



STUDY ON HIGH-DENSITY CONCRETE REINFORCED WITH STEEL FIBER AT ELEVATED TEMPERATURES

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ABSTRACT

High density concrete is used in nuclear power plants (NPP) for primary and secondary containments structures. High density aggregates like Barites, Hematite, iron-shots, goethite, etc are used to produce high density concrete the major performance requirement of this kind of concrete is durability that it should withstand adverse environments. Fire response of such concrete has to determine to estimate performance of concrete after fire attack occurred. Concrete exposed to high temperature tend to develop thermal stresses that which lead to cracks and openings in concrete due to expansion this will affect the concrete compressive and tensile property. Addition of steel fiber in the concrete increases the compressive strength, tensile strength and reduces spalling in concrete. This paper presents the experimental investigation on comparing the mechanical and thermal properties of concrete using normal siliceous aggregate (NC) and high density aggregate (HDC) including modulus of elasticity and drying shrinkage. In this research Barites are used as high density aggregate. Mixes were prepared using normal aggregate and barites aggregate. The results of two parameters namely steel fiber volume content (0%, 0.5%, 1%), temperature effects (room temperature, 200°C, 400°C and 600°C) on compressive property of concrete. HDC has high compressive strength than the NC but has less tensile and flexural strength. Specimens kept at 600°C have shown cracks and has a relative drop in strength. The addition of steel fiber has improved the mechanical properties of the concrete including the drying shrinkage, thermal conductivity and modulus of elasticity.

Keywords: high-density concrete, barites, steel fiber, elevated temperature, compressive strength, modulus of elasticity, thermal conductivity.

1. INTRODUCTION

High density concrete is used mainly as radiation shielding for radiology rooms in hospitals, to store nuclear waste and as counter weights. Concrete having density higher than 2600kg/m³ is called high density concrete. To produce high density concrete heavy weight aggregate are used such as barites, iron- ore, steel shots and hematite with specific gravity more than 4. Barites and hematite show significantly higher specific gravity of 3.5 to 4.5 in naturally available minerals [1]. Heavy weight aggregate have low impact strength and tensile strength considering with normal conventional aggregate. Due its extensive use in nuclear plants for radiation shielding concrete may be subjected to different temperature variations and it has to be studied whether it can withstand to adverse situations[2,3]. Concrete is a homogenous material consisting of chemically active substances when exposed to high temperatures lead to chemical reactions which form micro cracks in the concrete reducing its performance and durability. As 60% to 70% of the concrete consists of the aggregate the behavior depends highly on aggregate type. Normally used aggregates are thermally stable up to 300°C to 350°C. Aggregates may go crystal transformation leading to significant increase in volume between 500°C to 600°C with increase in volume of 5.7%. This makes the concrete brittle and leads to cracks and openings[3]. Steel fiber reinforced concrete is dispersed into concrete during mixing to improve the concrete properties steel fiber reinforced concrete is extensively used to increase the tensile strength, ultimate strength, reducing cracks [4]. As stated in ACI 544, 3R-2008[2] fiber volume fraction used in concrete should be within 0.5 to 1.5 % the more addition reduces the

workability of mix and causes balling or mat formed in the mix[4,5]. According to the ACI 544, 3R-2008[8] aspect ratio is considered to the ratio of fiber length to its diameter. The aspect ratio that is to be in range of 20 to 100. Aspect ratio more than 100 is not recommended. Addition of steel fibers into concrete reliably inhibits cracking and resistance to impact and shrinkage and thermal stresses [3, 6].

kilincarslan *et al.* have done experiment to study the effect of barites in concrete mix on mechanical and physical properties of concrete. It is obvious the density of concrete has increased with barites rate in concrete. He achieved 3507 kg/m³ of maximum density for concrete [7]. Topcu in his work used replaced barites aggregate in place of normal aggregate to increase the weight. He did many concrete mixes at different water cement ratio to determine the appropriate water to cement ratio and proposed that 0.4 is the appropriate water to cement ratio and cement content should be more than 350 kg/m³ [6]. Ahmed S. Ouda *et al.* stated that ACI method is most appropriate to produce high density concrete and he used different type of aggregate in different proportions and stated that concrete made using barites has high density among natural heavy weight aggregates[1]. G.M. Chen *et al.* stated that addition of steel fiber improves the mechanical strength of concrete including tensile strength, flexural strength, ductility and has ability to resist cracking and spalling. Adding steel fiber in to concrete is an effectual method to reduce shrinkage in concrete. The addition of steel fiber can reduce explosive spalling in case of elevated temperatures and increase its stress bearing capacity [5].



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

2. EXPERIMENTAL PROGRAMME

A total of 6 groups of specimens, each containing of standard cubes of 100x100x100mm, cylinders of 100øx200mm, cylinders of 150øx300mm, prisms of 500x100x100mm and specimens of 275x75x75mm were prepared to test for this study. The properties of materials that used, their mix proportions and test conducted are described in the following sections.

2.1. Constituent materials

- In this investigation OPC 53 grade conforming to IS - 12269-1987 [18] was used.
- Naturally found medium-fine sand with a density of 2580 kg/m³ is used.
- Normally used siliceous aggregate of specific gravity of 2.65 passing through 20mm sieve is used.
- A-grade Barites obtained from mangampet mines under authority of APMDC (Andhra Pradesh mineral development corporation limited). The aggregate specific gravity ranges from 4.12 aggregates characteristic conforming to ACI 304.3R-1996 ASTM C638 [10] and ASTM C637[10] for radiation shielding is used.
- Steel fiber made from ordinary steel with a melting point of 1500°C and density of 7.85 g/cm³ with length and diameter of 30mm and 0.5mm with aspect ratio of 60 end hooked has been used.

Table-1. Physical properties of cement.

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

Table-2. Physical properties of aggregates.

Physical property	NA	HDA
Bulk density(kg/m ³) (Dry roded)	1793	2468
Specific gravity	2.64	4.12
Water Absorption (%)	1.13	0.6
Fineness modulus	2.89	2.85

2.2. Mix proportions

Heavy weight concrete is proportioned by using the American concrete institute of absolute values. The ACI 211.1[2] method is approved as convenient to produce heavy weight concrete. Mix proportion for the 1m³ of concrete is designed as shown in Table-3. Six mixtures are produced to investigate the results they are referred as NC0 NC0.5 NC1 HDC0 HDC0.5 HDC1 (NC - Normal concrete, HDC-High-density concrete) in this study. Steel fiber of 0%, 0.5% and 1% is used as addition in the mixes. In this study, fixed constant cement content of 462 kg/m³ is maintained in all the mixtures, 0.4 water to cement ratio is fixed to all mixtures to produce 25mm slump.

Table-3. Mix proportions in kg/m³.

Mix id	Cement	Fine aggregate	Normal aggregate	High-density aggregate	water/cement	Steel fiber(%)
NC0	462	643	1095.53	-	0.4	0%
NC0.5	462	643	1095.53	-	0.4	0.5%
NC1	462	643	1095.53	-	0.4	1%
HDC0	462	841	-	1592.16	0.4	0%
HDC0.5	462	841	-	1592.16	0.4	0.5%
HDC1	462	841	-	1592.16	0.4	1%

2.3. Mixing curing and testing specimens

Mixing both NC and HDC is similar to conventional method. The materials placed in the mixer with capacity 150 kg in sequence of coarse aggregate, sand, cement, steel fiber are dry mixed for 2 min. After dry mix is done 80% of water is added and mixer is allowed to mix all the materials for 5 min and rest of the water is added. all the mixes were rotated for 5 min after mixing is done slump test is performed to find workability

of concrete according to the ASTM C143-2010^[12]. All the specimens were cast in three layers and each compacted by using vibrating table for consolidation. After 24± 0.5 hrs from casting specimens were de-moulded and kept in curing tank filled with potable water for curing at ambient temperature.



2.4. Compression test

This test is determined by curing the specimens at 7, 28 and 90 days according to IS 516-1959. This test was carried out using a 2000 kN compression testing machine and a loading rate of 2.5kN/s. Specimens are dried to reduce moisture. Test was conducted by exposing specimens at different temperatures (room temperature, 200°C, 400°C and 600°C) for 2 hrs. Specimens are taken out and let cooled to room temperature and compression test is carried to determine the strength of specimens.

2.5. Density test

The density of fresh concrete was performed according to ASTM C138 [12].

2.6. Modulus of elasticity

All specimens are cured for 28 days and are taken out and kept for drying before testing and tested according to ASTM C469 [11].

2.7. Thermal conductivity

At 28 days specimens are tested to determine the thermal conductivity. Cylindrical specimens with thickness range 23.5mm to 26.5mm are cut with cutter are prepared all the specimens are dried in oven at 100°C to reduce the available moisture content in the specimen. Specimens are tested with lee apparatus steel wool is wrapped around the specimen to reduce the heat loss while the specimen is tested.

2.8. Drying shrinkage

Drying shrinkage test is done according to the ASTM C157[12] all the specimens fully submerged in tank for 28 days on 28th day specimens were taken to measure the length using length comparator. To measure the reading sensual dial gauge of 0.005mm accuracy is used. The specimens are kept in oven for 44 hrs and test is repeated until the change in the specimen is 0.01 accurate it is calculated normally in micro strains.

3. RESULTS AND DISCUSSIONS

3.1. Physico-mechanical properties

3.1.1. Density of concrete

Density of fresh concrete made of normal aggregate, barites aggregate and steel fiber shown in Figure-1. It is known that to call a concrete as high density concrete it should have density more than 2600 kg/m³ according to TS EN 206-1-2002. The density of fresh concrete made with normal aggregate has shown a range of 2472kg/m³ and high density concrete with barites aggregate has shown a density of 3475 kg/m³. There is an increase in 30% of density compared to NC and HDC. Addition of steel fiber did not show noticeable change in density.

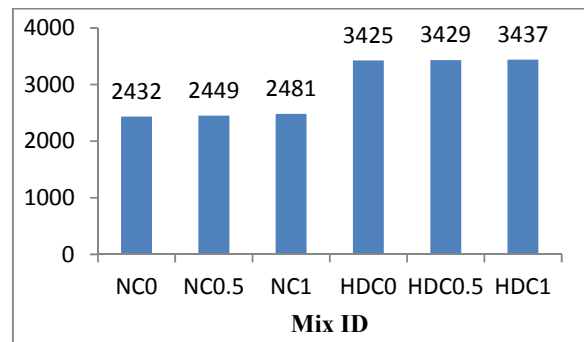


Figure-1. Density of fresh concrete in kg/m³.

3.1.2. Compressive strength

All the specimens were cured to 7, 28 and 90 days respectively. Specimens are tested by exposing them to varying temperatures (room temperature, 200°C, 400°C and 600°C). Specimens are kept in furnace for 2hrs after constant heat is achieved in the furnace. NC specimens have shown considerable increase in strength with varying steel fiber content. When exposed to elevated temperatures steel fiber has helped in reducing spalling and increased the compressive behaviour of concrete. HDC has high compression strength compared to NC as HDA has high compression strength than the NA. Aggregate degradation has been seen with naked eye in form of colour change to yellowish and brown colour. Specimens kept at 200°C have shown improved compression strength comparing to other temperature variants. Formation of cracks are seen for specimens kept at 400°C and 600°C with visible hair line cracks due to rehydration of CaO₂[4]. Addition of steel fiber has improved in holding the ingredients in compression. There is an increase in compression with increased steel fiber addition when compared to identical mixture at different temperatures.

3.1.3. Split tensile and flexural strength

Split tensile and Flexural strength were carried at age of 28 and 90 days. NC has more tensile and flexural strength than the HDC because HDA are brittle comparing to NA steel fiber improved the tensile and flexural property of both NC and HDC increment in steel fiber content has phenomenally increased tensile and flexural properties of concrete as shown in Figure-2 and Figure-3.

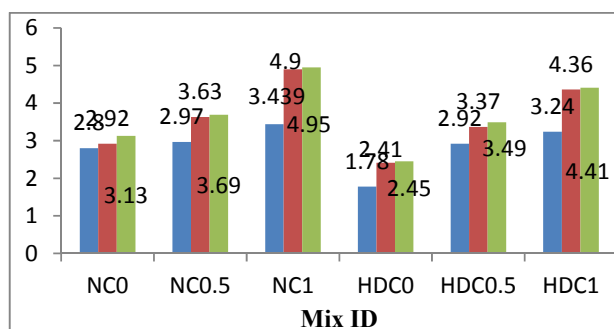


Figure-2. Tensile strength of concrete mixes in MPa.

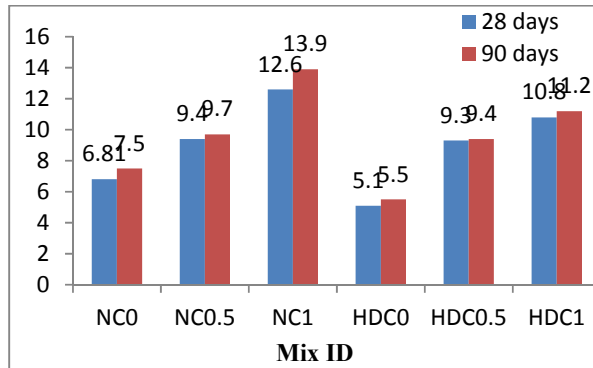


Figure-3. Flexural strength of concrete mixes in MPa.

3.1.4. Modulus of elasticity

Concrete specimens cured for 28 days are tested to find modulus of elasticity under compression machine with capacity of 2000KN. For each mix ultimate strength is found until specimen fails and to find the stress strain curve of the mix extensometer were fixed to find the axial strain of the specimen. The following Figure-4 shows the modulus of elasticity of the mixes. The following results stated that the HDC0 has high modulus of elasticity than other mixes barites aggregate concrete has tend to have more modulus of value than NC Due to its hardness and load bearing capacity. Addition of steel fiber has increased the ultimate load with increase in steel fiber content but decreased modulus value the stress strain curve has shown addition of steel fiber content has tend to have more strain.

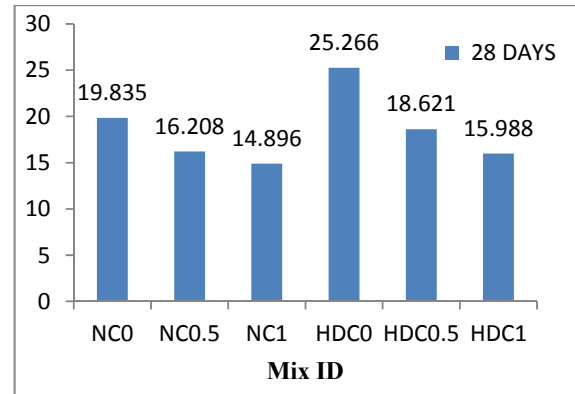


Figure-4. Modulus of elasticity of concrete mixes in GPa.

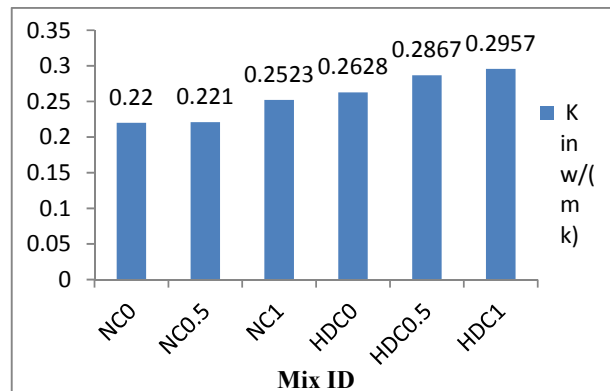


Figure-5. Thermal conductivity(K) in w/(mk) of concrete mixes.

3.1.5. Thermal conductivity

Thermal conductivity plays an important role on concrete dealing with high temperatures which are used at power plants, boilers etc. these type of concrete structures need to have more conductivity to reduce thermal stress in the concrete. The Figure-5 shows that the thermal conductivity of high density concrete with barites has high thermal conductivity and steady state temperature compared to all other mixes. Steel fiber content has increased steady state temperature of both NC and HDC with increase in steel fiber there is increase in thermal conductivity.

3.1.6. Drying shrinkage

Drying shrinkage is tested after immersion of specimens for 28 days in curing tank and tested using length comparator HDC has low drying shrinkage than NC and increase in steel fiber has shown Figure-6 reduction in drying shrinkage comparatively.

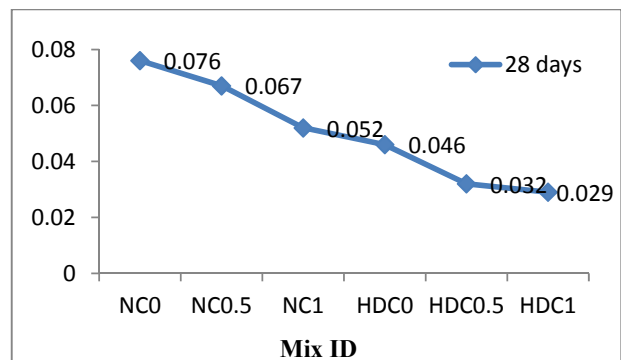


Figure-6. Drying shrinkage percentage of concrete mixes.

**Table-4.** Effect of temperatures on compressive strength in MPa at different age.

Temperature °C	MIX ID	7 Days	28 Days	90 Days
ROOM TEMP	NC0	32.6	38.2	45.9
	NC0.5	37.4	41.9	47.9
	NC1	34.2	48.2	51.5
	HDC0	34	43.1	47.1
	HDC0.5	36.3	45.6	52.1
	HDC1	39.4	46	56.9
200	NC0	36.6	43.4	51.2
	NC0.5	41.1	49.5	55.5
	NC1	46.2	49.9	60.8
	HDC0	34.4	45.3	53.9
	HDC0.5	48.2	50.2	58.7
	HDC1	49.2	55.9	62.3
400	NC0	26.6	36.6	46.5
	NC0.5	34.2	45.5	54.5
	NC1	4.2	49	56.7
	HDC0	32.9	39.2	46.3
	HDC0.5	46.8	46.9	47.9
	HDC1	49.7	49.2	54.6
600	NC0	25	33.2	41.5
	NC0.5	24.3	33.6	42.6
	NC1	30.8	38.2	46.8
	HDC0	27.2	33.9	39.0
	HDC0.5	37.9	41.7	42.1
	HDC1	40	45	46.1

4. CONCLUSIONS

The test results shows that concrete subjected to high temperature at 600°C has lost the compressive strength. But the specimens kept at 200°C and 400°C has shown increase in compressive strength. There is colour change in aggregates kept at 600°C for 2hrs showing pale yellowish and dark brown colours conforming the degradation of aggregate subjected to high temperatures with naked eye.

- There is an increase in strength when specimens are exposed to 200°C due to accelerated hydration and specimens have shown gradual decrease in strength at 400°C, 600°C.
- Addition of steel fiber has increased compressive strength of the specimen kept at 200°C, 400°C, 600°C for 2hrs comparatively to each other identical mix type.
- Tensile and flexural strength has increased with addition of steel fiber .normal aggregate with 1% steel fiber has shown high tensile and flexural strength. Concrete with high density aggregate and 0% steel fiber has less tensile and flexural property.
- Barites have increased density of concrete by 1.44 times than the concrete with normal aggregate.
- High density concrete with 0% has high modulus of elasticity value comparing with all mix types. Addition of steel fiber has gradually decreased the modulus of elasticity value .addition of steel fiber has increased ultimate strength of both high density concrete and normal aggregate concrete.

- Steel fiber addition has decreased spalling and reduced sudden failure of the specimen when subjected to its ultimate load while testing.
- Thermal conduction of high density concrete with 0% steel fiber has high conductivity comparing to other mix types.
- High density aggregate have low water absorption and shrinkage when compared to normal aggregate concrete. Addition of steel fiber has decreased shrinkage by 30% when compared between NC0 and NC1. HDC1 has shown decrease in 27.5% shrinkage compared to HDC0.HDC0 has 50% less shrinkage than NC0.

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