Study of Fire on Structural Materials and Its Protection

Siddharth Shah[1], Kashish Sonpal[2], Vardhan Garg[3], Yash Kulshreshtha[4]

[1, 2, 3, 4] *UG Student, Institute of Technology, Nirma University (Ahmedabad)*

***Abstract:* - Fire Safety is one of the important parameter in modern design philosophy. Effect of fire on structural elements made up of concrete and steel are quite different and is mostly considered as secondary effects. Both most widely used structural materials concrete and steel shows different response when subjected to fire of constant temperature. Thus detailed study on effect of fire on structural materials like concrete and steel under different loading conditions, exposure conditions and cooling methodology is essential. In the present study effect of fire on concrete cubes subjected to different loading conditions and cooling conditions are studied experimentally. Apart efficacy of protective coating made up of piezoelectric powder with structural epoxy for structural steel material subjected to temperature exposure is also explored. It has been found that, compressive strength of concrete cube reduces significantly when preloaded with load irrespective of types of cooling methods.**

***Key Words:* Fire Exposure, Concrete and Steel Material, Protective system**

I. INTRODUCTION

The intention of fireproofing a structure is to protect the building from structural failure due to fire exposure. Fire resistance is usually expressed in “period of time”. Regulations use this time periods to categorise fire resistance depending on the size and usage of the building.

All commonly used structural materials lose some of their strength when exposed to fire. Concrete has to satisfy fire safety requirements specified in Building Codes as fire is one of the most severe conditions and hence, is an important aspect of building design. Fire safety of a structure is measured in terms of the total time that the concrete structure exhibits resistance with respect to structural integrity and stability.

Concrete when compared to other building materials performs well against fire due to presence of aggregate and cement which when mixed makes a very resistant material to fire. The behavior of a concrete structural member exposed to fire is dependent, in part, on thermal, mechanical, and deformation properties of member of which the concrete is composed. These properties vary as a function of temperature and depend on the composition and characteristics of concrete.

When a structural member is subjected to a defined temperature time exposure during a fire, this exposure will cause a predictable temperature distribution in the member. Increased temperatures cause deformation change in the constitutive materials of a structural member.

With knowledge of deformations and property changes in constitutive material, the usual methods of structural mechanics can be applied to predict the fire resistance performance of a structural member. When concrete is subjected to high temperatures there is huge amount of loss in strength and also all the other properties change. At very high temperatures there is also spalling observed of concrete.

Steel, like concrete, has the advantage of being non-combustible. Its high thermal conductivity makes steel absorb heat much more than other materials, thus if the structural member has a relatively small mass, its temperature will increase very rapidly. Both the yield stress and modulus of elasticity of steel, the two material properties most important in determining load carrying capacity, decrease considerably with increasing temperatures.

Structural steel is the only construction material, which can recover its strength after fire and the steel temperature at which the member is no longer able to support the applied load is termed the critical temperature which is about 538°C.

Structural steel used for girders, beams, etc. need to be protected so that its load-carrying ability is not reduced. With work hardened reinforcing steel the ductility is often improved during heating but the temperatures at which this happens will usually cause a permanent loss in strength. Structural steel regains its strength when is cools back to ambient temperature from 600˚C for structural steel the yield strength reduces to about 60% at 400˚C and more increase in temperature reduces the strength further with attaining of yield point at around 538˚C.

Study on behavior of concrete and steel exposed to fire plays an important role in designing various structures to increase their design life and protect them against disastrous effects during an unwarranted situation. In this paper effect of fire on concrete and steel material is studied by casting concrete cubes and tensile test for specimen of steel. Various modes of cooling the test specimens are adapted to find effectiveness of each one of them.

II. TEST SPECIMENS

2.1 Concrete Cubes

For preparing the mix design of the concrete, the properties like specific gravity of cement, fine aggregates and coarse aggregates was obtained.

The results obtained are following:

1) Specific gravity of cement = 3.13
2) Specific gravity of F.A. = 2.57
3) Specific gravity of C.A. = 2.72

Concrete mix design is carried out as per IS 10262:2009 to cast 21 no. of cube specimen of size 150mm × 150mm × 150mm. Details of mix design for M25 grade of concrete is given in table 1. All cubes are casted together and cured for 28 days by placing them under water tank and ambient temperature. Details of concrete cube test specimen prepared for various types of cooling methods are given in table 2.

Table 1: Concrete Mix Design for M25 Grade Concrete Cubes

MATERIAL	MASS (Kg/m^3)
Cement	297
Fine Aggregates	594
Coarse Aggregates	1056
Water	185
Fly ash	74
Admixture (Super plasticizer)	3.7
Polypropylene Fibers (12mm length)	1.3
Cement : Fine Aggregate: Coarse Aggregate	1 : 1.6 : 2.85
Water/Cement Ratio	0.5

Table 2: Details of Concrete Cube Test Specimen for different types of conditions

Sr.No	Description	No. of Cubes	Curing Period
1	Without Preload, cooling naturally	3	28 days
2	Without Preload, sprinkling water immediately and instant testing	3	28 days
3	Without Preload, sprinkling water immediately and testing after one day	3	28 days
4	With Preload, cooling naturally	3	28 days
5	With Preload, sprinkling water immediately and instant testing	3	28 days
6	With Preload, sprinkling water immediately and testing after one day	3	28 days
7	Controlled Cubes for Comparison	3	28 days

2.2 Steel Specimen

Steel specimen of 10mm diameter and 500mm length is prepared as per IS 1608: 2005. Total 4 no. of test specimens are prepared from HYSD Steel of grade Fe500. Three different types of steel test specimens are prepared which are further subjected to fire and fourth specimen is used as a reference specimen which is not subjected to fire. The three specimens are as follows:-

(i) Normal HYSD steel test specimen
(ii) Fully Coated HYSD steel test specimen using piezoelectric (PZT) powder mixed with structural epoxy (SP5A).
(iii) HYSD steel test normal specimen coated with PZT powder based coating for half the length.

These tests specimens are prepared to see the effect of fire on bare (non-coated) and coated specimen and thus establishing efficacy of the latter.

III. EXPERIMENTAL PROGRAMME

3.1 Concrete Cube Testing

As discussed in section 2.1, 21 no. of concrete cubes are casted and cured for 28 days. Out of 21 no. of concrete cube specimen, 3 no. of concrete cubes are tested under axial compression load on Compression Testing machine (CTM) of 2000 KN capacity and average result of concrete cubes are extracted.

In order to simulate physical conditions of concrete during an event of fire, 9 no. of concrete cubes are preloaded using CTM by an amount of 20% of design load.

18 no. of concrete cubes are placed into automatic gas fire furnace for a steady state temperature of 538°C for 1 hour (60 minutes) exposure time. Fig-1 shows inside view of gas furnace of capacity 1000°C used to expose concrete cubes to fire at 700°C. After taking out 12 no. of concrete cubes from furnace, they were cooled by sprinkling water jet of normal pressure and 6 no. of concrete cubes are immediately tested for compression load while other 6 no. of concrete cubes were tested after 1day (24 hours) of sprinkling water. Remaining 6 no. of concrete cubes were allowed to cool naturally at ambient temperature for 24 hours after taking them out of gas furnace and then they were tested for compressive load.

Fig-1 Inside view of the fire chamber with terrawool as insulating material

Fig-2 Fire affected concrete cube

3.2 Experimental Work For Steel

Steel bars of diameter 10 mm and Fe 500 of length 500 mm each. PZT coating was applied on them for different combinations. PZT (piezoelectric) coating can be prepared using the following method:

1. PZT: P (Lead) + Z (Zirconate) + T (Titanate)
2. PZT is a ceramic-based powder. PZT + Adhesive will make a structural epoxy.
3. Based on trials, the best ratio of PZT: Epoxy was found to be 6:1.
4. Epoxy is composed of a hardener and a resin in the ratio 2:5.
5. The hardener used was HV 998 and the resin used was AV 138.
6. PZT used was SP 5A.
7. First weigh the resin.
8. Add IPA (Isopropyl Alcohol) and mix it. IPA is added to reduce the viscosity of the mix. Being a volatile substance, its amount of addition doesn't matter.
9. Add PZT powder. Again add IPA and mix it thoroughly.
10. Add hardener to the mix and again IPA is added. The coating mix is ready for application.

PZT coating prepared was applied as a double coat on the steel bars in the following manner:

- One bar was coated to its full length.
- One bar was coated to its half-length.
- Two bars were kept without coating.

The bars were kept for 24 hours for air curing, so that the coating dries easily. Double coat was applied only after a period of 24 hours and the bars again kept for air curing for 24 hours.

The steel bars after curing were placed in the automatic gas fire furnace first at 700˚C and then again at 550˚C for a period of 1 hour each time. Only three out of the four bars were placed under the fire effect. One of the bars without coating was not placed under fire effect to measure the natural properties of the steel bars.

After allowing the bars to cool for sufficient period of time the steel bars were tested for tensile strength under Universal Testing Machine (UTM). The results were obtained for all four bars and the stress vs strain graph was plotted for all the four and the Modulus of Elasticity (E) and Modulus of Resilience were obtained from the graph.

Fig-3 Coating of the steel bars

Fig-4 Effect of fire on coating

Fig-5 Tensile Test Setup for Steel Specimen

IV. RESULTS

4.1 CONCRETE

The concrete cubes were tested for their compressive strengths after giving them fire effect in the automatic gas fire furnace. The results were thus obtained and were compared with normal concrete cubes.

Table-3: Comparison of various concrete results

SR. NO	**TYPE OF TESTING**		**REDUCTION IN STRENGTH**	**RELATIVE COMPRESSIVE STRENGTH**	**FAILURE LOAD (kN)**
1	**WITHOUT PRELOAD**	NATURAL COOLING	4.56%	0.95	534
2		SPRINKLING WATER IMMEDIATELY AND INSTANT TESTING	15.32%	0.86	484
3		SPRINKLING WATER IMMEDIATELY AND TESTING AFTER ONE DAY	6.14%	0.94	528
4	**WITH PRELOAD**	NATURAL COOLING	10.34%	0.89	500
5		SPRINKLING WATER IMMEDIATELY AND INSTANT TESTING	38.19%	0.62	348
6		SPRINKLING WATER IMMEDIATELY AND TESTING AFTER ONE DAY	18.91%	0.81	486

The reduction of strength of the cubes is deduced from comparison of that from the normal strength and the relative compressive strength is the ratio of the obtained strength to that of normal strength.

4.2 STEEL

Likewise the steel bars were tested for their tensile strengths after giving them fire effect in automatic gas fire furnace. The results were thus obtained and were compared with normal steel bars.

Table-4: Comparison of various Steel bars

SR. NO.	**TYPE OF BAR**	**YIELD STRESS (N/mm^2)**	**ELONGATION IN LENGTH (mm)**	**REDUCTION IN DIAMETER (mm)**	**MODULUS OF ELASTICITY (N/mm^2)**	**MODULUS OF RESILIENCE (N/mm^2)**
1	**RB***	549.29	17	4.68	203712	0.74
2	**FC***	486.87	9.94	3.14	122484	0.97
3	**HC***	480.63	8	4.2	171715	0.67
4	**WC***	468.15	9.66	3.16	178923	0.61

***RB** = Reference Bar, **FC** = fully coated bar, **HC** = Half coated bar, **WC** = without coated bar

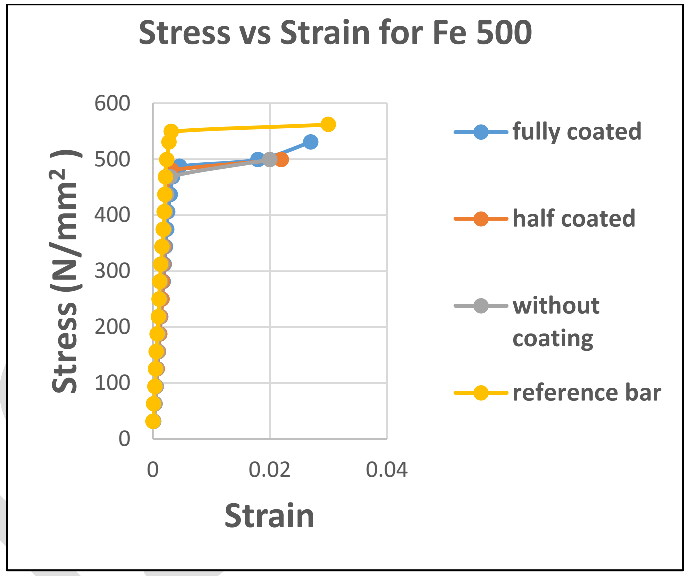

Fig-6 Stress vs. strain graph for steel specimen

V. CONCLUSIONS

The following things can be concluded from our experiments.

1. The strength of concrete, which is been tested at elevated temperatures, is significantly less.
2. The strength of cubes without preload is observed to be greater than the strength of cubes with preload.
3. Pouring instant water on heated concrete and testing it instantaneously reduces the strength of concrete considerably.
4. Pouring instant water on heated concrete, allowing it to cool naturally and then testing it after 24 hours gives comparatively higher strength values as compared to instant testing.
5. Polypropylene fibers help retain strength to large extent.
6. The yield stress of steel bar kept as a reference bar was maximum.
7. The yield stress for the coated bars increased with the increase in amount of coat applied.

ACKNOWLEDGEMENT

We would like to express our deepest appreciation to all those who provided us the possibility to complete this report. A special gratitude to our guide Prof. Sharad Purohit whose contribution in stimulating suggestions and encouragement helped us to coordinate our project.

Furthermore we would also like to acknowledge with much appreciation the crucial role of the staff of Civil Engineering Department, Nirma University, who gave the permission to use all required equipment and the necessary materials to complete the task. Special thanks go to ours FRIENDS, who helped us to assemble the parts and gave suggestion about the task. We have to appreciate the guidance given by other supervisors as well as the panels especially in our project presentation that has improved our presentation skills. Thanks to their comment and advices.

REFERENCES

[1]. Jong-Pil Won. , Soo-Hwan Kim. , Su-Jin Lee. , Se Jin Cho, "Shrinkage and durability characteristics of eco-friendly fireproof high-strength concrete", Construction and Building Materials, 40 (2013): 753–762.

[2]. Jong-Pil Won. , Hee-Byoung Kang. , Su-Jin Lee. , Joo-Won Kang, "Eco-friendly fireproof high-strength polymer cementitious composites", Construction and Building Materials, 30 (2012): 406–412.

[3]. Se Jin Choi. , Soo-Hwan Kim. , Su-Jin Lee. , Rosa Won., Jong-Pil Won. ," Mix proportion of eco-friendly fireproof high-strength concrete", Construction and Building Materials, 38 (2013): 181–187.

[4]. Young-Sun Heo. , Jay G. Sanjayan , Cheon-Goo Han , Min-Cheol Han, "Synergistic effect of combined fibers for spalling protection of concrete in fire", Cement and Concrete Research, 40 (2010): 1547–1554.

[5]. F. Walda, L. Simo es da Silva, D.B. Moore, T. Lennon, L. Borges, M. Benes, "Experimental behaviour of a steel structure under natural fire", Fire Safety Journal, 41 (2006): 509–522.

[6]. Venkatesh Kodur, "Properties of Concrete at Elevated Temperatures", Received 18 September 2013; Accepted 16 January 2014; Published 13 March 2014.

[7]. Institute for Steel Development & Growth (INSDAG), "Guide Book on Fire Protection of Steel Structures", INS/PUB/70, April 2004

[8]. Fire Resistant Test Of Structures IS 3809-1979.

[9]. Standard Test Method for Fire Test of Building Construction and Materials, ASTM E119.

[10]. Guide For Determining Fire Endurance Of Concrete Elements, ACI 216.