y = ß_0 + ß_1x_1 + ß_2x_2 + ß_3x_3 + ß_{11}x_1^2 + ß_{22}x_2^2 + ß_{33}x_3^2 + ß_{12}x_1x_2 + ß_{13}x_1x_3 + ß_{23}x_2x_3$$

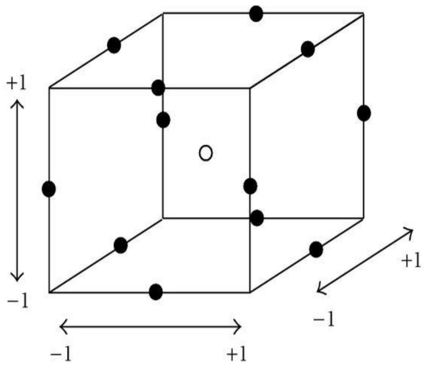

Figure. I Box Behnken Design For Three Factors

Details of specimens

To study the effect of elevated temperature on concrete cubes of size 150mm x150mmx150mm were tested in order to determine the compressive strength of the concrete. Three different temperatures were choosen are ambient temperature, 200°C and 400 °C and denoted by T_0, T_{200}, T_{400}. Specimen with fiber percentage 0%, 0.5%, 1% are represented by S_0, $S_{0.5}$, $S_{1.0}$ respectively. Specimen with W/C ratio 0.35, 0.4 and 0.45 are considered and represented by $R_{0.35}$, $R_{0.4}$, $R_{0.45}$.

Test on fresh properties of concrete – Slump test

It is used to study the workability of prepared concrete during the progress of work and to check the uniformity of concrete. Workability is one of the physical parameters of concrete which affects the strength and durability as well as the cost of labor and appearance of the finished product. Concrete is said to be workable when it is easily placed and compacted homogeneously without bleeding or segregation**.** Slump values obtained are tabulated shown in Table II.

Table II. Details Of Mixes Corresponds To Slump

Mix designation	Water/cement ratio	Superplastizer (% of cement)	Slump obtained (mm)
R0.35	0.35	0.5	66
R0.4	0.4	0.5	80
R0.45	0.45	0.5	95

Heating of test specimens

The study includes the effect of temperature on the concrete. The specimens were heated in the electric oven. The inside of the oven is cylindrical in shape with an internal diameter of 400 mm and a depth of 600 mm. The temperatures are set accordingly using the control box. In this study two temperature are choosen 200 and 400°C. After attaining desired temperature, one hour is provided to the specimen to maintained in that level for reaching steady state condition. After that the oven was swithched off and allow the specimen to cool off. It is observed that the mass of the specimen decreases after subjected to temperature and the loss in concrete mass is considerably less in steel fiber reinforced specimen compared to the control mix specimen. Mainly there are two types of cooling are adopted water cooling and air cooling. In this work air cooling is adopted ,water cooling produce thermal shock to the specimen and it results in sudden loose in strength. so water cooling is not considered.

III. Result And Discussions

Tests on hardened concrete - compression test

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. Out of many strength test applied for concrete, this is the most important which gives an idea about all the characteristics of concrete. Usually cubes and cylinders are used for this. The test specimens were subjected to compression test after 28 days of curing and desired degree of heating. The specified specimen is removed from water after curing period and wipe out excess water from the surface. The test result of the specimen as shown in the Table III.

Table III .Test Results

Designation	Temperature (Degree celsius)	Steel fiber (%)	Average compressive strength (N/mm^2)
$R_{0.35}$ S_0 T_{200}	200	0	43.4
$R_{0.35}$ $S_{0.5}$ T_0	27	0.5	53.2
$R_{0.35}$ $S_{0.5}$ T_{400}	400	0.5	50.5
$R_{0.35}$ $S_{1.0}$ T_{200}	200	1	55.5
$R_{0.4}$ S_0 T_0	27	0	40.2
$R_{0.4}$ S_0 T_{400}	400	0	35.4
$R_{0.4}$ S_0.5 T_{200}	200	0.5	41.2
$R_{0.4}$ $S_{1.0}$ T_{400}	400	1	43.0
$R_{0.4}$ $S_{1.0}$ T_0	27	1	44.5
$R_{0.45}$ $S_{1.0}$ T_{200}	200	1	45.4
$R_{0.45}$ $S_{0.5}$ T_0	27	0.5	42.3
$R_{0.45}$ $S_{0.5}$ T_{400}	400	0.5	40.5
$R_{0.45}$ S_0 T_{200}	200	0	35.6

From the table it is clear that compressive strength is increases with increase in % of steel fiber.But temperature increases the compressive strength decreases in the case of 0% steel fiber specimen .While there were only Small decrease in the compressive strength in the case of 1% steel fiber specimens. So addition of steel fibers is more effectively increases the compressive strength of the specimen. The crack formation is also very small in fiber specimen compared to the non fiber specimens. So as the temperature increases then also the steel fibers has a significant role in increasing the strength as well as reducing the crack propagation and results in increasing the durabilityof the concrete.

Result analysis by *Box-behnken design* **using regression technique**

Experiments were performed using the Box–Behnken experimental design. Box–Behnken experimental design is a type of response surface methodology. Response surface methodology is an empirical optimization technique for evaluating the relationship between the experimental outputs and factors called x_1, x_2, and x_3. For obtaining the results for Box-Behnken design, analysis of variance has been calculated to analyze the accessibility of the model and was carried in Microsoft Office Excel 2007. The test result of the specimen using Box–Behnken design as shown in the Table IV.

Table IV. Design Results

Designation	Temperature (Degree celsius)	Steel fiber (%)	Predicted compressive strength (N/mm^2)
$R_{0.35}$ S_0 T_{200}	200	0	45.05
$R_{0.35}$ $S_{0.5}$ T_0	27	0.5	53.01
$R_{0.35}$ $S_{0.5}$ T_{400}	400	0.5	49.92
$R_{0.35}$ $S_{1.0}$ T_{200}	200	1	54.60
$R_{0.4}$ S_0 T_0	27	0	38.60
$R_{0.4}$ S_0 T_{400}	400	0	34.44
$R_{0.4}$ S_0.5 T_{200}	200	0.5	41.20
$R_{0.4}$ $S_{1.0}$ T_{400}	400	1	44.40
$R_{0.4}$ $S_{1.0}$ T_0	27	1	45.64
$R_{0.45}$ $S_{1.0}$ T_{200}	200	1	43.74
$R_{0.45}$ $S_{0.5}$ T_0	27	0.5	42.93
$R_{0.45}$ $S_{0.5}$ T_{400}	400	0.5	40.62
$R_{0.45}$ S_0 T_{200}	200	0	36.49

Box Behnken design was successfully adopted and the experiments were designed choosing the input parameters for the levels selected. Response surface methodology using Box-Behnken design proved very effective and time saving model for studying the influence of process parameters on response factor by significantly reducing the number of experiments and hence facilitating the optimum conditions. The conclusions obtained from the test results are:

- The compressive strength increases with the increase in the % of steel fibers.
- As temperature increases the compressive strength decreases in the case of 0% Steel fiber mixes.
- Due to increase in temperature the compressive strength reduction is very small in fiber containing specimen.
- As in the case of 1% Steel fiber the compressive strength is very much higher compared to the control mix.
- In the case of 1% fiber specimen exposed to 400°C temperature ,there were a small decrease in compressive strength compared to 0% fiber specimen exposed to 400°C.
- Reduction in compressive strength appears to decrease in a systematic manner with increase in steel fibers.

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