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Effect of High Temperatures on Properties of NSC and HSC

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***Abstract:** Disasters due to fire accidents have become frequent resulting in concrete subjected to high temperatures leading to severe loss of life and property. The usage of High Strength Concrete (HSC) as a structural material has led to the demand to understand the effects of fire on concrete. This paper is aimed at understanding the properties of both HSC and normal strength concrete (NSC) at high temperatures. The experimental work mainly focuses on physical & mechanical properties of M20 grade NSC and M60 Grade HSC subjected to high temperatures. Color change, weight loss, crack width, thermal expansion and residual compressive strength were observed under high temperatures ranging from 100^{0}C to 800^{0}C with an increment of 100^{0}C at exposure duration of three hours. The effect of high temperatures on HSC is more prominent than that of NSC. The performance of HSC is marginally poor compared to NSC at temperatures upto 800^{0}C.*

***Key Words:** Normal Strength Concrete, High Strength Concrete, Fire, High Temperatures, Color Change, Crack Width, Residual Compressive Strength.*

I INTRODUCTION

High Strength Concrete is one of the chief civil engineering material used in the construction industry . With the invention of HSC, high rise buildings, long span bridges and special structures such as reactor pressure vessels, pavements etc are possible to be constructed economically. HSC has a lower toughness leading to brittle failure. As this risk is found more under high temperatures, it is essential to understand the behavior of performance of HSC compared with NSC at high temperatures.

II LITERATURE REVIEW

Potha Raju et al[1] studied the effect of age on HSC and found that HSC is less ductile than NSC in both compression and tension. The behavior of HSC is noticed as similar as NSC from Split Tension Point of view. The modulus of rupture is greater for HSC compared to its corresponding theoretical value.

Omer Arioz[2] studied the impact of elevated temperatures on the physical and mechanical properties of various concrete mixres. Distinct cracks were witnessed at 800 ^{0}C and they increased at 1000 ^{0}C. The relative strength of concrete reduced with increase in high temperature.

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The high temperatures affected evidently on concrete produced by river gravel aggregate. Saad et al[3] studied the effect of high temperature on physical and mechanical properties when OPC is partially replaced by silica fume. The consequences of this examination demonstrated that the substitution of standard Portland cement by 10% of silica fume possess the highest compressive strength values at high temperatures up to 600 ^{0}C.

Chen[4] studied the properties of compressive and splitting tensile strength of concrete exposed to high temperatures. The influence of the temperature range, period of curing, and the cooling type on the strengths of concrete was observed. .Up to an exposure of 800 ^{0}C, early-age concrete post cured for a certain period after exposure regained 80% of its strength. The early-age strength (3d) was observed to retain most of its strength. The relative strengths of concrete cooled in water are lower than that cooled in air after exposing to 800^{0}C

Sari[5] et al studied temperature effect on the structural light weight concretes produced with Pumice (LWC) . Normal weight aggregate concrete (NWC) exhibited major strength losses than LWC. LWC with 2% super plasticizer retained 38 % of the initial strength.

Potha Raju et al[6] studied the effect of high temperatures on compressive strength of HSC and concluded that the rate of increase in the compressive strength is gradual from 100^{0}C to 250^{0}C and nominal from 250^{0}C to 350^{0}C. The rate of decrease in compressive strength of HSC is gradual from 400^{0}C to 700^{0}C and it is faster from 800^{0}C to 950^{0}C.

Husem[7], conducted experimental studies on compressive and flexural strengths of ordinary(OC) and high-performance micro concrete (HPMC) at high temperatures up to 1000^{0}C. It was found that the experimental samples were damaged to a great extent. The loss of compressive strength was observed in HPMC and OC when both of them are cooled after exposure to 800^{0}C & 600^{0}C temperatures respectively.

III EXPERIMENTAL PROGRAMME:

Materials:

Ordinary Portland cement of 53-grade (Table 1) confirming to IS 12269: 2013[19] was used. The properties of the Micro silica used were listed in Table – 2. The locally available river sand (Table-3) and gravel (Table-4) were used as fine and coarse aggregates. CONPLAST SP 430 (Table – 5) was used as Super-plasticizer.

Table.1 Properties of OPC 53 Grade Cement

S.No	Description	Result
1	Chemical Compositions Loss on Ignition Insoluble residue SO3 MgO Chloride LSF A/F	 3.12 % 3.19 % 2.33 % 0.85 % 0.01 % 0.81 1.22
2	Physical Properties Fitness Specific gravity Standard consistency Initial setting time Final setting time Lee Chatlier expansion Compressive Strength 3days 7days 28days	 8.56 3.185 33% 55 Minutes 380 Minutes 2 mm 38.6 N/mm^2 47.8 N/mm^2 59.8 N/mm^2

Table- 2 Properties of Micro Silica

S.No	constituents	Results (%)
1	Silica, SiO2	92.0
2	Moisture content, percentage by mass, Maximum	1.0
3	Loss on Ignition, percentage by mass,, Maximum	2.50
4	Alkalies as Na2O2, percentage , Maximum	1
5	Specific Surface, m^2/g, Minimum	18.9

Table-3 Properties of Fine Aggregate

S.No	Description	Results
1	Specific Gravity	2.62
2	Water absorption	0.4%
3	Fineness Modulus	2.48
4	Zone	II

Table-4 Properties of CA

S.No	Description	Results	
		20 mm	10 mm
1	Specific Gravity	2.64	2.76
2	Water absorption	0.6%	0.4%
3	Fineness Modulus	7.3	6.07

Table-5 Properties of Conplast SP 430

SI.No	Characteristics	Value
1	Color	Dark brown liquid
2	Specific gravity	1.2
3	Air entrainment	Max. 1%
4	Chloride content	Nil to BS 5075: 1982

The mix proportions and compressive strengths of both NSC of grade M20 and HSC of grade M60 were presented in Table-6. Concrete cubes of size 150 X 150 X 150 mm were cast as per IS 516[16]. For testing the concrete at elevated temperatures, the specimens were heated in a Boogie hearth furnace for temperatures ranging from 100^{0}C to 800^{0}C at an increment of 100^0 C. After attaining the required temperature, the cubes were exposed to three hour duration. The colour change, Weight loss, Elongation and crack width of the concrete after exposed to elevated temperatures were observed. The compressive strength tests on concrete after heat were also carried out according to IS: 516-1959[14].

Table 6 Mix Proportions of NSC and HCS

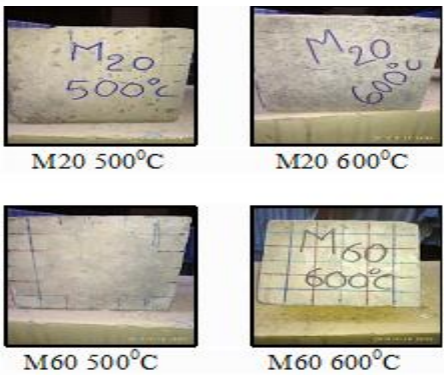
S. No	Designation	Cement (Kg/m3)	F.A (Kg/m3)	C.A (Kg/m3)	Water (Kg/m3)	w/c	w/b	SP %	Micro Silica %
1	NSC	372	835.6	1054.9	186	0.5	-	-	-
2	HSC	470	818.62	1072	164.5	0.35	0.35	1	6

IV Test Results and Discussions

A. Colour changes:

The colour change is used to assess the fire damage of the concrete. The changes in colour of both NSC and HSC observed after exposure to a temperature of 800^{0}C for every increment of 100^{0}C were presented in Fig-1.

Both the concretes of NSC and HSC not exhibited any colour change till the exposure to 500^{0}C. After cooling to room temperature NSC turned to dark grey and HSC turned to pale white colour beyond 500^{0}C. This colour change observed in NSC may be due to the chemical changes in the cement paste and in HSC it is due to chemical changes in binder.



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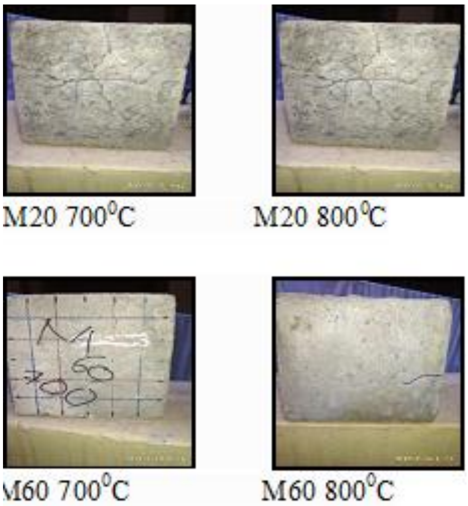
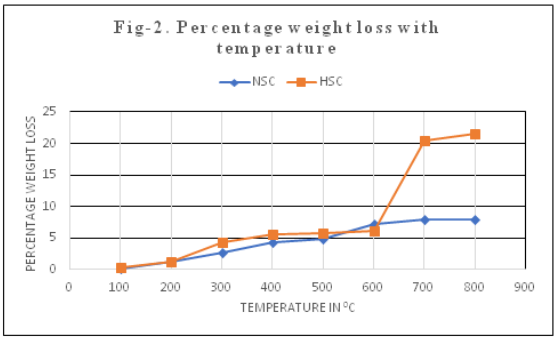


Fig 1 Colour changes in NSC & HSC

B. Percentage Weight Loss:

Loss of weight in concrete due to heat is expressed as percentage of weight loss. The weight loss increased with the rise in temperature in both the concretes as depicted in Fig-2. HSC exhibited more weight loss than NSC at all temperatures.

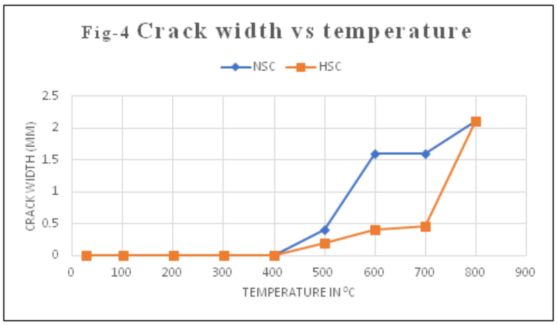
The percentage loss in the weight of the concrete is more in HSC than NSC at all temperatures up to 800^{0}C. This higher weight loss in HSC may be due to formation of stronger CSH structure .



C. Crack Width:

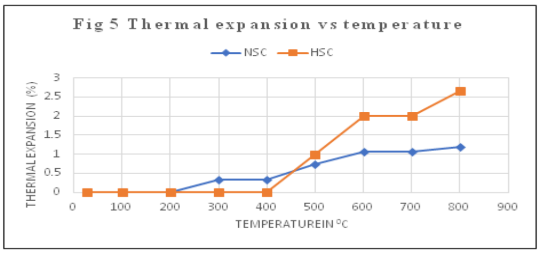
The crack width is measured with optical microscope after cooled to room temperature as shown in Fig-3. The variation of crack width with temperature for both NSC and HSC is presented in Fig-4. No cracks were observed in both NSC and HSC up to 400^{0}C. The crack widths increased with increase in temperature beyond 400^{0}C. NSC exhibited little but wider cracks than HSC beyond 400^0 C. This may be attributed to the internal pressure developed due to thermal gradient and evaporation of water. Notable difference in crack width is observed between NSC and HSC in the temperature ranging from 600 to 700 ^{0}C. however both the NSC and HSC exhibited same crack width at 800^{0}C.

Fig-3 Image showing crack



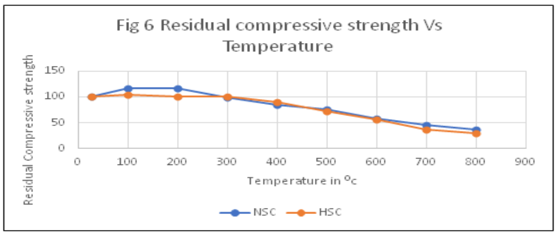
D. Thermal Expansion:

Thermal expansion is used to assess thermal stresses that are introduced in a structural member due to fire.The thermal expansion was measured with the help of vernier calipers after cooled to room temperature. The variation of thermal expansion with temperature is shown in Fig-5. NSC has not demonstrated any expansion till the exposure temperature of 200^{0}C where as no expansion was recorded in HSC till 400^{0}C. Beyond 400 ^{0}C both the concretes demonstrated increase in thermal expansion with temperature. However, HSC demonstrated higher thermal expansion compared to NSC. Higher thermal Expansion of HSC may be attributed due to the formation of more number of cracks.



E. Compressive Strength

E. Compressive Strength : The variation of the residual compressive strength of both NSC and HSC with temperature was presented in Fig-6. Both concretes exhibited increase in compressive strength up to 200^{0}C. Heating beyond 200^{0}C caused degradation of strength in both the concretes up to 800^{0}C. The maximum deterioration in the strengths noted were 63% and 71% in NSC and HSC respectively.



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V CONCLUSIONS

This study presents some properties of NSC and HSC at high temperatures. The effect of high temperature on weight loss, thermal expansion, crack width and compressive strength of both the concretes was summarized below.

1) No change in colour was exhibited by both NSC and HSC till 500^{0}C. NSC turned to dark grey and HSC turned to pale white beyond 500^{0}C.
2) HSC lost more weight than NSC at all temperatures up to 800^{0}C. The loss is more significant beyond 600^{0}C.
3) No cracks were observed in both NSC and HSC up to 400^{0}C. The crack were widened with increase in temperature beyond 400^{0}C. NSC exhibited little but wider cracks than HSC beyond 400^0 C.
4) No expansion was exhibited by NSC & HSC up to 200^{0}C & 400^{0}C respectively. Thermal expansion increased with temperature beyond 400 ^{0}C in both the concretes. However, HSC demonstrated higher thermal expansion compared to NSC.
5) Both the concretes exhibited increase in compressive strength up to 200^{0}C. Beyond 200^{0}C degradation of strength in both the concretes up to 800^{0}C is observed, maximum deterioration being 63% for NSC and 71% for HSC.

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