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Behavior of High Performance Fiber Reinforced Concrete Using Carbon Nano Tubes

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Abstract: — **High performance concrete (HPC) is a specialized concrete designed to provide several benefits in the construction of concrete structures. The use of fibres in concrete has gained enormous popularity in the last decade. Studies have shown increasing evidence that the brittle behavior of HPC can be overcome by the addition of short steel fibres of small diameter in the concrete mix. The present study aims to investigate the integration of Carbon Nano tubes (CNTs)and steel fibers with HPC of a designed mix of M60 grade of concrete. The influence of the cementations material dosage, nano material, cement/ultra-fine ratio, percentage of fibers, and the mixing procedures on the mechanical properties of nano based carbon concrete was studied by preparing several concrete mixes. CNTs specifically designed for use with concrete composites as admixture. Six different concentrations such as 0.025%, 0.050%, 0.075%, 0.1%, 0.125% and 0.15% of CNTs by weight of cement were used. Carbon Nano tubes were first dispersed in water and surfactant using an ultrasonic mixer as per state-of-the-art techniques and then combined with fibre reinforced high performance concrete. The various mechanical properties like Compressive, Flexural and Split tensile strength can be improved with the addition of low concentrations of CNT in high performance fiber reinforced concrete.**

Key words: **High Performance Concrete (HPC) , High Performance Fiber Reinforced Concrete (HPFRC), Carbon Nano tubes(CNTs), Crimped end steel fibers, Compressive Strength , Flexural Strength and Split tensile strength,**

I. INTRODUCTION

Concrete plays a vital role in civil engineering construction. However, over the past several years, structural deterioration has become a critical issue the loss of structural capacity over time is caused mainly by the nucleation and growth of micro-cracks / micro-defects and their evolution into macro-cracks, which degrades the structural strength and stiffness of concrete structures. The control of concrete damage requires implementing inspection, maintenance, and rehabilitation programs, resulting in high costs. A more economical approach is to prevent deterioration and avoid the resulting high cost of the rehabilitation and replacement. The key to damage-resistant concrete and long-life concrete structures, which has been known for a long time, lies in enhancing the tensile strength and fracture toughness of concrete material. Therefore, many new macro-to-micro reinforcements have been utilized in order to increase the tensile strength and fracture toughness of concrete but all have led to marginal improvements. This can be achieved by integration of CNTs, HPC and fiber in concrete.

II. LITERATURE REVIEW

High Performance Concrete is multi-componental interactive construction material. High Performance Concretes (HPC) is a concrete with properties or attributes, which satisfy the performance criteria. Generally concretes with higher strengths and attributes superior to conventional concretes are desirable in the construction industry. High performance concrete (HPC) could be considered as high strength concrete if other attributes are satisfactory in terms of its intended application. Generally concretes with higher strengths exhibit superiority of other attributes. In North American practice, high strength concrete is usually considered to be a concrete with 28-day compressive strength of at least 6000 psi (42 Mpa). In a recent CEB-FIP State –of-the-Art Report on High Strength Concrete having a minimum 28-day compressive strength of 8700 psi (60 Mpa). Clearly then, the definition of high strength concrete is relative; it depends upon both the period of time in question and the location .HPC is an engineered concrete possessing the most desirable

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properties during fresh as well as hardened concrete stages[2,3,4]. HPC is far superior to conventional cement concrete as the ingredients of HPC contribute most optimally and efficiently to the various properties[5,6,7]. The use of nanotechnology-based nano-filaments such as carbon nano tubes (CNTs) and nano fibers (CNFs) as reinforcement in improving the mechanical properties of cement paste as a construction material Therefore, this study aspires to bridge the gap between nano-technology and construction engineering. Carbon nano-tubes (CNTs) have unique mechanical properties where their stiffness, strength, and resilience exceed any current material such that they offer tremendous opportunities for the development of fundamentally new material systems in modern construction.CNT are expected to have several distinct advantages as a reinforcing material for cements as compared to more traditional fibers[8,9,11]. First, they have significantly greater strengths than other fibres, which should improve overall mechanical behaviour. Second, CNT have much higher aspect ratios, requiring significantly higher energies for crack propagation around a tube as compared to across it than would be the case for a lower aspect ratio fibre. Thirdly, the smaller diameters of CNT means both that they can be more widely distributed in the cement matrix with reduced fibre spacing and that their interaction with the matrix may be different from that of the larger fibres. As with other CNT composites, the major issues to overcome in preparing high quality CNT/cement composites including distributing the CNT within the cement and obtaining suitable bonding between the two materials. One route is to disperse the CNT in a surfactant mixed with water or another solvent, as has commonly been used for polymer composites. While substantial research on Carbon Nano tubes (CNTs) has been focused around their incorporation within polymers[12], very diminutive attention has been focused on assimilation of CNTs with cement. Therefore, the research on integration of CNTs in cementatious materials is at a relatively novel stage; currently, very limited research regarding their effectiveness in enhancing the tensile strength or toughness of concrete has been conducted. Hence an attempt has been made through the present investigation to study the effect of CNTs in high performance concrete along steel fiber on the basic mechanical properties of concrete like compressive strength, split tensile strength and flexural strength.

2.1 Carbon nanotubes as reinforcing materials in cement composites

CNTs are expected to have several distinct advantages as a reinforcing material for cements as compared to more traditional fibers. Firstly, they have significantly greater strengths than other fibres, which should improve overall mechanical behaviour. Secondly, CNT have much higher aspect ratios, requiring significantly higher energies for crack propagation around a tube as compared to across it than would be the case for a lower aspect ratio fibre. Thirdly, the smaller diameters of CNT means both that they can be more widely distributed in the cement matrix with reduced fibre spacing and that their interaction with the matrix may be different from that of the larger fibres

2.2 Carbon Nanotubes

Discovered in 1991, carbon nanotubes (CNT) [13] are a unique form of carbon that has desirable mechanical, thermal and electronic properties. They can be easily visualized by considering a single graphene sheet, a lattice of carbon atoms distributed in a hexagonal pattern. A single walled CNT looks like a single sheet rolled up into a tube, while multi-walled CNT look like multiple sheets rolled into a series of tubes, one inside the other. A single walled CNT is typically 1-3 nm in diameter and a micrometer or more long. Multi-walled CNT (MWCNTs) typically range in diameter from 10 to 40 nm. Mechanically, CNT show elastic behaviour, with a Young's Modulus of approx, 1 TPa. Single walled CNT have measured yield stresses of between 20 and 60 GPa, with measured yield strains of up to 10%. Theoretical considerations suggest that the yield stress for single walled CNT may be as high as 100 GPa.

III. EXPERIMENTAL PROGRAM

This experimental program is designed to investigate the integration of Carbon Nanotubes, steel fibre with High Performance Concrete of a design mix of M60 grade of concrete. The influence of the cementations material dosage, nano material, cement/ultra-fine ratio, and the mixing Procedures on the mechanical properties of High Performance Fiber Reinforced Concrete Using Carbon Nano Tubes together with the workability was studied by preparing several concrete mixes. The test procedures, details and equipment used to assess concrete properties are illustrated in the following subsections

3.1 Materials used in the present study

In the present work Ordinary Portland cement 53 grade, crushed granite with a maximum nominal size of 12.5 mm down size, fine aggregates satisfying the requirements of Zone II, Silica Fume, Ground Granulated Blast Slag (GGBS), Multi-walled CNT (MWCNTs) having average diameter 25 nm with length of 30 to 60µm, Glenium ACE30, a high-range water reducing polycarboxylate-based admixture as super-plasticizer, Crimped end steel fibers having aspect ratio of 80, were used. Detailed mechanical properties of materials are shown in Table No.1

Table.1 Properties of Materials used

Parameter	Specification
Cement Specific Gravity	3.15
Fineness modulus of FA	2.64
Specific Gravity of FA	2.68
Fineness modulus of CA	6.1
Specific Gravity of CA	2.75
Specific Gravity of Silica Fume	2.26
Specific Gravity of GGBS	2.32
Nano Material	MWCNTs
Nano Material Colour	Black
Purity of MWCNTs	>92%
Specific Surface Area of MWCNTs	350m^2/Kg
Average diameter of MWCNTs	20 n m

3.2 Test specimens

A series of specimens are chosen for the investigation and all are having a unique nominal sectional dimensions for cubes 150 mm, cylinders 150 mm dia. and 300mm height and prisms 100 X 100 X 500mm respectively. The test specimens consists of, four different trail mix of designed grade of M60 with varying percentage of silica fumes and GGBS as cementations replacements and CNTs vary Percentage from 0.025 to 0.15% regards to cement content.

MIX 1. M60 (Cement 79% + SF 6% + GGBS 15%)

MIX 2. M60 (Cement 71% + SF 9% + GGBS 20%)

MIX 3. M60 (Cement 63% + SF 12% + GGBS 25%)

MIX 4. M60 (Cement 55% + SF 15% + GGBS 30%)

From the above mentioned trail mixes, MIX 2 M60 (Cement 71% + SF 9% + GGBS 20%) found to satisfy sustainable point of view and optimized to obtain maximum compressive strength to which a nano material (CNTs) carbon nanotubes are added.[14] The mixing of CNTs in MIX 2 M60 (Cement 71% + SF 9% + GGBS 20%) was again divided into following trail mixes.

MIX N 1 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.025% CNTs

MIX N 2 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.050% CNTs

MIX N 3 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.075% CNTs

MIX N 4 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.10% CNTs

MIX N 5 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.125% CNTs

MIX N 6 = MIX 2 (M60 (Cement 71% + SF 9% + GGBS 20%) + 0.150% CNTs

Again from the above mentioned trail mixes, **MIX 2 N4** M60 (Cement 71% + SF 9% + GGBS 20%) + 0.1% CNTs found to satisfy sustainable point of view and optimized to obtain maximum compressive strength. Further steel fibers with different percentages are added to **MIX 2 N4.**

The integration of steel fibers in **MIX 2 N4 M60** (Cement 71% + SF 9% + GGBS 20% + 0.1% CNTs) was again divided into following trail mixes to optimized the steel fiber content, the Crimped end steel fibers are added 0.5%,1.0% & 1.5% w.r.to volume of concrete (for which optimization of GGBFs, Silica Fume, and CNT has been considered) [14]

MIX 2 N4S1, M60 = MIX 2 N4 (M60 (Cement 71% + SF 9% + GGBS 20%) +
0.10% CNTs + 0.5% steel fibers.

MIX 2 N4S2, M60 = MIX 2 N4 (M60 (Cement 71% + SF 9% + GGBS 20%) +
0.10% CNTs + 1.0% steel fibers.

MIX 2 N4S3, M60 = MIX 2 N4 (M60 (Cement 71% + SF 9% + GGBS 20%) +
0.10% CNTs + 1.5% steel fibers.

IV. EXPERIMENTAL PROCEDURE

The present investigation involves the following
4.1 Dispersion of CNTs in water
4.2 Casting the specimens for compressive strength, tensile strength and flexural strength

4.1. Dispersion of CNTs in water

In Primary Phase, the entire dispersion of CNTs has been done, first the CNTs are dispersed in water. For carbon nano-filaments to be fully utilized within materials, they must first be properly dispersed.

The following chemicals are used for dispersion of CNTs

(a) ACETONE: Acetone is an organic compound with formula (CH3)2CO is colourless, flammable liquid and is the simplest ketone. It is mainly used as a solvent and is a product of methyl methaacrylate and bisphenol.

(b) HDF (SODIUM DODCYL SULPHATE): HDF is an organic compound with formula CH3(CH2)11SO4Na. This salt is an organo-sulfate consisting of 12-Carbon tail attached to a sulphate group giving the material the amphiphilic properties required of a detergent.

(c) TWEEN 20: This is a type of Polysorbate surfactant whose stability and relative non0toxicity allows it to be used as a detergent and emulsifier in pharmacological applications.

To prepare each mixture, water, surfactant, and either CNTs are first measured, and then mixed with water and chemicals. In order to ensure a well-dispersed solution, an ultrasonic mixer is used, which can deliver up to 500 watts at 20 kHz. The energy in the shock waves is extremely high and significantly accelerates chemical reactions and breaks the clumps and agglomerations of particles. CNTs are mixed for 20 minutes.

The entire dispersion of CNTs has been done at AZYME BIOSCIENCE PVT. LTD. BANGALORE, first the CNTs are dispersed in water. For carbon nano-filaments to be fully utilized within materials, they must first be properly dispersed. Dispersion is the process of separating the bundles of either CNTs or CNFs into individual filaments within a matrix. The method is to mechanically separate the nano-filaments by either ultrasonic or high-shear mixing. However, without the use of chemical surfactants, the vander Waals interactions will pull the nano-filaments back out of suspension and agglomerate (bundle) together again.

4.2. Casting the specimens

In casting the specimen, Weigh Batching is used for the experimental study. Cement is weighed & slowly mixed with weighed Silica fume and GGBS the whole dry sample is mixed for 5 minutes. Fine aggregate and coarse aggregate are weighed & mixed with above ternary blended mixer then water is measured in a measuring jar and mixed with Super plasticizer and dispersed CNTs of known volume. The Concrete mix is mixed until a uniform homogeneous mix is obtained, the mixing time should not exceed 3-4 minutes. Care should be taken when using CNTs. The dispersed solution of CNTs is added to the mix & the mixing is continued until the lump free homogeneous mix is obtained. For preparing specimens, care was taken to maintain the quality of concrete by standardizing the materials, proper batching of material, and proper mixing of materials, proper method of compaction, adequate compaction, compaction time, initial hardening, curing and method of testing.

V METHODOLOGY OF TEST

In the present study Compressive strength, Split tensile strength & flexural strength are taken in to account. The experimental setup, casting , curing of specimen and testing procedure in accordance with IS 456-2000& 516:1959, *Clause 5.1 upto 5.6* for determination of compressive respectively.

VI RESULTS AND DISCUSSIONS

The experimental values obtained for different concrete mixes used in the present investigation are tabulated in following tables and corresponding graphs.

6.1 Results for compressive strength

The compressive strength is the main criteria for the purpose of structural design, the compression tests are relatively easy to carry out. The test for determining compressive strength for concrete, employs a cube specimen of 150mm size and cured for 3, 7, and 28 days which is subjected to compression in a compression testing machine. The experimental results are tabulated in the Tables – 2,3 & 4 and sown in fig – 1 & 2. It is seen that 1.0% of steel fiber content, obtain maximum compressive strength than other concrete matrix used.

Table 2: Compressive Strength (MIX 2 N4S1, M60)

Age of Sample	Load (KN)	Strength (N/mm^2)	Average Strength (N/mm^2)
3	1048	46.57	46.21
	1035	46.00	
	1032	45.86	
7	1420	63.11	63.74
	1433	63.68	
	1452	64.53	
28	1750	77.77	77.53
	1744	77.51	
	1738	77.24	

Table 3: Compressive Strength (MIX 2 N4S2, M60)

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Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	1080	48.00	48.62
	1088	48.35	
	1095	48.66	
7	1480	66.22	66.48
	1478	65.68	
	1496	66.48	
28	1812	80.53	80.55
	1805	80.22	
	1815	80.66	

Table 4: Compressive Strength (MIX 2 N4S3, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	1070	47.55	47.80
	1076	47.82	
	1080	48.00	
7	1475	65.55	65.3
	1468	65.24	
	1465	65.11	
28	1760	78.22	78.42
	1753	77.91	
	1769	78.31	

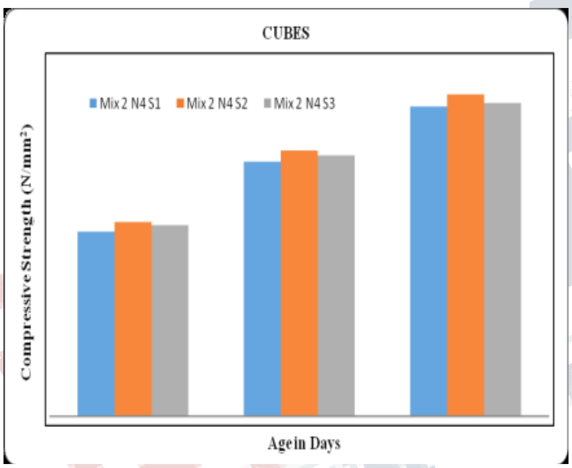

Fig. 1: Comparison -of Compressive Strength MIX 2 N4S3

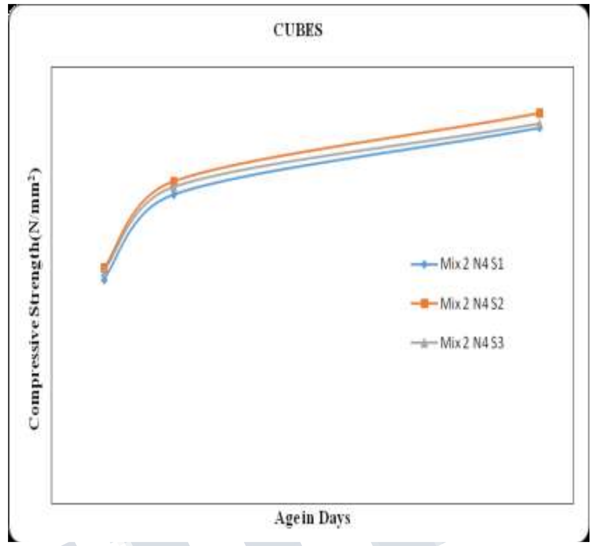

Fig. 2: Variation of Compressive Strength MIX 2 N4S1, S2, S3

6.2 Results for split tensile strength

This is an indirect test for tensile strength of concrete. This method is developed in Brazil and has come in to general use and been standardized throughout the world. The specimen is a 150Φx300mm cylinder made and cured in the same manner as similar to compressive test. Two wooden strips are placed. One at the top and the other at the bottom of the specimen and the same is loaded in compression. The tensile strength computed in this manner is apparently about 15% higher than that determined by direct tension tests. In order to obtain the split tensile strength for 3, 7 and 28 days, tests are conducted on cylinders. The results of split tensile strength test were tabulated below in the Tables – 5,6 & 7 shown if fig-3 & 4 It is observed that 1.0% of steel fiber content, obtain maximum split tensile strength than other concrete matrix used.

Table 5: Split Tensile Strength (MIX 2 N4S1, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	145	2.05	2.23
	159	2.41	
	170	2.26	
7	244	3.46	3.65
	265	3.74	
	269	3.82	
28	290	4.10	4.10
	304	4.31	
	284	4.03	

Table 6: Split Tensile Strength (MIX 2 N4S2, M60)

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Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	184	2.61	2.4
	174	2.44	
	152	2.17	
7	251	3.56	3.54
	259	3.63	
	237	3.37	
28	326	4.62	4.62
	315	4.44	
	337	4.76	

Table 7: Split Tensile Strength (MIX 2N4S3, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	163	2.32	2.29
	170	2.43	
	156	2.21	
7	244	3.43	3.65
	255	3.62	
	266	3.77	
28	287	4.04	4.15
	305	4.31	
	294	4.18	

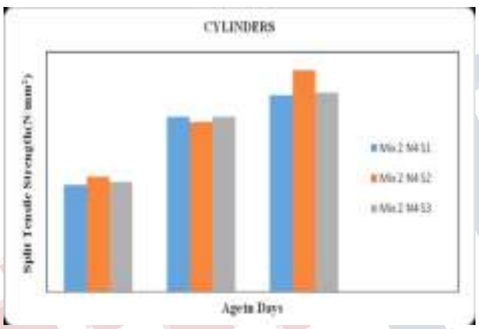

Fig. 3: Comparison of Split Tensile Strength MIX 2N4S3

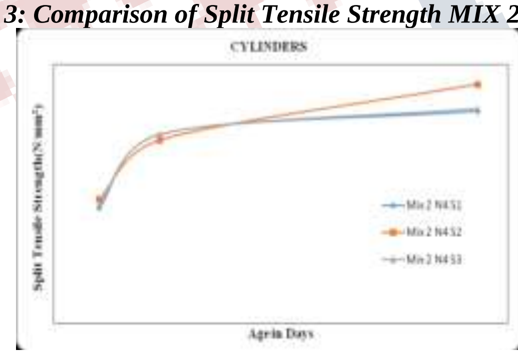

Fig 4: Variation of Split Tensile Strength MIX 2N4S1, S2, S3

6.3 Results for flexural strength

When concrete is subjected to bending, Tensile, compressive stresses and in many cases direct shearing stresses occur. The most common example of concrete structure subjected to flexure are highway pavements and the strength of concrete for pavements is commonly evaluated by means of bending tests on 100x100x500mm beam specimens. Flexural strength is expressed in terms of "Modulus of rupture" which is the maximum tensile (or compressive) stress at rupture as tabulated in Tables – 8, 9 & 10 and shown in fig – 5 & 6. Experimental results, shows that 1.0% of steel fiber content obtain maximum flexural strength than other concrete matrix used.

Table 8: Flexural Strength (MIX 2N4S1, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	8.10	4.05	4.15
	8.2	4.10	
	8.7	4.35	
7	10.4	5.20	5.22
	9.9	4.95	
	10.9	5.45	
28	16.1	8.05	8.15
	16.6	8.35	
	15.9	7.95	

Table 9: Flexural Strength (MIX 2N4S2, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	8.9	4.45	4.21
	8.5	4.25	
	7.9	3.95	
7	10.3	5.15	5.30
	11.2	5.60	
	10.6	5.30	
28	17.2	8.60	8.33
	16.2	8.10	
	16.7	8.35	

Table 10: Flexural Strength (MIX 2N4S3, M60)

Age of Sample	Load (KN)	Strength (N/mm²)	Average Strength (N/mm²)
3	8.3	4.15	4.18
	7.9	3.95	
	8.9	4.45	
7	10.9	5.45	5.28
	11.2	5.60	
	9.6	5.80	
28	16.9	8.45	8.20
	16.6	8.30	
	15.8	7.90	

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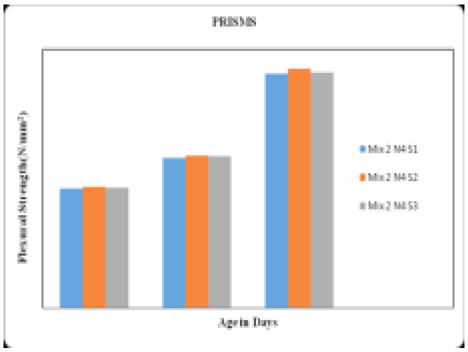

Fig. 5: Comparison of Flexural Strength MIX 2N4 S1 S2, S3

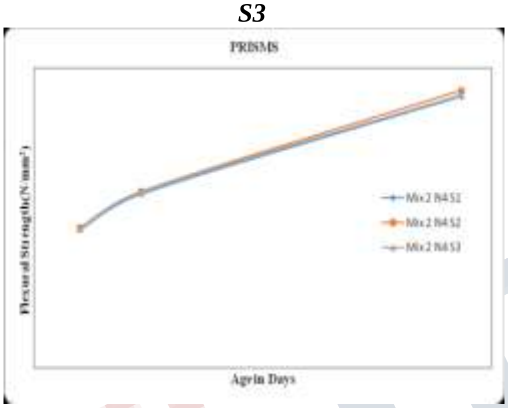

Fig. .6: Variation of Flexural Strength MIX 2N4 S1, S2, S3

VII. CONCLUSION

Based on the results of the experimental investigation the following conclusion are drawn.

A number of variables can cause changes in the physical and mechanical behaviour of high performance fiber reinforced concrete using Carbon Nano tubes. These include the composition of concrete mix, type of aggregate and their shape, admixtures, CNTs and addition of fibres.
The matrix used in the investigation with varying amount of cementatious materials such as Silica Fumes and GGBS. The compressive, split tensile and flexural strength at 28 days for mix M60 (SF 9% + GGBS 20%) was found to be increased significantly, and same has been optimized. Hence, MIX 2M60 is integrated with various percentages of CNTs from 0.025% to 0.125% with respect to cement content. Integration of CNTs at 0.1% satisfy sustainable point of view and same is optimized to obtain maximum compressive strength.(Mix 2N4).[14]

The concrete matrix namely Mix 2N4S1, Mix2N4S2 Mix2N4S3, M60 with 0.5%, 1.0% and 1.5% of steel fibre are added. Mix2N4S2,M60 shows significant enhancement in Flexural Strength, split tensile strength and compressive strength at 1.0% of steel fiber than other concrete matrix used.
The compressive strength, Split tensile strength and Flexural strength at 28 days for Mix 2N4S2, M60 was found to be increased satisfactorily to that of remaining mixes of concrete.

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