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Enhancing the Durability Properties of Concrete prepared with Multiwalled Carbon Nanotubes

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ABSTRACT: This paper describes the study of durability aspects of concrete incorporated with different dosages of (0 % - 0.40 %) of Multiwalled Carbon Nanotubes (MWCNTs). Each specimen was subjected to Acid attack test, Chloride attack test, Sulphate attack test and water permeability test for a duration of 28, 56 and 90 days respectively. It has been observed from the experiments that the specimen of 0.25% Multiwalled Carbon Nanotubes shows an extraordinary performance among the other specimens. It was also observed that this mix performed much better than the control specimen.

KEYWORD: Multiwalled Carbon Nanotubes (MWCNTs), Durability, Acid attack, Chloride attack, Sulphate attack, Water Permeability, Penetration depth.

1 INTRODUCTION

Multi-walled carbon nanotubes (MWCNTs) are known for their high tensile strength and elastic modulus which makes them one among the stiffest materials [1]. Though carbon nanotubes are known to possess high strength properties they are weak in shear between the adjacent shells and tubes [2]. It has been observed that application of high energy electron radiation increases the strength of Multi-walled carbon nanotubes to around 60 Gpa. The deposition parameter and nature of synthesis [3] plays a vital role in the dimensions and properties of carbon nanotubes (CNTs). Various methods such as arc discharge [4], Laser ablation [5] and chemical vapour deposition (CVD) [6] are used in the manufacture of CNTs of which CVD is the most economical method for mass production of CNTs [7-8]. However this method produces carbon nanotubes with a non-negligible amount of defects, less strength and these carbon nanotubes are very difficult to disperse [9]. On the positive side, these defects help the MWCNTs to play a key role in cement reinforcement application. Defects free CNTs obtained by graphitization process achieved by high treatment at high temperature in a vacuum, in spite having good mechanical properties [10], are incapable of forming proper adhesion with a matrix which is called sliding [11]. Prevention of the satisfactory load transfer can be arranged by nanotubes bundle additionally. A previous study indicates that the carbon nanotubes cement matrix gives a steeper increase in strength characteristics of engineered cement composites [12]. The MWCNTs contains mechanical strength and other fibers which are most beneficial reinforcing material. But the prevailing main challenge remains in case of geopolymer properties of the surface [13-14]. In order to magnify mechanical properties corresponding to strength and stiffness, numerous researchers are practicing carbon nanotubes to mix with cement paste and mortars for the last few years [15-25].

In the present study multiwalled carbon nanotubes have been used as an additive in cement and the optimum dosage of MWCNTs are identified.

2 MATERIALS AND EXPERIMENTAL METHODS

2.1. Materials

In this study, 53 grade ordinary Portland cement was used. The standard requirements, physical properties and chemical compositions of Ordinary Portland Cement are shown in Table 1. Natural locally available fine aggregate and coarse aggregate was used and their physical properties of used aggregates are shown in Table 2. Table 3 shows the characteristic of superplasticizer, the properties of MWCNTs are shown in Table 4.

2.2 Methodology

Table 5 indicates the approach of the research; nine achievable mixes were distinguished with various ratios of MWCNTs for this experimental work.

2.3 Dispersion of MWCNTs

Investigation on the dispersion of carbon nanotubes (CNTs) and its influence on the mechanical properties of the cement matrix have been carried out by Sobolkine et. al. In the present study, ultrasonicator was used to disperse the multiwall carbon nanotubes (MWCNTs) for about 60 minutes per sample.

Firstly the MWCNTs should be dispersed in water by using ultrasonicator for about 60 minutes. Cement, fine aggregate and coarse aggregate were mixed in a dry condition in a pan mixer. To produce fresh concrete, prepared MWCNTs solution was added to the well-mixed dry materials and mixed for about 5 minutes. Finally, super plasticizer was added to achieve a workable mix. Prior to casting, the inner sides of cube mould were layered with lubricating oil to prevent adhesion with the concrete specimens. The moulds were filled in three layers, with each layer being well compacted. The casted specimens were kept open at the room temperature of $30 \pm 20\ ^{o}c$ and relative humidity of 65 ± 5^{o} c. Mix design details for the MWCNTs concrete is given in Table 6.

2.4 Testing

All the hardened concrete cube specimens of size 150 mm ×150 mm ×150 mm were subjected to acid attack, Sulphate attack, and Chloride attack by immersing in Sulphuric acid, Sodium sulphate and Chloride for 28, 56 and 90 days. For Sulphuric acid attack, the ph of the Acidic solution was checked every week and maintained at a value of 1 by adding the required amount of the concentrated acid solution. The acidic solution was completely replaced every 30 days. Similarly, for Sulphate and Chloride attack, the solution replacement was done. The change in weight and compressive strength of specimens were tested at an interval of 28, 56 and 90 days of immersion. Testing for compressive strength was conducted on cube specimen, using a 2000 KN compression testing machine as per Indian standard specification [26]. The density of the hardened concrete before and after 28, 56 and 90 days of immersion were found out for all the hardened concrete specimens.

Table 1– Physical properties and chemical compositions of OPC.

Properties& compositions	**OPC**
Standards	IS: 12269-1987
Chemical compositions	
Insoluble Residue, % by mass	0.86
Loss on Ignition, % by mass	1.29
Magnesia (MgO) % by mass	1.17
Sulphuric Anhydride (SO_3), % by mass	2.06
Lime Saturation Factor	0.92
Alumina Iron ratio, % by mass	1.16
Alkalies, % by mass	0.5
Chlorides, % by mass	0.01
CaO	63.4
SiO_2	20.1
Al_2O_3	4.1
Fe_2O_3	3.3
MgO	3.6
Na_2O	0.2
K_2O	0.4
SO_3	2.1
LOI	2.4
Physical compositions	
Specific Surface (M^2/kg)	303
Le chatelier method (mm)	0.50
Autoclave (%)	0.936

Table 2– Physical properties aggregates

Type	IS sieve	Specifications	Fineness modulus	Specific gravity	Absorption
Fine aggregates	4.75mm	Zone II of IS: 383-1987	2.60	2.69	0.96%
Coarse aggregates	20mm 10mm	IS: 383-1987	7.00 6.30	2.86 2.78	0.9% 0.91%

Table 3– Characteristic of super plasticizer

Main component	Type	Density (g/cm3)	Usage %
PC (polycarboxilic ether)	Liquid	1.05	1–4

Table 4– Properties of MWCNTs

MWCNTs	Description
Available form	Black powder
Diameter	20nm
Length	10 microns
Purity	>95%
Metal particles	<4%
Amorphous Carbon	<1%
Specific surface area	$320 m^2/g$
Bulk density	$0.05 g/cm^3$

Table 5– Proportions of MWCNTs

S. NO	Mix Ids	Addition of MWCNTs by weight of cement
1	MWCNTs-0	0
2	MWCNTs-0.05	0.05
3	MWCNTs-0.10	0.10
4	MWCNTs-0.15	0.15
5	MWCNTs-0.20	0.20
6	MWCNTs-0.25	0.25
7	MWCNTs-0.30	0.30
8	MWCNTs-0.35	0.35
9	MWCNTs-0.40	0.40

Table 6– Mix design

Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (Kg/m^3)	Super plasticizer (Kg/m^3)
425.6	1258.8	817.1	149.8	2.1

3 RESULTS AND DISCUSSION

3.1 *Acid attack test*

Concrete cubes consisting of various concrete mixtures of size 150 mm ×150mm × 150 mm were cast and cured for a period of 28 days, after which they were allowed to dry for one day and the weight of the cubes was measured respectively. Sulphuric acid attack test was conducted for which 5 Wt % of sulphuric acid was used. In this test, the cast concrete cubes were immersed in acid water with a constant Ph level of 3, for a period of 90 days. The

Compressive strength and the weight of the concrete cubes were periodically tested for 28, 56 and 90 days respectively. The resistance of concrete to acid attack is obtained by the percentage loss of weight and strength of the specimen after immersion in acid water [27-31].

3.1.1 *Weight loss due to sulphuric acid*

The weight of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35, and MWCNTs-0.40, after 28days of immersion was found to be 8.59 Kg, 8.43 Kg, 8.62 Kg, 8.51 Kg, 8.49 Kg, 8.61 Kg, 8.74 Kg, 8.55 Kg and 8.67 Kg as given in Fig-1 and its corresponding percentage weight loss was found to be 8.52 %, 7.67 %, 6.98 %, 6.23 %, 5.86 %, 4.99 %, 5.01 %, 6.21 %, and 9.12 % respectively. In the case of 56 days of immersion it was 8.1 Kg, 8.57 Kg, 8.49 Kg, 8.77 Kg, 8.56 Kg, 8.72 Kg, 8.55 Kg, 5.48 Kg, and 8.65 Kg and its corresponding percentage of weight loss was found to be 11.1 %, 9.86 %, 8.76 %, 8.51 %, 6.59 %, 5.78 %, 7.88 %, 9.01 %, and 13.34 % respectively . In the case of 90 days of immersion was noted to be 8.54 Kg, 8.72 Kg, 8.44 Kg, 8.65 Kg, 8.48 Kg, 8.71 Kg, 8.66 Kg, 8.52 Kg and 8.79 Kg and its corresponding percentage of weight loss was found to be 15.58 %, 13.98 %, 12.65 %, 12.24 %, 10.97 %, 9.84 %, 12.32 %, 14.12 %, and 16.67 %.

3.1.2 *Strength loss due to sulphuric acid*

After 28 days of sulphuric acid attack, compressive strength of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 was reported as 50.65Mpa , 56.39 Mpa , 59.16 Mpa , 63.14 Mpa , 66.47 Mpa, 72.82 Mpa, 59.94 Mpa, 54.65 Mpa and 46.81 Mpa are given in Fig-2 and its equivalent percentage loss in compressive strength was noted as 10.1 %, 9.87 %, 9.53 %, 9.11 %, 8.92 %, 6.54 %, 9.53 %, 9.99 % and 10.86 %. The test results exhibited that MWCNTs-0.40 experienced maximum strength loss, whereas MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, and MWCNTs-0.35 experienced minimum loss at all test intervals. Out of all specimens, MWCNTs-0.25 performed better against acid attack throughout all the immersion duration.

After 56 days of sulphuric acid attack, compressive strength of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 was reported as 45.91 Mpa, 52.26 Mpa, 54.99 Mpa, 58.89 Mpa, 61.00 Mpa, 68.40 Mpa, 55.29 Mpa, 49.39 Mpa and 40.35 Mpa and its equivalent percentage loss in compressive strength was noted as 19.89 %, 18.1 %, 17.92 %, 17.45 %, 17.01 %, 13.01 %, 18.98 %, 19.28 % and 21.59 % . The test results exhibited that MWCN-0.40 experienced maximum strength loss, whereas, in the case of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, and MWCNTs-0.35 experienced minimum loss at all test intervals. Out of all specimens, MWCN-0.25 performed better against acid attack throughout all the immersion duration.

After 90 days of sulphuric acid attack, compressive strength of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 was reported as 43.81 Mpa, 51.49 Mpa, 53.79 Mpa, 57.43 Mpa, 59.21 Mpa, 66.69 Mpa, 55.55 Mpa, 47.78 Mpa and 38.52 Mpa its equivalent percentage loss in compressive strength was noted 24.56 %, 21.02 %, 20.86 %, 20.12 %, 20.01 %, 18.19 %, 20.10 %, 22.56 % and 26.89 %. The test results exhibited that MWCNTs-0.40 experienced maximum strength loss, whereas in the case of MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30 and MWCNTs-0.35experienced minimum loss at all test intervals (In general compressive strength loss was proportional to the increase in immersion duration). Out of all specimens, MWCNTs-0.25 performed better against acid attack throughout all the immersion duration.

Incorporation of CNTs in concrete has been observed to enhance the physical and mechanical properties of concrete [35-37]. The introduction of CNTs in concrete has resulted in the growth of microcrystals in pores and voids of C-S-H gel in the micro level, thereby reducing the cement paste porosity in nano level and compaction of interporous structure resulting in increased compressive strength.

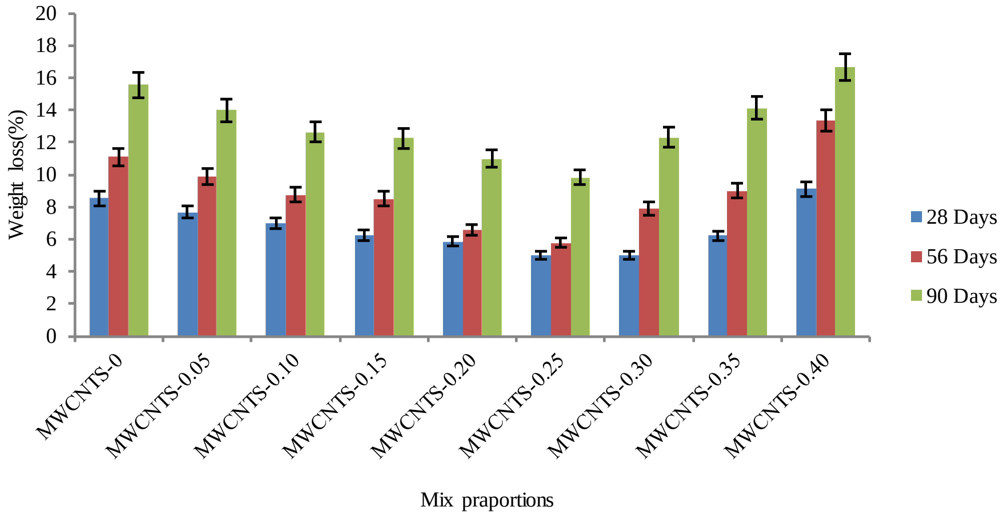

Figure 1 - Weight loss due to acid attack for 28, 56 and 90 days.

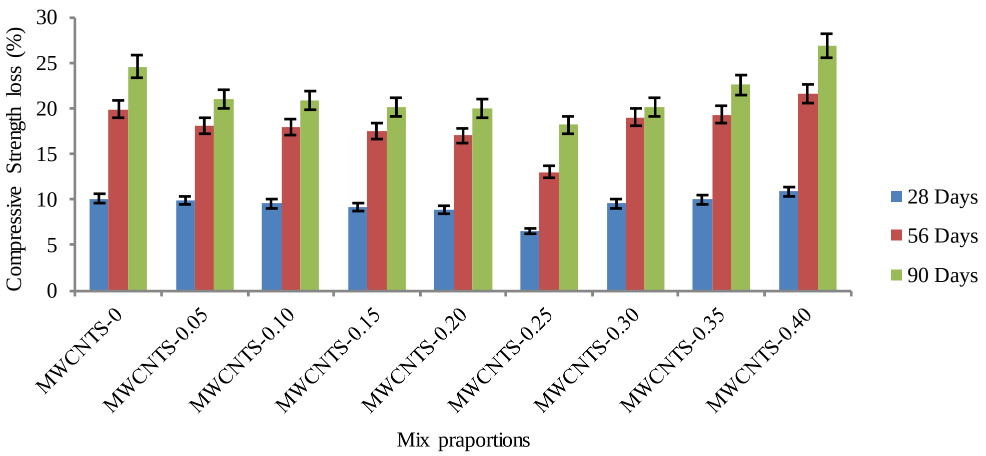

Figure 2 - Strength loss due to acid attack for 28, 56 and 90 days.

3.2 *Sulphate test*

To determine the resistance of concrete to sulphate attack test is carried out [32]. Where in the percentage loss of compressive strength or variation in compressive strength of the specimens subjected to sulphate test was found with respect to the specimens which were not subjected to sulphate test [33]. The concrete cubes of 150mm×150mm×150mm of size after being cured for a period of 28 days is immersed in water containing 5 % of (Na_2so_4) by weight of water. After an immersion period of 90 days, the specimen is wiped and cleaned of grit from the surface of the cubes. These cubes are then subjected to compressive strength testing following the procedure if IA-516-1959. This procedure of accelerated testing to find the compressive strength for assuring the sulphate resistance of concrete [34].

3.2.1 *Weight loss due to sulphate attack*

After 28 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.43 Kg, 8.71 Kg, 8.62 Kg, 8.55 Kg, 8.49 Kg, 8.68 Kg, 8.63 Kg, 8.70 Kg and 8.51 Kg as given in Fig-3 and undergone percentage weight loss of 1.01 %, 0.91 %, 0.83 %, 0.76 %, 0.71 %, 0.62 %, 0.81 %, 0.99 % and 1.52% respectively.

After 56 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.70 Kg, 8.75 Kg, 8.89 Kg, 8.54 Kg, 8.76 Kg, 8.79 Kg, 8.72 Kg, 8.63 Kg, 8.89 Kg and undergone percentage weight loss of 1.98 %, 1.72 %, 1.64 %, 1.54 %, 1.51 %, 1.23 %, 1.67 %, 1.89 % and 2.89 % respectively.

After 90 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.84 Kg , 8.57 Kg, 8.80 Kg, 8.58 Kg, 8.85 Kg, 8.65 Kg, 8.78 Kg, 8.63 Kg, 8.76 Kg and undergone percentage weight loss of 2.11 %, 1.83 %, 1.79 %, 1.65 %, 1.62 %, 1.45 %, 1.86 %, 1.99 % and 3.01 % respectively.

3.2.2 *Strength loss due to sulphuric acid*

After 28 days of sulphate attack, compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 51.84 Mpa, 57.90 Mpa, 60.75 Mpa, 64.70 Mpa, 68.23 Mpa, 73.62 Mpa, 61.62 Mpa, 55.94 Mpa and 48.01 Mpa as given in Fig-4 and its equivalent percentage strength loss in compressive strength were noted as 7.99 %, 7.45 %, 7.11 %, 6.86 %, 6.32 %, 5.51 %, 6.99 %, 7.87 % and 8.57 % respectively.

After 56 days of sulphate attack, compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 51.83 Mpa, 57.92 Mpa, 60.99 Mpa, 65.32 Mpa, 67.47 Mpa, 73.05 Mpa, 62.17 Mpa, 55.34 Mpa and 46.37 Mpa and its equivalent percentage strength loss in compressive strength were noted as 9.56 %, 9.23 %, 8.97 %, 8.43 %, 8.21 %, 7.09 %, 8.9 %, 9.56 % and 9.89 % respectively.

After 90 days of sulphate attack, compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 50.86 Mpa, 57.36 Mpa, 59.90 Mpa, 63.68 Mpa, 65.86 Mpa, 73.46 Mpa, 61.19 Mpa, 54.16 Mpa and 75.73 Mpa and its equivalent percentage strength loss in compressive strength were noted as 12.43 %, 12.01 %, 11.87 %, 11.42 %, 11.03 %, 9.89 %, 11.99 %, 12.23 % and 13.2% respectively. Studies [35] have shown that increasing the quantity of CNTs in concrete does not result in a higher strength.

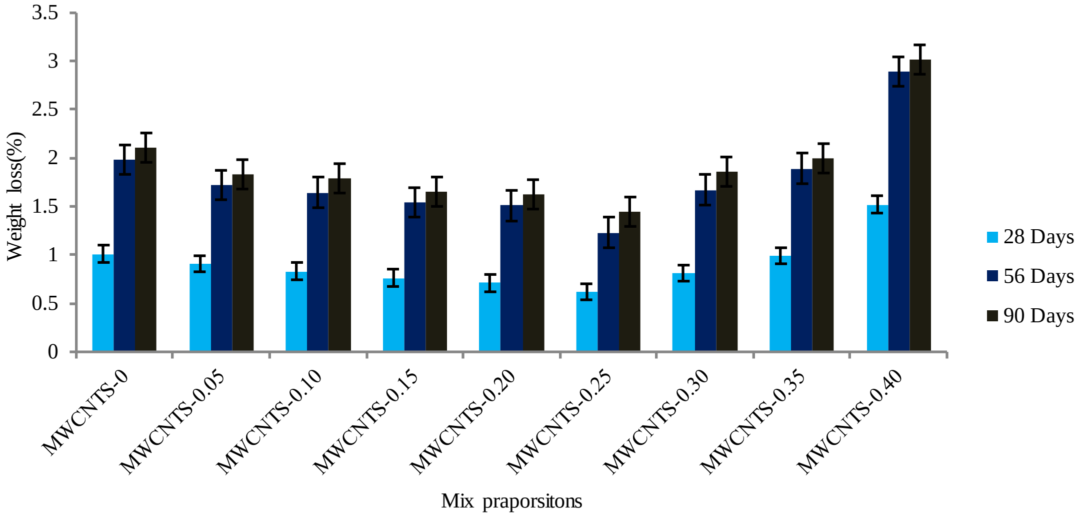

Figure 3 - weight loss due to sulphate attack for 28, 56 and 90 days

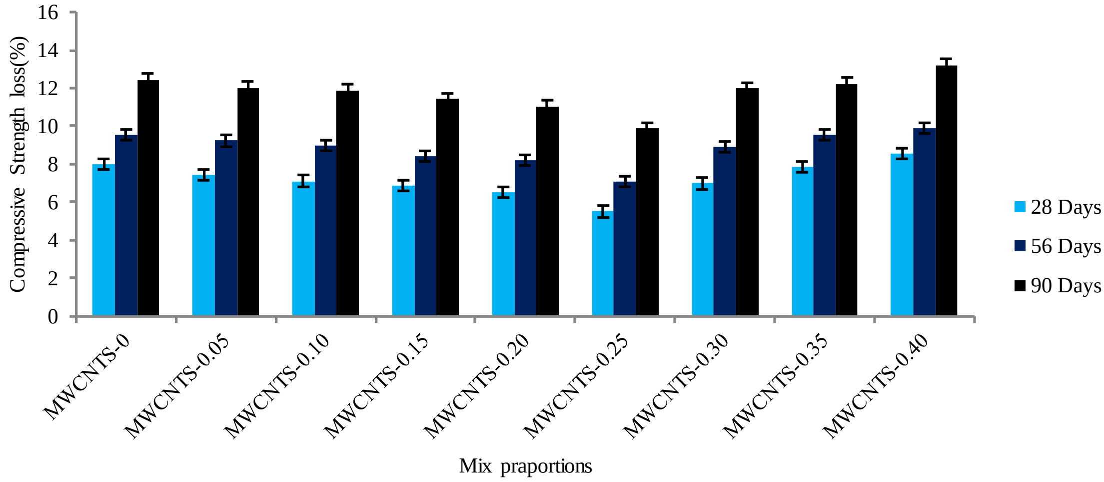

Figure 4- Strength loss due to sulphate attack for 28, 56 and 90 days.

3.3 *Chloride test*

Chloride test is used to find out the weight loss and strength loss of concrete specimens subjected to chloride attack. Concrete cubes of size 150 mm ×150 mm ×150 mm were immersed in water containing 5 % of NaCl [36] by weight of water, after a curing period of 28 days. Periodic measurement of weight and compressive strength of the test specimens were obtained for 25, 56 and 90 days respectively. The loss in the weight and strength of the test specimens in comparison with the specimens not subjected to chloride test gives the measurement of chloride attack on concrete.

3.3.1 *Weight loss due to chloride attack*

In this study all the specimens were subjected to 5 % of chloride solution. After 28 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.53 Kg, 8.31 Kg, 8.63 Kg, 8.49 Kg, 8.47 Kg, 8.43 Kg, 8.62 Kg, 8.52 Kg and 8.62 Kg as given in Fig-5 and undergone a percentage weight loss of 0.34 %, 0.29 %, 0.27 %, 0.22 %, 0.20 %, 0.19 %, 0.21 %, 0.29 % and 0.47 % respectively.

After 56 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.63 Kg, 8.50 Kg, 8.57 Kg, 8.72 Kg, 8.39 Kg, 8.61 Kg, 8.66 Kg, 8.56 Kg and 8.41 Kg and undergone percentage weight loss of

0.68 %, 0.55 %, 0.51 %, 0.47 %, 0.42 %, 0.38 %, 0.44 %, 0.58 % and 0.77 % respectively.

After 90 days of immersion the specimens are MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed as 8.38 Kg, 8.61 Kg, 8.38 Kg, 8.59 Kg, 8.44 Kg, 8.67 Kg, 8.49 Kg, 8.55 Kg and 8.38 Kg and undergone percentage weight loss of 0.79 %, 0.64 %, 0.60 %, 0.58 %, 0.52 %, 0.47 %, 0.62 %, 0.69 % and 0.68 % respectively.

3.3.2 *Strength loss due to chloride attack*

After 28 days of chloride attack , compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 51.84 Mpa, 57.90 Mpa, 60.75 Mpa, 64.70 Mpa, 68.23 Mpa, 73.62 Mpa, 61.62 Mpa, 55.94 Mpa and 48.01 Mpa as given in Fig-6 and its equivalent percentage strength loss in compressive strength were noted as 7.99 %, 7.45 %, 7.11 %, 6.86 %, 6.32 %, 5.51 %, 6.99 %, 7.87 % and 8.57 % respectively.

After 56 days of chloride attack, compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 53.22 Mpa, 59.43 Mpa, 62.69 Mpa, 67.04 Mpa, 69.25 Mpa, 75.15 Mpa, 63.95 Mpa, 56.90 Mpa and 47.58 Mpa and its equivalent percentage strength loss in compressive strength were noted as 7.12 %, 6.86 %, 6.43 %, 6.02 %, 5.79 %, 4.42 %, 6.30 %, 7.01 % and 7.55% respectively.

After 90 days of chloride attack, compressive strength for MWCNTs-0, MWCNTs-0.05, MWCNTs-0.10, MWCNTs-0.15, MWCNTs-0.20, MWCNTs-0.25, MWCNTs-0.30, MWCNTs-0.35 and MWCNTs-0.40 were weighed and noted as 52.34 Mpa , 58.97 Mpa, 61.84 Mpa, 65.72 Mpa, 67.95 Mpa, 76.63 Mpa, 63.57 Mpa, 55.55 Mpa and 47.29 Mpa and its equivalent percentage strength loss in compressive strength were noted as 9.87 %, 9.54 %, 9.01 %, 8.59 %, 8.21 %, 6.01 %, 8.57 %, 9.98 % and 10.23 % respectively.

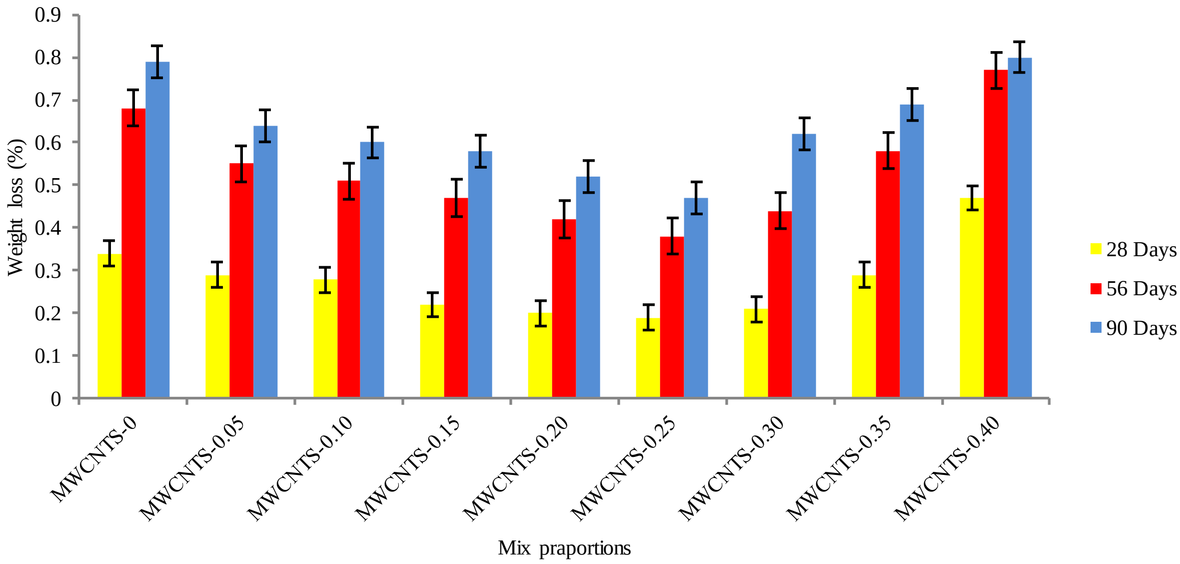

Figure 5- weight loss due to chloride attack for 28, 56 and 90 days.

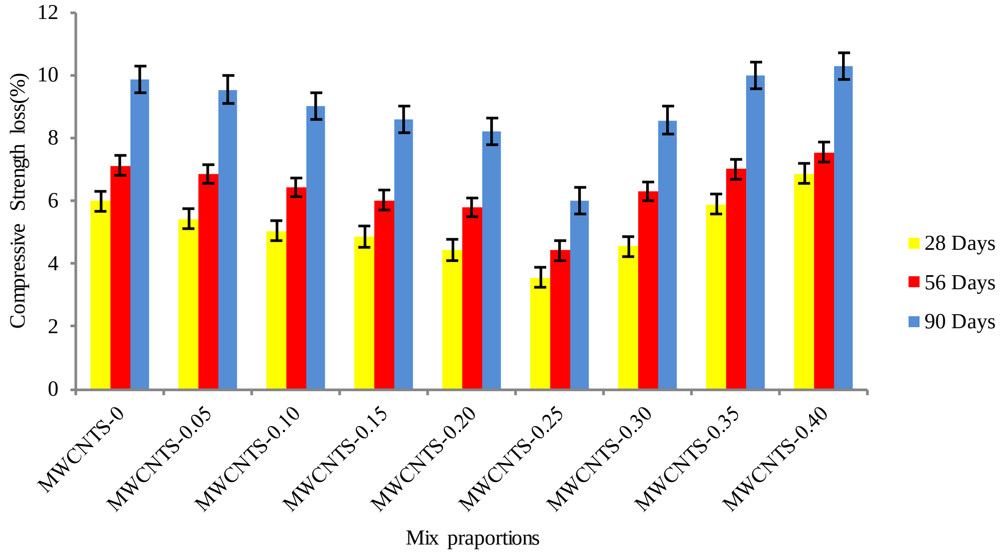

Figure 6- Strength loss due to chloride attack for 28, 56 and 90 days

3.4 *Water permeability test*

In this test, the depth of penetration of water in concrete under pressure can be measured. The procedure is to immerse concrete cube specimens inside water under a pressure of 0.5 Mpa for a period of 72 hours, after which the specimen is split into two halves, and to measure the average depth of wet profile inside the sample due to penetration of water. A high value of depth corresponds to higher permeability and thereby measuring less durability of concrete [37]. Water permeability test results are given in Fig-7. Test results show the less penetration depth in MWCNTs-0.25 for all the ages and higher penetration depth shows in MWCNTs-0.40 for all the ages.

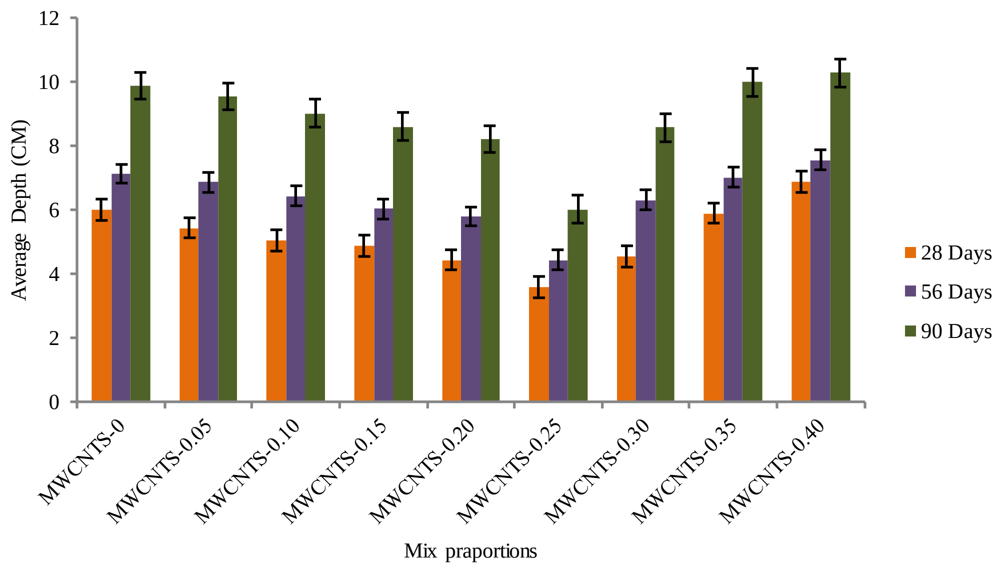

Figure 7- Water permeability results for 28, 56 and 90 days.

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4 CONCLUSIONS

Based on the results and discussion on durability properties of concrete influenced by Multiwalled Carbon Nanotubes (MWCNTs), the following conclusions were made:

Based on the results and discussions on the durability characteristics of concrete along with MWCNT it can be concluded that the addition of MWCNT enhances the behavior and durability aspects of concrete considerably until the certain limit of additions. Through the mechanical behavior and durability tests, it was identified that the concrete increases its strength and resistance when 0.25% of MWCNT addition is made. The results suggest that the specimens with 0.25% of addition resist the penetration of chloride, sulphate, acid, and water. The specimens consisting of more than the stipulated value losses its integrity and strength, this will have an effect on the longevity of MWCNT admixed concrete. The addition of MWCNT should be limited to 0.25%, after which the concrete losses its strength. From the results, it is concluded that the addition of MWCNT increases the performance of concrete. Thus 0.25% is the best-preferred usage to manufacture a concrete of high durability.

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REFERENCES

1. Yu, M.F., Lourie, O., Dyer, M.J., Moloni, K., Kelly, T.F. and Ruoff, R.S., Strength and breaking mechanism of multiwalled carbon nanotubes under tensile load. *Science*, *287*(5453), 2000, pp.637-640.
2. Filleter, T., Bernal, R., Li, S. and Espinosa, H.D., Ultrahigh strength and stiffness in cross-linked hierarchical carbon nanotube bundles. *Advanced Materials*, *23*(25), 2011, pp.2855-2860.
3. Musso, S., Tulliani, J.M., Ferro, G. and Tagliaferro, A., Influence of carbon nanotubes structure on the mechanical behavior of cement composites. *Composites Science and Technology*, *69*(11-12), 2009, pp.1985-1990.
4. Ando, Y., 1994. The preparation of carbon nanotubes. *Fullerenes, Nanotubes, and Carbon Nanostructures*, *2*(2), pp.173-180.
5. Li, X., Cao, A., Jung, Y.J., Vajtai, R. and Ajayan, P.M., Bottom-up growth of carbon nanotube multilayers: unprecedented growth. Nano letters, 5(10), 2005, pp.1997-2000.
6. Musso, S., Porro, S., Giorcelli, M., Chiodoni, A., Ricciardi, C. and Tagliaferro, A., Macroscopic growth of carbon nanotube mats and their mechanical properties. Carbon, 45(5), 2007, pp.1133-1136.
7. Thostenson, E.T., Ren, Z. and Chou, T.W., Advances in the science and technology of carbon nanotubes and their composites: a review. Composites science and technology, 61(13), 2001,pp.1899-1912.
8. Andrews, R., Jacques, D., Qian, D. and Dickey, E.C., Purification and structural annealing of multiwalled carbon nanotubes at graphitization temperatures. Carbon, 39(11), 2001, pp.1681-1687.
9. Musso, S., Giorcelli, M., Pavese, M., Bianco, S., Rovere, M. and Tagliaferro, A., Improving macroscopic physical and mechanical properties of thick layers of aligned multiwall carbon nanotubes by annealing treatment. Diamond and Related Materials, 17(4-5), 2008, pp.542-547.
10. Saez de Ibarra, Y., Gaitero, J.J., Erkizia, E. and Campillo, I., 2006. Atomic force microscopy and nanoindentation of cement pastes with nanotube dispersions. Physica Status solidi (a) 203(6), 2006, pp.1076-1081.
11. Gay, C. and Sanchez, F., Performance of carbon nanofiber–cement composites with a high-range water reducer. Transportation Research Record, 2142(1), 2010 pp.109-113.
12. Kumar, S., Kolay, P., Malla, S. and Mishra, S., Effect of multiwalled carbon nanotubes on mechanical strength of cement paste. Journal of Materials in Civil Engineering, 24(1), 2011, pp.84-91.
13. Jin, F.L. and Park, S.J., A review of the preparation and properties of carbon nanotubes-reinforced polymer composites. Carbon letters, 12(2), 2011, pp.57-69.
14. Saafi, M., Andrew, K., Tang, P.L., McGhon, D., Taylor, S., Rahman, M., Yang, S. and Zhou, X., Multifunctional properties of carbon nanotube/fly ash geopolymeric nanocomposites. Construction and Building Materials, 49, 2013, pp.46-55.
15. Yazdanbakhsh, A., Grasley, Z.C., Tyson, B. and Al-Rub, R.A., Carbon nano filaments in cementitious materials: some issues on dispersion and interfacial bond. Special Publication, 267, 2009, pp.21-34.
16. Tyson, B.M., Abu Al-Rub, R.K., Yazdanbakhsh, A. and Grasley, Z., Carbon nanotubes and carbon nanofibers for enhancing the mechanical properties of nanocomposite cementitious materials. Journal of Materials in Civil Engineering, 23(7), 2011, pp.1028-1035.

17. Al-Rub, R.K.A., Ashour, A.I. and Tyson, B.M., On the aspect ratio effect of multi-walled carbon nanotube reinforcements on the mechanical properties of cementitious nanocomposites. Construction and building materials, 35, 2012, pp.647-655.
18. Sobolkina, A., Mechtcherine, V., Khavrus, V., Maier, D., Mende, M., Ritschel, M. and Leonhardt, A., Dispersion of carbon nanotubes and its influence on the mechanical properties of the cement matrix. Cement and Concrete Composites, 34(10), 2012, pp.1104-1113.
19. B. Wang, Z. Guo, Y. Han, T. Zhang, Electromagnetic wave absorbing properties of multi-walled carbon nanotube/cement composites, Construction and building materials, 2013.
20. Chuah, S., Pan, Z., Sanjayan, J.G., Wang, C.M. and Duan, W.H., Nano reinforced cement and concrete composites and new perspective from graphene oxide. Construction and Building Materials, 73, 2014, pp.113-124.
21. Hu, Y., Luo, D., Li, P., Li, Q. and Sun, G., Fracture toughness enhancement of cement paste with multi-walled carbon nanotubes. Construction and Building Materials, 70, 2014, pp.332-338.
22. Kim, H.K., Nam, I.W. and Lee, H.K., Enhanced effect of carbon nanotube on mechanical and electrical properties of cement composites by incorporation of silica fume. Composite Structures, 107, 2014, pp.60-69.
23. Siddique, R. and Mehta, A., Effect of carbon nanotubes on properties of cement mortars. Construction and Building Materials, 50, 2014, pp.116-129.
24. Taqa, A.G.A., Al-Rub, R.K.A., Senouci, A., Al-Nuaimi, N. and Bani-Hani, K.A., The effect of fiber geometry and interfacial properties on the elastic properties of cementitious nanocomposite material. Journal of Nanomaterials, 16(1), 2015, p.133.
25. Mohsen, M.O., Al-Nuaimi, N., Al-Rub, R.K.A., Senouci, A. and Bani-Hani, K.A., Effect of mixing duration on flexural strength of multi walled carbon nanotubes cementitious composites. Construction and Building Materials, 126, 2016, pp.586-598.
26. IS: 516-1959, Methods of Tests for strength of concrete. Bureau of Indian standards, New Delhi (1999).
27. Meyer, A.H. and Ledbetter, W.B., Sulfuric acid attack on concrete sewer pipe. Journal of the Sanitary Engineering Division, 96(5), 1970, pp.1167-1182. 28. Hughes, B.P, and Guest, J.E, Limestone and siliceous Aggregate Concretes subjected to sulphuric Acid Attack, Magazine of Concrete Research (London)30(102), Mar 1978, pp11-18.
29. Fattuhi, N.I, and Hughes, B.P, Effect of Acid Attack on Concrete with Different Admixtures or Protective Coatings, Cement and Concrete Research , 13(5), Sept 1983, pp.655-665.
30. Raju, P.S.N, and Dayaratnam, P, Durability of concrete Exposed to Dilute Sulfuric Acid, Building and Environment, 19(2), 1984, pp.75-79.
31. Kong, Hendrick, L, and Orbison, James G, Concrete Deterioation Due to Acid Precipitation , ACI Materials Journal , 84(2), Mar - Apr 1987, pp110-116.
32. Z.J.Li, Advanced Concrete Technology, JohnWiley&Sons, Hoboken, 2011.
33. Ouyang, W.Y., Chen, J.K. and Jiang, M.Q., 2014. Evolution of surface hardness of concrete under sulfate attack. Construction and Building Materials, 53, pp.419-424.
34. Mehta, P.K. and Burrows, R.W., 2001. Building durable structures in the 21 st century. Indian Concrete Journal, 75(7), pp.437-443.
35. Morsy, M.S., Alsayed, S.H. and Aqel, M., Hybrid effect of carbon nanotube and nano-clay on physico-mechanical properties of cement mortar. Construction and Building Materials, 25(1), 2011, pp.145-149.
36. Al-Gahtani, A.S. and Al-Saadoun, S.S., Influence of construction practices on concrete durability. Materials Journal, 86(6), 1989, pp.566-575.
37. Faella, C., Lima, C., Martinelli, E., Pepe, M. and Realfonzo, R., Mechanical and durability performance of sustainable structural concretes: an experimental study. Cement and Concrete Composites, 71, 2016, pp.85-96.