EFFECT OF CHLORIDE & SULPHATE ATTACK ON HIGH STRENGTH CONCRETE WITH ELEVATED TEMPERATURE

Prof. Pramod B. Salgar*

Prof. Pramod R .Thorat**

***ABSTRACT*:**

Now a day's High-Performance concrete (HPC) is widely used throughout the world. Super-plasticizers and different kinds of cement replacement materials are used in these concretes to achieve the required workability. Today concrete has been used with an increased strength and durability in connection with the developments in technology in pre-stressed concrete, concrete and reinforced concrete structures which are sometimes exposed to fires and many structures get damaged and out of use. 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. As it is known, high temperatures caused as a result of fire decreases the concrete strength and durability of such structures. The most important design parameter for concrete structures is compressive strength. This critical parameter drives the design process and can influence the cost of a project. Through the use of certain mineral admixtures, the cost of concrete can be reduced. These admixtures also enhance the properties of mortar or concrete.

Keywords- *High-Performance concrete (HPC), Thermal shielding,*

* M.E.(Structures), Assistant Professor, RIT, Sakharale, Sangli, 415413

** M.E.(Structures), Assistant Professor, AITRC, Vita, Sangli.

1. *INTRODUCTION*:-

Various studies are carried out on high strength concrete with different parameters such as cementitious materials (fly ash, slag etc), with varying high temperatures, cooling condition and duration of heating. Some structures are subjected to accidental fire, because of which they are subjected to very high temperature, due to which concrete abruptly changes its physical, mechanical and chemical properties.

Now days, it is a need to check the safety of structure against fire. It is a challenge to build fire resistant structure in an economical way. Thus the study is required to analyze the concrete subjected to high temperature & then its relative strength. With the increasing application of HSC in different concrete structures, the risk of exposing it to elevated temperatures has increased significantly. The researcher is considering situation like, a particular structure got under fire. It is adversely affecting the structure. Some time there may be delay to overcome the fire due to inability of fire brigade and/or lack of other facilities.

The attempt has been made to check the fire resistance of high strength concrete when it is subjected to elevated temperature. So in this dissertation work, study will be carried out by considering above parameters simultaneously.The main aim of the reacherch is to find out the effect of high temperature and cooling conditions on the properties of HSC (M50) containing varying percentage of silica fume which is the replacement material for cement by weight. The compressive strength of concrete is found by subjecting it to high temperature and then cooling in dry and wet condition. In addition to this the weight loss of concrete is also found out. The experimental results are presented and discussed. Some of the structures in which concrete is subjected to elevated temperatures are as mentioned below,

1) In chimney construction, concrete walls have replaced the usual firebrick lining where elevated temperatures are encountered.
2) In metallurgical and chemical industries, glassmaking 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.
3) In take-off areas of jet aircraft, localized areas of concrete are subjected to the effects of the exhaust gases of the jets. This 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.

4) 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 to as well as acting as a shield to radiation.
5) In case of accidental fire in residential & commercial building components of structures such as column, beam, slab etc. are exposed to accidental fire and then method of control to fire i.e. Air & Water cooling.

In order to assess the structural safety of structures exposed to elevated temperatures, it is essential that the effect of exposure to elevated temperatures on the strength of concrete should be fully understood.

2. *OBJECTIVES*:-

1) To determine the compressive strength of M50 grade (HSC) concrete using PPC with addition of varying percentage of SF by replacement of cement.
2) To determine the weight loss of concrete specimens for increased fire rating.
3) To analyze the effect of controlled elevated temperature on compressive strength of M50 grade (HSC) concrete.
4) To compare compressive strengths of M50 concrete before and after exposing to high temperature and sulphate attack.
5) To compare flexural strengths of M50 concrete before and after exposing to high temperature and sulphate attack.
6) To find weight loss of M50 concrete due to high temperature and sulphate attack.

3. *METHODOLOGY:-*

Experimental methodology is adopted for this dissertation work. The details of experimental work are as follows,

1) Designing concrete mix for M50 grade using Pozzolona Portland Cement and casting cubes of (150x150x150) mm size.
2) Curing above cubes for 28 days in water at 24^{o}C to 30^{o}C temperature & subjecting them to elevated temperature (200^{o}C, 400^{o}C, & 600^{o}C) for 4 hours.
3) Determining the weight changes, the specimens are weighed prior to heating and after cooling. The changes are expressed as percentages of the initial weights.

4) Testing specimens in the laboratory in compression testing machine (CTM-2000KN)

4. EXPERIMENTAL WORK:-

4.1 Mix Design for M50 Grade Concrete

The main aim of the project is to find out the effect of high temperature and cooling conditions on the properties of HSC (M50) containing varying percentage of silica fume which is the replacement material for cement by weight. The compressive strength of concrete is found by subjecting it to high temperature and then cooling in dry and wet condition. In addition to this the weight loss of concrete is also found out. M50 (HSC) mix is used. The Mix proportion Cement: F.A: C.A: SP is 1:1.43:2.23:1.3%. The water cement ratio is 0.30

The experimental work includes the casting, curing and testing of concrete exposed to elevated temperature and cooling conditions. A concrete mix of M50 grade is designed. The locally available fine aggregate and coarse aggregate are used.

Table 1 Initial Mix proportions for M50 grade concrete

Cement	Water	Sand(fine aggregate)	Coarse Aggregate	SP
510 kg/m^3	152 kg/m^3	705 kg/m^3	1115 kg/m^3	7.65 kg/m^3
1	0.29	1.52	2.5	1.5%

With above mix desired compressive strength is not achieved, hence by adjusting W/C ratio and proportions of fine aggregate, coarse aggregate and superplasticizer, following mix proportion is finalized.

Table 2Final Mix proportions for M50 grade concrete

Cement	Water	Sand(fine aggregate)	Coarse Aggregate	SP
512 kg/m^3	158 kg/m^3	760 kg/m^3	1145 kg/m^3	6.91 kg/m^3
1	0.30	1.43	2.23	1.3%

4.2 Compressive Strength of Concrete:-

For casting of the cube specimens, moulds of size (150 x 150x 150) mm are used. Oil is applied on inner surface of mould before placing of concrete. The values of compressive strength of concrete after 28 days at room temperature are as per Table 3

Table 3 Compressive strength of M50 grade concrete

Sr. No.	Identification of specimen	7 days Comp. Strength (MPa)	7 days Avg. Comp. Strength (MPa)	28 days Comp. Strength (MPa)	28 days Avg. Comp. Strength (MPa)
1.	0%SF1	45.66	42.73	65.33	63.10
2.	0%SF2	44.33		63.33	
3.	0%SF3	38.22		60.66	

4.3 Mix Proportion for Test Specimens:-

Table 4 Description of different mixes for cube specimens

Mix Type	Cement (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	SP (kg/m^3)
0%SF	512	0	158	760	1145	6.91
5%SF	486.4	25.6	158	760	1145	6.91
10%SF	460.8	51.2	158	760	1145	6.91
15%SF	435.2	76.8	158	760	1145	6.91
20%SF	409.6	102.4	158	760	1145	6.91

5. EXPERIMENTAL PROGRAM

5.1 EXPERIMENTAL PROCEDURE:-

The experimental work includes the casting, curing and testing of M50 grade concrete exposed to elevated temperature and subjecting to different cooling conditions. Weight loss of each concrete specimen is found out.

With the increase in use of HSC, blending of cements with mineral admixtures is also increased. The use of HSC for the construction of the inner containment structures of nuclear power plants is also in vogue. Therefore studies of such concretes when exposed to elevated temperatures have gained importance. Normally in structures such as nuclear reactor pressure vessels, storage tanks for hot crude oil and water, coal gasification and liquefaction vessels in petrochemical industries, accidental fire etc. the concrete will be subjected to a maximum of 600^{o}C. Hence the study is limited to a maximum temperature of 600^{o}C. To suit the above needs, HSC of M50 grade using the temperature range 200^{o}C, 400^{o}C to 600^{o}C have been considered.

The present investigation is to evaluate the compressive strength and weight loss of concrete when subjected to elevated temperatures of 200^{o}C, 400^{o}C, and 600°C.Ingredients of the mix are taken as per the mix proportion as shown in Table 3.9. Concrete is filled in three layers.

The top surface of the specimens is hand toweled. The moulds are stripped after 24 hrs. The concrete are cured for 28 days. The specimens are demoulded after 24 hours of air cooling and kept for water curing for 28 days. After curing, the specimens are dried for one day in shed. Then they are placed in electric furnace at requisite temperatures of 200°C, 400°C, and 600°C at constant time interval of 4hours. After removal from furnace, they were allowed to cool in dry and wet conditions and are tested for compressive strength.

To determine the weight changes, the concrete are weighed prior to heating (Wi), then heated and weighed after cooling (Ws) with an accuracy of 0.01g. The changes (W) are expressed as percentages of the initial weight as,

$$W = \frac{Wi - Ws}{Wi} x100$$

From the data obtained, weight changes of the HSC with varying temperatures are presented.

5.2 HEATING EXPOSURE TECHNIQUE:-

Electric furnace of maximum temperature of 1000°C is used. Concrete specimens are placed in the furnace chamber which is at room temperature and then temperature is increased to reach desired degrees with increase at 10°C/min. After 4 hours of heating at constant temperature, the furnace is switched off and allowed to cool and then concrete specimens are taken out and cooled with dry and wet cooling conditions & then they are tested. (Photo 6, 7 & 8)

5.3 TESTING PROCEDURE OF CONCRETE:-

After 28 days curing period, the concrete specimens are taken out of curing tank and tested under a compression testing machine of 2000KN capacity. The crushing loads are noted and the average compressive strength of three specimens is determined. The compressive strength values of concrete containing varying percentage of SF subjected to elevated temperature under different cooling conditions are presented in Tables and the variations are presented in Figures. (Photo 11)

Details of all mixes are shown in Table 3.9.In each mix; concrete are divided into three groups: elevated temperature, chloride attack and sulphate attack.

PART: - A

5.4 CONCRETE SPECIMENS SUBJECTED TO ROOM TEMPERATURE:-

Step.1.Preparation of concrete specimens:-

In order to study experimental investigation on the compressive strength of high strength concrete M50 with a total no. of 09 cube specimens [150x150x150mm] & 09 beams specimens [500 x 100 x 100 mm] are cast. Details of specimens are as shown in Table 5.1.

Table 5.1 Details of specimens for room temperature

Type of curing condition	Normal curing	Shulphate attack	Chloride attack	Total specimens
Room Temp	3 Cubes	3 Cubes	3 Cubes	09 Cubes
Room Temp	3 Beams	3 Beams	3 Beams	09 Beams

Ingredients of the mix are taken as per the mix proportion. Concrete is filled in three layers. The top surface of the concrete is hand troveled. The moulds are stripped after 24 hrs. The concrete are cured for 28 days.

Step.2.Testing:-

Then concrete of each mix type are tested for their compressive strength at room temperature.

PART: - B

5.5 CONCRETE SPECIMENS SUBJECTED TO ELEVATED TEMPERATURE:-

Step.1.Preparation of concrete specimens:-

In order to study effect of elevated temperature on the compressive strength of High strength concrete prepared with a total number 09 cube specimens [150x150x150mm] & 09 beams specimens [500 x 100 x 100 mm] are cast. After the heat treatment 09 cube specimens are cooled. Details of specimens are as shown in Table 5.2.

Table 5.2 Details of specimens

Exposure duration	**Temperature(^{o}C)**			**Total**
	200	**400**	**600**	
4 hr	3 Cubes	3 Cubes	3 Cubes	09 Cubes
4 hr	3 Beams	3 Beams	3 Beams	09 Beams

Ingredients of the mix are taken as per the mix proportion. Concrete is filled in three layers. The top surface of the concrete is hand traveled. The moulds are stripped after 24 hrs. The concrete are cured for 28 days. After curing the concrete are dried for one day in shed.

Step.2.Heating:-

The concrete are kept in furnace at required temperature, 200^{o}C, 400^{o}C and 600^{o}C for 4 hours at constant temperature. After heating, the concrete are taken out and cooled in room temperature.

Step.3.Testing:-

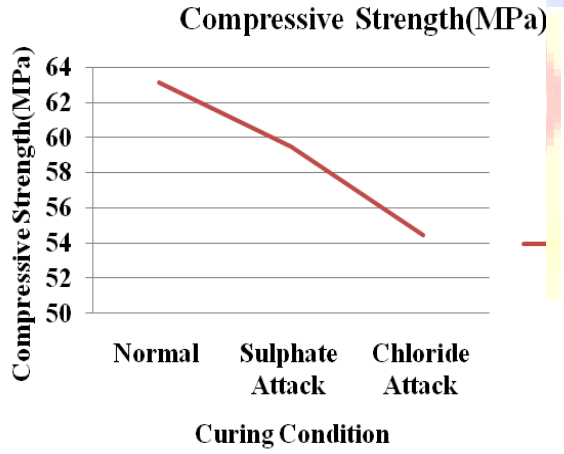
Then concrete of each mix type are tested for their compressive strength at room temperature. To find out weight loss of concrete after heat treatment, concrete are weighted before heating and after heating.

6. Results and Discussion-

6.1 Compressive Strength of Concrete at Room Temperature:-

Table 6.1 Compressive strength results at room temperature

Curing Condition	Normal	Sulphate Attack	Chloride Attack
Compressive Strength(MPa)	63.1	59.44	54.43



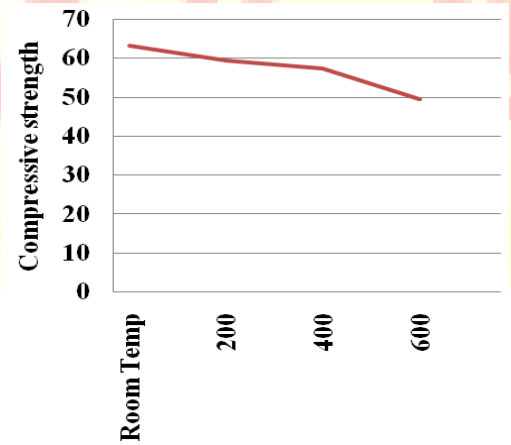


Figure 6.1 Compressive Strength at room temp. Figure 6.2 Compressive strength at elevated temp.

As per Figure 6.1, as curing condition changes compressive strength decreases and shows maximum 63.10MPa for Normal Water curing, 59.44 MPa for Sulphate attack & 54.43 MPa for Chloride attack

6.2 Compressive Strength of Concrete after Exposed To Elevated Temperature:-

As per Figure 6.2, the effect of elevated temperature on HSC specimens show decrease in compressive strength with increase in temperature. 13.77 MPa strength loss is observed at 600°C. Strength decreases from 63.1MPa to 49.33MPa with respect to increase of temperature from Room Temperature 200°C, 400°C to 600°C.

6.3 Percentage Decrement in compressive strength:

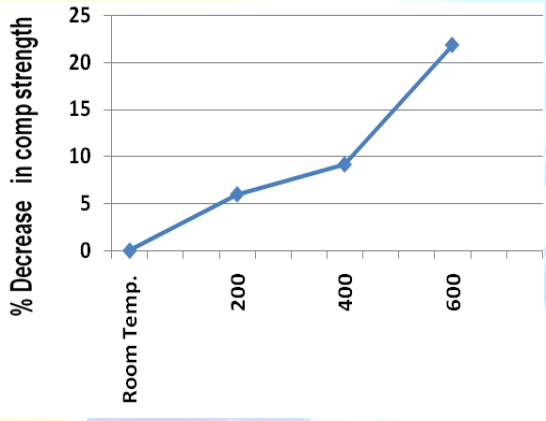


Figure 6.3 Percentage Decrement in Compressive strength at elevated temp.

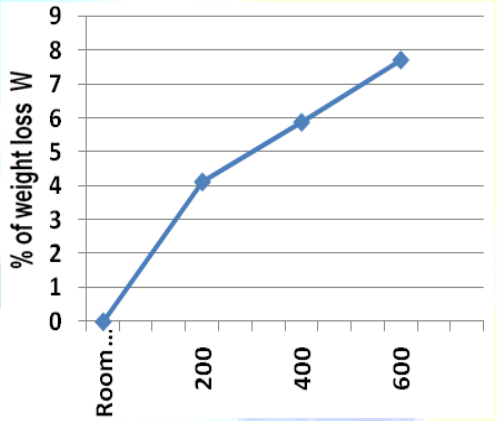


Figure 6.4 Percentage Weight loss at elevated temp

As per Figure 6.3 & Table 6.2 it is observed that, the compressive strength of HSC is less than that of the reference specimens (i.e. concrete at room temperature) by 5.97 % for 200^{o}C, 9.14 % for 400^{o}C, 21.82% for 600^{o}C,

6.4 Percentage Weight loss of concrete cube specimens:-

At elevated temperature 200°C, 400°C & 600°C concrete shows maximum weight loss of 7.714% at 600°C. As per Figure 6.4 & Table 6.2, the weight loss of HSC after exposing to 200°C, 400°C, & 600°C for duration of 4 hrs is less than that of the reference specimens (i.e. concrete at room temperature) these values are 4.125%, 5.882%, and 7.714%, respectively.

6.5 Flexural strength results when concrete beam specimens are subjected to Sulphate Attack & Chloride Attack at room temperature

Table 6.2 Flexural strength results at room temperature

Curing Condition	Normal	Sulphate Attack	Chloride Attack
Flexural Strength(MPa)	24.85	23.11	22.65

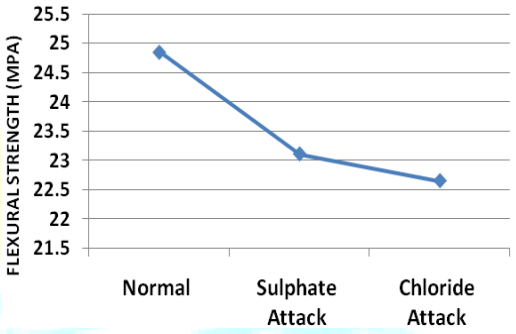


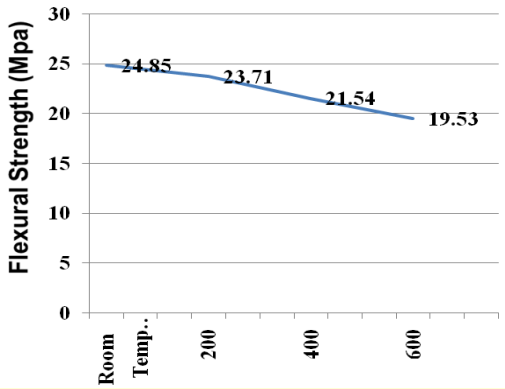
Figure 6.5 Flexural Strength at room temp.

As per Figure 6.5, as curing condition changes flexural strength decreases and shows maximum 24.85MPa for Normal Water curing, 23.11 MPa for Sulphate attack & 22.65 MPa for Chloride attack

Table 6.3 Flexural Strength of concrete beam specimens Results

Temp. (^oC)	Weight before placing electric furnace Wi (kg)	Weight after removing from electric furnace Ws (kg)	% of weight loss W	Flexural Strength (MPa)	Average Flexural strength (MPa)
Room Temp.	13.65	13.78	0.12	25.05	24.85
	13.22	13.35		24.1	
	13.26	13.38		25.01	
200	13.14	12.89	2.84	21.3	23.71
	13.09	12.575		24.2	
	13.2	12.845		25.65	
400	13.08	12.54	4.05	20.5	21.54
	13.09	12.575		21.7	
	12.95	12.42		22.42	
600	13.015	12.305	5.33	15.5	19.53
	12.89	12.255		18.8	
	13.005	12.275		24.3	

6.6 Flexural strength of concrete beam specimens after elevated temperature:-



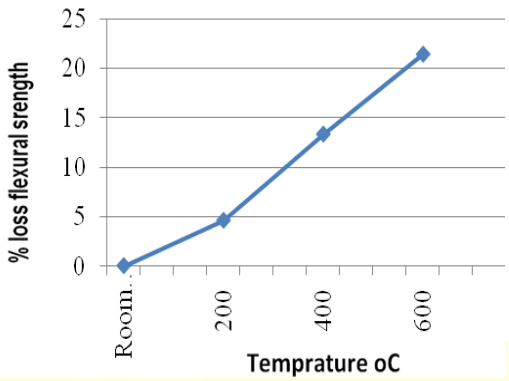


Fig. 6.6 Flexural strength of concrete beam elevated temperature

Figure 6.7 Percentage Decrement in Flexural Specimens after strength at elevated temp.

As per Figure 6.4, the effect of elevated temperature on HSC specimens show decrease in flexural strength with increase in temperature. 5.53 MPa strength loss is observed at 600°C. Strength decreases from 24.85 MPa to 19.53 MPa with respect to increase of temperature from Room Temperature, 200°C, 400°C to 600°C.

6.8 Percentage Decrement in Flexural strength:-

As per Figure 6.5 & Table 6.3 it is observed that, the Flexural strength of HSC is less than that of the reference specimens (i.e. concrete at room temperature) by 4.59 % for 200^{o}C, 13.32 % for 400^{o}C, 21.41% for 600^{o}C.

6.9 Weight loss of concrete beam specimens:-

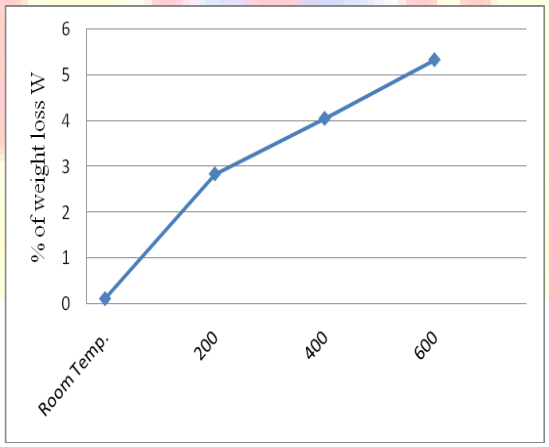


Figure 6.7 Weight loss at elevated temp.

At elevated temperature 200°C ,400°C & 600°C concrete shows maximum weight loss of 5.33% at 600°C.

As per Figure 6.6 & Table 6.3, the weight loss of HSC after exposing to 200°C, 400°C, & 600°C for duration of 4 hrs is less than that of the reference specimens (i.e. concrete at room temperature) these values are 2.8%, 4.05%, and 5.33%, respectively.

7.Conclusions:-

[1] There is very little variation in weight loss with M50 grade concrete (HSC) subjected to elevated temperature from 200°C to 600°C.

a) Weight loss is in between 0% to 7.714% for M50 grade concrete (HSC) at 600°C.

b) Maximum weight loss is 7.714% for normal cooling condition for M50 grade concrete (HSC) at 600°C.

[2] The compressive strength is decreased as the test temperature is increased.

a) M50 grade concrete (HSC) with exhibited decrease in compressive strength with increase in temperature.

b) The maximum percentage decrement in compressive strength of concrete is 59.33%, 57.33%, 49.33% with reference specimen i.e. concrete at room temperature.

[4] The compressive strength of concrete subjected to elevated temperature increased.

a) The compressive strength of concrete subjected to elevated temperature at 200^{o}C is 59.33%.

b) The compressive strength of concrete subjected to elevated temperature at 400^{o}C is 57.33%.

c) The compressive strength of concrete subjected to elevated temperature at 600^{o}C is 49.33%.

Scope for Further Study:-

1) The effect of very high temperature like 600^{o}C to 1000^{o}C on the properties of concrete.
2) The effect of alternate heating and cooling on the properties of high strength concrete.
3) The effect of elevated temperature exposure more than 4 hours (i.e. 6 to 8 hours) duration on the properties of high strength concrete.
4) The effect of elevated temperature on other parameters like Tensile Strength, Flexural strength etc. of high strength concrete.
5) The effect of elevated temperature on high strength concretes of M60, M70 grades etc.

6) The effect of elevated temperature on shrinkage properties of high strength concrete.

REFERENCES:-

[1] Chandramouli.K, Srinivasa Rao.P, Pannirselvam, Seshadri Sekhar.T, and Sravana.P (2010), "The Effect of Weight Loss on High Strength Concrete at Different Temperature and Time", Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS): Pp 698-700.

[2] Emre Sancak, Y. Dursun Sari, Osman Simsek (2006), "Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and super plasticizer", Cement & Concrete Composites 30 (2008): Pp 715–721.

[3] Halit Yazıcı (2005), "The effect of curing conditions on compressive strength of ultra high strength concrete with high volume mineral admixtures" Building and Environment 42 (2007): Pp 2083–2089

[4] Tarun R. Naik, Rudoiph N. Kraus (2002), "Temperature effects on High-performance concrete", 6th International Symposium on "Utilization of high strength/High performance Concrete" June 16 – 20, 2002.

[5] Ivan Janotka, Terezia Nurnbergerov (2004), "Effect of temperature on structural quality of the cement paste and high-strength concrete with silica fume", Nuclear Engineering and Design 235 (2005): Pp 2019–2032..

[6] Leyla Tanaçan, Halit Yas Ersoy , Umit Arpacıog (2007), "Effect of high temperature and cooling conditions on aerated concrete properties", Construction and Building Materials 23 (2009): Pp 1240–1248.

[7] M. Potha Raju, K. Srinivasa Rao and P. S. N. Raju (2007), "Compressive strength of heated high-strength concrete", Magazine of Concrete Research, 59, No. 2, March (2007): Pp 79–85.

[8] J. E. Park, Y. S. Shina, And H. S. Kima (2010), "Various Factors Influencing on Thermal Behaviors of High Strength Concrete (HSC) Columns under Fire", The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction Procedia Engineering 14 (2011): Pp 427–433

[9] IS 456:2000:- Indian Standard Plain And Reinforced Concrete Code Of Practice (Fourth Revision)

[10] IS 1489-1991(Part-I):- Indian Standard Portland-Pozzolana Cement Specifications Part 1 Fly Ash Based (Third Revision)

[11] IS 383:1970:- Indian Standard Specification for Coarse and Fine aggregates from Natural Sources for Concrete(Second Revision)

[12] IS 9103:1999:- Indian Standard Concrete Admixtures – Specification (First Revision)

[13] IS 15388:2003:-Indian Standard Silica Fume — Specification.

PHOTOGRAPH:-

Photo 1. .Slump Test

Photo 2.Compaction of concrete

Photo 3. Specimens are kept in after 28 days of curing

Photo 4.Electric furnace at Malti Industries, air MIDC,Palus(Dist. Sangli)

Photo 5. Placing of Specimens in Furnace

Photo 6. Temperature of Furnace reached to 100°C

Photo 7.Specimens at dry cooling condition after elevated temperature

Photo 8.Compression test on concrete cube