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High-Density Concrete Reinforced With Steel Fibre at Elevated Temperatures

Sachin Kumar ¹, Ravi Kumar ²

P.G. Student, Department of Civil Engineering, Swami Devi Dyal Institute of Engineering and Technology, Haryana,
India¹

Assistant Professor, Department of Civil Engineering, Swami Devi Dyal Institute of Engineering and Technology,
Haryana, India²

ABSTRACT: High density concrete possesses shielding properties because of which it is widely used in radioactive shielding as in nuclear power plants and radiology rooms in hospitals like structures. Some of the High density aggregates like Hematite, Barites, iron-shots, hematite, etc. are used for converting normal concrete to high density concrete. Durability is the major reason to use this kind of high density concrete so that it can withstand adverse environments. To estimate the response of concrete in the situation of fire, fire response of the concrete is essential to be determined. Because of the high temperature in concrete, it tends to develop thermal stresses that which results to the development of various cracks and openings in concrete due to expansion and this will affect its tensile and compressive property. By adding proportion of steel fibre in the concrete increases the tensile and compressive strength, there is also reduction in spalling in concrete. In This particular study, presenting the experimental research work on comparing the thermal and mechanical properties of concrete with the usage of normal siliceous aggregate (NC) and aggregate with high density (HDC) including modulus of elasticity and drying shrinkage. Barites are the type of aggregate used as high density aggregate in this research process. Normal aggregate and barites aggregate, two types of mixes were prepared. The results of two parameters namely steel fibre volume content (0%, 0.5%, and 1%), temperature effects (at room temperature, at 200°C, 400°C and at 600°C) the compressive property of concrete were determined. High density concrete has high compressive strength when compared with normal aggregate concrete but has less tensile and flexural strength. After keeping the Specimen at temperature 600°C it shows the cracks and has a relative drop in strength. By adding steel fibre to concrete, it has improved its mechanical properties including the drying shrinkage, thermal conductivity and modulus of elasticity.

KEYWORDS: Concrete having High-density, Steel fibre, Barites, Compressive strength, Modulus of elasticity, Thermal conductivity, Elevated temperature

I. INTRODUCTION

High density concrete is a versatile and conventional density concrete which is commonly used for both its applications and its usability and it is commonly used to meet high strength specifications in the case of special conditions where the weather conditions are extreme or marine environment is there or in the case of radioactive radiation shielding. As it is clear from its title the high density concrete is having density higher than 2600 kilogram per meter cube and it provides approximately twice the density in about half of the space which can be beneficial according to today's space constraint issues. To achieve the high density of the concrete, high density aggregates are used which are mainly a hematite, lemonade, limonite, ferrophosphorus, steel punching and Steel shots which can be used to achieve this much strength. To achieve this density of the concrete high water content in fixed amount is required. In the modern days due to the use of concrete structural members in the buildings it becomes necessary to satisfy the appropriate safety requirements as specified in the building codes because it is one of the most severe condition to which any structure can be subjected.

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Therefore there should be provision for appropriate safety from fire for structural members during building design. Any building can be termed as safe from fire according to the resistance of concrete to fire which is the duration in which any structural member can withstand the fire situation with its stability, temperature transmission and structural integrity. This behaviour mainly depends upon the mechanical, thermal and the deformation properties of the concrete which changes with the temperature range change associated with the type of aggregate used. The aggregate required should have the specific gravity with the value of more than 4. Due to the minerals present in hematite and other minerals they are having the specific gravity more than 3. In the case of normal concrete when it is exposed to very high temperatures, it ignites the chemical reactions due to which there are micro cracks produced in the concrete and due to these cracks the performance and durability of the concrete decreases. But in the case of high density concrete due to the use of heavy weight aggregates which possess low impact strength, they may be subjected to different temperature variations and can withstand adverse weather conditions. These are commonly used in nuclear plants and in Radiology rooms in various hospitals to store nuclear waste. In concrete the major portion of the concrete consists of aggregate hence the type of aggregate mainly affects the type of concrete after the type of cement. During the testing of aggregates for their thermal stability it was found that up to the temperature of 300 to 350 degree Celsius, there is thermal stability in the normal aggregate but when the temperature is increased to about 500 to 600 degrees then it was found that with the increase in the temperature there is increase in the volume of the aggregate because of which there are small openings and cracks and it makes concrete brittle due to the Crystal transformation of aggregates. To counter this issue Steel fibres are dispersed into the concrete to improve the tensile strength and to reduce the cracks in the concrete due to temperature increase. The Steel fibres to be used should be in the limit of 0.5 to 1.5%. Excessive of addition of Steel fibre will cause the reduction in the workability of mix and will cause inverse effect. The ratio between the lengths of fibre to its diameter should be in the range of 2200 and it is not recommended to be more than 100 because excessive addition will cause cracking and shrinkage with the addition of thermal stresses.

II. RELATED WORK

[1] Naus, D.J. have done experimental study the effect of elevated temperatures on concrete materials and structures. That shows no explosive spalling has been observed and in their mechanical property, modulus of elasticity was found to be worst affected property. [2] Kilincarslan et al. have done experiment to study "By adding of barites in concrete mix on physical and mechanical properties of concrete. As result it was found that there is increase in density of concrete with the addition of barites. The value of 3507 kg/m^3 was achieved for maximum density of concrete. [3] Topcu in his work studied the replaced barites aggregate instead of normal aggregate and hence the overall weight was increased. In his study he prepared various concrete mixes with varied ratio of water and cement for determination of appropriate water / cement ratio and as a result he proposed that appropriate water to cement ratio is 0.4 and the content of the cement used should be more than 350 kg/m^3 . [4] Ahemed S.Ouda et al. gave the most appropriate method to produce high density concrete and he used different type of aggregate in different proportions and stated that by mixing barites with concrete has high density among natural heavy weight aggregates. [5] Harshavardhan.C. in his studies concluded that due to addition of Steel fibre content there is increase in steady state temperature of both type of mixtures.

Against the above conditions, this paper presents thermal conductivity of high density barites aggregate concretes comparing to normal aggregate concrete under addition of steel fibre the experimental study on mechanical properties, including modulus of elasticity, drying shrinkage. This study shows the behaviour of concrete when exposed to elevated temperatures and role of steel fibre in improving the performance of concrete.

III. MATERIAL AND METHODOLOGY

In our study we prepared 6 groups of specimens, in which each of them contains standard cubes of having dimension $100 \times 100 \times 100 \text{ mm}$, cylinders of dimension $100 \phi \times 200 \text{ mm}$ and $150 \phi \times 300 \text{ mm}$, prisms of dimension $500 \times 100 \times 100 \text{ mm}$ and

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other specimens of 275x75x75mm were prepared for testing .The various properties of materials used in proposed study, their mix proportions and the various tests conducted are described as following.

A. Constituent materials:

- In this study Ordinary Portland Cement of 53 grade as per IS -12269-1987 [18] was used.
- Sand with density of 2580 kg/m³ found naturally of medium-fine quality is used.
- Siliceous aggregate with specific gravity 2.65 was used which passed through 20mm sieve.
- A-grade Barites was obtained from MAHAVIR CHEMICAL INDUSTRY DELHI. The specific gravity of aggregate is in the range from 4.43g/cm. The specific gravity of aggregate ranges from characteristic 4.12 aggregates as per ACI 304.3R-1996 ASTM C638 [10] and ASTM C637[10].
- Steel fibre made up with the help of ordinary steel with a density of 7.85 g/cm³ with melting point of temperature 1500°C having length of 30 mm and diameter 0.5mm end hooked with aspect ratio of 60 has been used.

Physical property	Result
Fineness	1.5%
Normal consistency	29%
Initial setting time (min)	46
Final setting time (min)	195
Specific gravity	3.25

Table 1: Physical Properties of cement

Physical property	NA	HDA
Bulk density(kg/m ³) (Dry roded)	1790	2468
Specific gravity	2.6	4.43
Water Absorption (%)	1.1	0.6
Fineness modulus	2.9	2.85

Table 2: Physical properties of aggregates

B. Mix proportions:

According to ACI of absolute values the proportioning of Heavy weight concrete is done. 6 different type of mixtures are prepared or determination of various test results .They are referred as NC0 NC0.5 NC1 HDC0 HDC0.5 HDC1 where NC represents Normal concrete, HDC represents High-density concrete in this study. Steel fibre of 0%, 0.5% and 1% is used as addition in the mixes resulting in the different types of mixes. In this study, cement content is fixed to 465 kg/m³ and it is maintained throughout in all of the mixtures. The W/C ratio of 0.4 is fixed for all mixtures which produces the slump of 25mm.

Mix id	Cement (kg/m ³)	Fine aggregate	Normal aggregate	High-density aggregate	w/c ratio	Steel fibre(%)
NC0	465	617	1163	-	0.4	0%
NC0.5	465	617	1163	-	0.4	0.5%
NC1	465	617	1163	-	0.4	1%
HDC0	465	838	-	1584	0.4	0%
HDC0.5	465	838	-	1584	0.4	0.5%
HDC1	465	838	-	1584	0.4	1%

Table 3: Mix proportions in kg/m³

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C. Mixing curing and testing specimens:

For the mixing curing and testing the conventional method is used. The various ingredients as coarse aggregate cement sand and steel fibre is mixed together constituting a total of 150 kg and then is mixed for 2 minutes. After the process of mixing it in the tri state the 80% of water is mixed into it and for approximately 5 minutes the water is allowed to mix into the mixture. Slump test is performed to find out the workability of concrete. Proper compaction of the concrete is done with the usage of vibration table. After the initial setting of the concrete blocks they are moulded and the concrete blocks are placed in the curing tanks which is filled with water without any impurities at a normal surrounding temperature.

D. Compression test:

Compression test is performed to determine the compressive strength of the concrete at different ages in this test the operation test was conducted after 7:28 and 90 days after curing. Standard compression testing machine was used. Before placing the specimen in the compression machine they were thread properly to reduce the motion content. The various specimen place at different temperature for example at room temperature 600 degree Celsius 400 degree Celsius and at 200 degree Celsius for 2 hours respectively. Father they were cold at room temperature and the strength of specimen was determined.

E. Density test:

The density of fresh concrete was determined according to ASTM C138 [12],

F. Modulus of elasticity:

According to ASTM C469 [11], curing of all specimens for 28 days is done and specimen are dried before testing.

G. Thermal conductivity:

Thermal conductivity was determined after 28 days with help of cylindrical specimens with thickness of 23.5 mm to 26.5 mm. The water content is reduced by placing the specimen in the oven at hundred degrees Celsius. To ensure that the heat loss is minimum the specimen are tested with Lee operators and for the steel wool is wrapped around it.

H. Drying shrinkage:

Drying shrinkage is one of the important properties that is supposed to be determined after 28 days with the help of length comparator. Sensual Dial code of 0.005 mm is accuracy is used the specimen is placed in a 1 for 44 hours until the value is 0.01 accurate.

IV. RESULTS AND DISCUSSION

A) Density of concrete:

The density of concrete mainly depends upon the type of aggregate used. For higher density concrete, aggregate used are having high density. Aggregate and steel fibre is used and as we know that high density concrete has density more than 2600 kilogram per meter cube.

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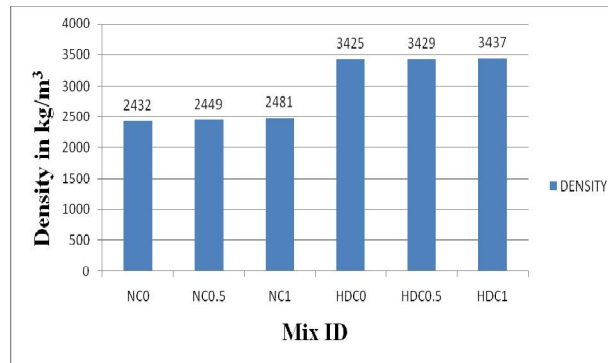


Fig.1: Density of fresh concrete (kg/m³)

It was found that the density of normal aggregate concrete was about 2472 kilogram per meter cube as compared to the high density concrete with barite aggregate has density of about 3475 kilogram per meter cube which is approximately 30% increase in its density. In the case of addition of Steel fibre there is not any considerable change in the density.

B) Compressive strength:

Compressive strength is one of the main characteristics of the concrete which shows the strength achieved by concrete. The prepared specimens are tested for the compressive strength after curing of 7, 28 and 90 days respectively. Before the process of testing the prepared specimen were placed in elevated temperatures of room temperature, about 200 degrees, 400 degrees and 600 degrees respectively. The heating is done with the help of furnace where the specimen is placed for approximately 2 hours. It is found that there is increase in strength as different proportion of Steel fibre is added in the case of normal concrete. Due to the addition of Steel fibre even in the case of elevated temperatures there is a reduction in spalling and the compressive strength is increased. In the case of high density concrete it is found that there is also increase in compressive strength as compared to normal aggregate but in the case the temperature is elevated from 200 to 400 degree Celsius and further from 400 to 600 degree Celsius then there is formation of cracks and a yellowish colour is shown by the aggregates which show the aggregate degradation. Due to the addition of Steel fibre there is also improvement in the compression as compared to the identical mixtures without any addition of Steel fibre at different temperature variations.

Temperature °C	MIX ID	7 Days	28 Days	90 Days
ROOM TEMP	NC0	33	40.7	44
	NC0.5	38.3	43.4	48.4
	NC1	35.5	49.8	52
	HDC0	33	45.2	48
	HDC0.5	38.3	47.7	53.3
	HDC1	41.1	48.9	57.3
200	NC0	37.2	45.5	53
	NC0.5	42.4	50.1	56.8
	NC1	46.8	52.4	61.5
	HDC0	34.8	46	55
	HDC0.5	48.5	52	60.3
	HDC1	50.2	56.7	63

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400	NC0	28	38.6	47.1
	NC0.5	35.3	47.5	55.6
	NC1	44	50	57.4
	HDC0	36	40.2	46.3
	HDC0.5	48.7	50.9	48.2
	HDC1	51.7	52	53
600	NC0	25.3	33	41.5
	NC0.5	24	33.2	44.2
	NC1	30.9	37	45
	HDC0	27.2	33.9	37.4
	HDC0.5	38	41.5	41
	HDC1	40.5	44.1	45.3

Table 4. Effect of temperatures on compressive strength at different age

C) Split tensile and Flexural strength:

Test for determination of split tensile and flexural strength were performed after the time period of 28 and 90 days. It was found that in the case of normal concrete it has more flexible and higher tensile strength as compared with high density concrete. The reason for this is that in the case of high density concrete due to the addition of high density aggregates it becomes brittle as compared to normal aggregate. Due to the addition of Steel fibre the tensile and flexural property of both normal as well as high density concrete shows improvement. The various values of tensile strength and flexural strength are shown in the figure

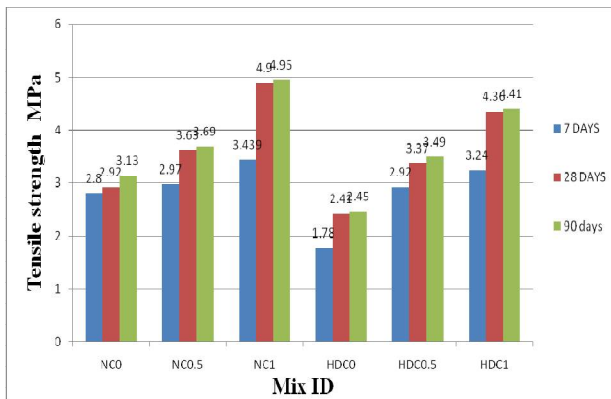


Fig.2: Tensile strength of concrete mixes (MPa)

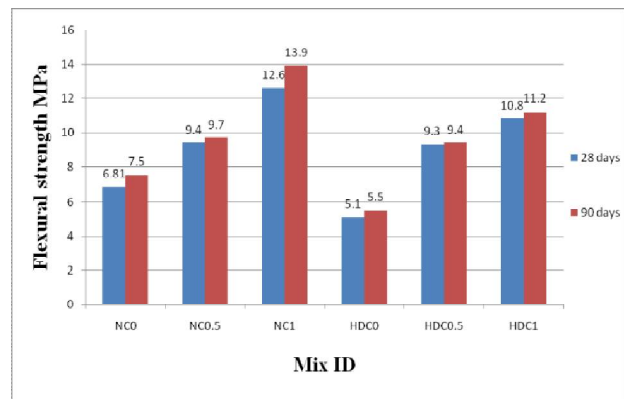


Fig.3: Flexural strength of concrete mixes (MPa)

D) Modulus of elasticity:

The modulus of elasticity of concrete at low stress level shows a constant value but with the increase in stress level there is decrease in elasticity of concrete. The modulus of elasticity of the complete specimen after curing was determined with help of compression machine. Ultimate strength of each mix was determined and the stress strain curve of the mix was used to find the axial strain of the specimen. It was found that high density concrete with no addition of fibre reinforcement shows high modulus of elasticity when compared to other mixes. With the addition of Steel fibre there was increase in ultimate load but considerable decrease in modulus value since it has more strain value. The various values are shown in the figure 4.

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E) Thermal conductivity:

Thermal conductivity is a property of concrete which enables it to deal with high temperatures. In some particular constructions the amount of heat is very high as in the case of power plants and in boilers etc. Hence these structures are supposed to have more thermal conductivity so that the amount of thermal stress can be reduced in the concrete. It was figured out that in the case of high density concrete with barites shows high thermal conductivity. Also there is steady state temperature when it compared to the all other type of mixes. Due to the addition of the steel fibre steady state temperature increases in both cases as in normal concrete and high density concrete and hence it can be concluded that there is increase in the thermal conductivity.

F) Drying shrinkage:

There is contraction on hardening of concrete mixture due to the loss of water which is known as concrete shrinkage. It is mainly due to the increase in tensile stress which may lead to cracking or warping. The concrete specimen immersed into curing tank for the curing period of 28 days and was tested using length comparator. It was found that in the case of high density concrete it has lower shrinkage when compared to normal concrete. It was concluded that with the addition of Steel fibre there is reduction in shrinkage in all type of mixture. The various values are shown in the figure

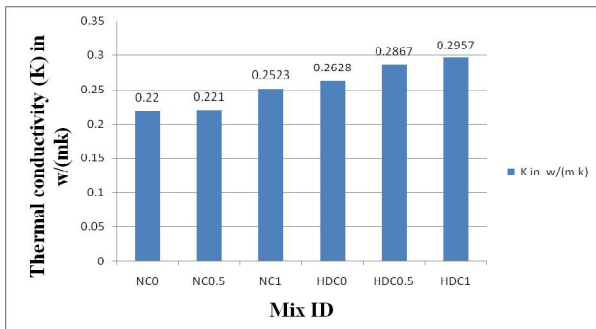


Fig.4. Thermal conductivity of concrete mixes

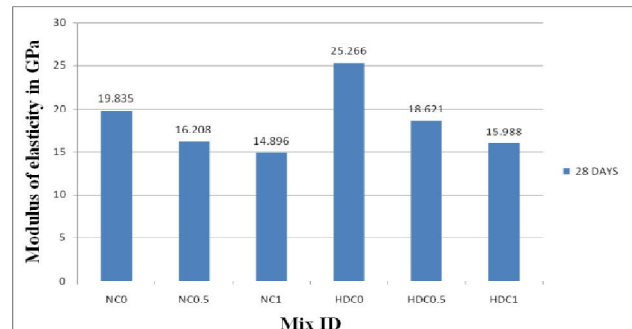


Fig.5: Modulus of elasticity of concrete mixes (GPa)

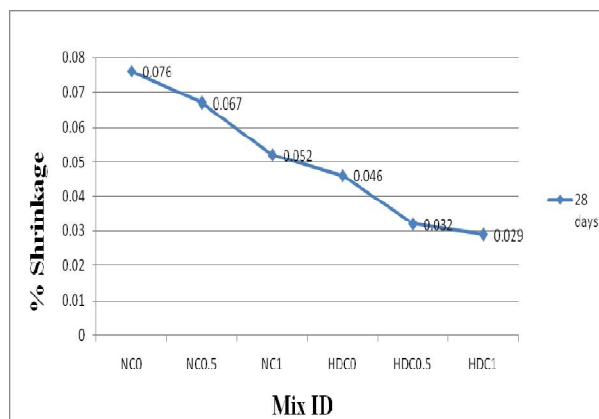


Fig.6: Drying shrinkage of concrete mixes

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V. CONCLUSION

The test conducted shows that when the high density concrete is subjected to elevated temperatures then it affects the compressive strength in the case of temperature more than 600 degree Celsius. There is considerable decrease in compressive strength whereas when the specimen is placed at a temperature in the range of 200 degrees to 400 degrees then there is increase in compressive strength. Also there is degradation of aggregate due to the high temperatures which can be confirmed with the change in colour of aggregate which is showing yellowish and dark brown colour when it is placed under 600 degree Celsius for a time period of 2 hours. The various results obtained from the tests are as

1. Due to the addition of Steel fibre, the compressive strength increases at 200 degrees Celsius as well as at 400 degree Celsius and 600 degree Celsius.
2. With the addition of barite in concrete there is increase in density of the concrete by approximately 1.4 times.
3. With the rise in temperature for up to 200 degrees there is increase in strength which is primarily due to acceleration in hydration whereas there is gradual decrease in the strength as there is increase in temperature for example at 400 degree Celsius and at 600 degree Celsius.
4. Due to the addition of Steel fibre there is increase in tensile and flexural strength. From the tests conducted it is clear that with approximately 1% replacement with steel fibre ensures high tensile and flexural strength as compare to the 0% Steel fibre replacement in high density concrete which shows less tensile and flexural properties.
5. Due to the addition of Steel fibre there is gradual decrease in modulus of elasticity whereas when it is compared to the high density concrete in which there is no Steel fibre then the modulus of elasticity is higher in that case.
6. Due to the addition of Steel fibre the ultimate strength also increases in both of the cases as in high density concrete as well as in normal aggregate concrete.
7. The thermal conductivity is greater with no Steel fibre (0% Steel fibre) as compared to other types of mix.
8. Due to the addition of Steel fibre there is decrease in spalling. It is found that there is reduction in the failure when it is subjected to ultimate load failure test.
9. There is decrease in water absorption as well as in shrinkage in the case of high density aggregate concrete as compared to the normal aggregate concrete. This decrease is due to the addition of Steel fibres which reduces the shrinkage by approximately 30%. Also in the case of high density concrete with 1% Steel reinforcement replacement there is decrease in shrinkage by approximately 27% when it is compared to high density concrete with 0% Steel fibre replacement.

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