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Experimental Investigation on the Effect of Nano carbon Tube on Concrete Strength

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ABSTRACT

This work presents in evaluation regarding to the addition of CNTs dispersion in water ultrasound before its incorporation into concrete mass. The dispersion of carbon Nanotubes has been achieved by the use of carboxylate along with vigorous agitation by sonification. The various researches have reported varied results experimenting with different amounts of CNTs and different dispersion techniques leading to a conclusion that 0.02% to 0.5% additions of CNTs to cement enhance the properties greatly. Nanoparticles have filled the porosity of concrete, therefore reduced permeability and increased the concrete strength and its sustainability. In this research, the Nanocarbon tube for enhancing the physical properties was used. For the experimental work in this research, 5 control specimens 50 x 50 x 50 mm and 5 samples containing 0.03% Nanocarbon as a percentage of sand and cement, specimens were made based on ASTM C349. In addition, water absorption test, SEM tests, electrical resistance test which show the corrosion rate, and flexural strength tests were carried out on the control and 0.03% CNTs specimens. Considering the results obtained from the experiment, the 0.03% CNT multi-wall added to the mortar the compressive strength increased by 39%; the electrical resistance increased by 78%, and flexural strength increased by about 13%. This can be attributed to the dispersion of CNT in concrete and protecting concrete from progressive cracks. In other words, treated CNT in the composite concrete matrix, provided more surface connection due to high specific areas resulted transferring more forces, so they provided better connection, therefore preventing matrix surrounding from any micro-structures cracks of the samples, also improved properties greatly.

Keywords: concrete properties, carbon Nanotube, stability, compressive strength, microstructure.

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1. INTRODUCTION

Various researches for improving the qualities of concrete are carried out worldwide. More researches were concentrated on concrete compositions. Supplementary cementing materials such as micro-silica, fly ash, and slag is more common cement replacement materials. Nanomaterial is new developed materials in concrete. The nanomaterial causes improvement in concrete mechanical properties. Nano can react physically with porosity existed in concrete and chemically with hydrated cement. Due to the fact that concrete behavior is formed on a micro-scale, therefore, using Nanoparticles can play an important role in enhancing the properties of the concrete. Also, by producing new Nano with a high specific surface and using them in concrete as a composite material, compressive strength properties, durability, and quality can be improved. A research work by Marcondes et al. [1] Focused on the importance of performing the CNTs dispersion in water ultrasound before incorporation into the concrete mass. Three concrete mixtures were performed, one without CNTs (as control), one with previous, dispersion in water an additive using ultrasonic and other without dispersion. They were used multi-walled CNTs. 0.3% CNTs with respect to cement is used in each mixture. In their research, properties such as fluidity, compressive, tensile strength, and water absorption were analyzed. As a result, in the series test with and without CNTs dispersion with ultrasonic 37% and 17% in compressive strength increased respectively, in comparison with control samples. The tensile strength also increased by 17% and 19%, respectively. The water absorption by the addition of CNTs is reduced. Shubham [2] carried out a comprehensive investigation in the field of CNTs. The additions of CNT in small amounts that are up to 0.5%, and its effect on increasing durability, flexural strength, compressive strength, and reduced porosity was investigated. CNTs-cement composite is posed by the insolubility of CNTs in any aqueous and organic solvent ordinarily. The dispersion of CNTs has been achieved by use surfactants and other chemical compounds along with vigorous agitation by sonication. Addition 0.05% to 0.5% CNTs to mixtures have been suggested. Further research, epecially in the methods of dispersion, is required.

Tanvir et al. [3] have investigated the great potential of CNTs in the materials for repairing cracks. The applicability of multiwall CNTs reinforced cement composites as concrete repair materials have been evaluated in their study in terms of setting time, bleeding, and bond strength (slant shear) tests. As a result, the setting time of CNTs cement composites hardened quite more rapidly than normal cement mortar. No sign of bleeding observed in CNTs composite. Bleeding can adversely affect the overall strength and durability of repair material. At different ages 3, 7, and 28 days slant shear of CNTs composite test shows higher value than normal control plain concrete. Safety precaution and potential health hazards are recommended in testing and using CNTs in this paper.

The state of the art review by Araj Al et al. [4] was carried out research mainly on the structural performance of flexural and toughness of CNTs, and they mentioned that enhancing of 45% and 25% respectively. Also, they look at the high cost of producing CNT itself. The optimum of CNT was used as a weight of 0.25% of cement. Bryan [5] carried out a research on Carbon nanotubes (CNTs), and carbon nanofibers (CNFs) are quickly becoming two of the most promising nanomaterials because of their unique mechanical properties. The size and aspect ratio of CNFs and CNTs mean that they can be distributed on a much finer scale than commonly used micro reinforcing fibers. As a result, microcracks are interrupted much more quickly during propagation in a nano-reinforced matrix, producing much smaller crack widths at the point of the first contact between the moving crack front and the reinforcement. In this study, untreated CNTs and CNFs are added to cement matrix composites in concentrations of 0.1 and 0.2% by weight of cement.

Within the last few decades, researchers started testing discrete macro- to microfibers to control crack growth in cementitious materials (e.g., cement paste, cement grout, concrete) [6-11]. Recently, exceptional types of carbon nanofilaments have raised the interest of some concrete researchers because of their remarkable mechanical, chemical, electrical, and thermal properties, and excellent performance in reinforcing polymer-based materials [12, 13 and 14]. Experimental tests on CNFs have shown them to have a Young's Modulus as high as 400 GPa, with a tensile strength of 7GPa [15]. Alternatively, CNTs have an average Young's modulus around 1TPa, a tensile strength of 60 GPa, and an ultimate strain of 12% [16]. Although previous research has shown successful results in dispersing both CNTs and CNFs within aqueous solutions [17, 18 and 19], few of these techniques can be applied to cementitious materials because of the retarded (i.e., delayed) hydration of the cement paste caused by large quantities of surfactants [20].

Flexural strength is a mechanical parameter for brittle material, defined as a material's ability to resist deformation under load. When an object formed of a single material is bent, it experiences a range of stresses across its depth at the extreme fibers. Most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the beam fails is its flexural strength. The flexural strength found to be increased with the inclusion of CNTs when compared to the plain cement paste, but with a higher aspect ratio of CNTs, flexural strength found to be dependent on the concentration of CNT. Also, CNTs were found to be better than carbon fibers in enhancing flexure strength [21].

In this research work, a water absorption test, compression strength test, scan electron microscopic test, and flexural strength test were carried out on the control mix and 0.03% CNTs specimens. The tests procedure and the results are described.

2. MATERIALS AND METHODS

2.1. PERFORMANCE OF CARBON NANOTUBE IN CEMENT PASTE

Calcium Silicate Hydrate (C-S-H) is the most important product in cement hydration. Cement paste is formed from hydrated clinker and partially from non-hydrated. C-S-H hydrated is consists of about 50 to 60 percent of all hydrated cement paste. The surface area is 100 to 700m2/gr. This is tended to well-adhered particles together, also tends to attach to the hydration products with smaller lateral area or calcium hydroxide the clinker and sand, cement particles are attached together. The strength of calcium silicate, which hydrated, is based on the equation of Van der Waals. The size of gel voids or space between solid parts is about 18 angstrom (1nanometer =10 angstrom). Carbon Nanotube multi- walls the size is about 10 to 100 Nanometer, initially, CSH that their size is near carbon nanotube (CNT) is reacted. CNT absorbed the crystal hydroxide calcium and reducing the amount of them in concrete. These causes compaction the transition area and capillary holes and fill the voids in CSH gel, and concrete became more compact with low permeability concrete. Carbon Nanotubes has cylindrical microstructure, made up of rolled-up graphene sheets. The CNTs can be produced in various purities, usually containing 70 to 90% carbon. The carbon Nanotube of mainly two types of Single-walled CNT, having only one graphene sheet with dimensions ranging from 4nm to 10 nm and lengths several times than diameters and Multi-walled Nanotube having several layers with a diameter of 4nm to 100nm. Figure 1 illustrated the structure. The separations in MWCNT are of order 34nm. The ends can be capped by a half fullerene molecul.

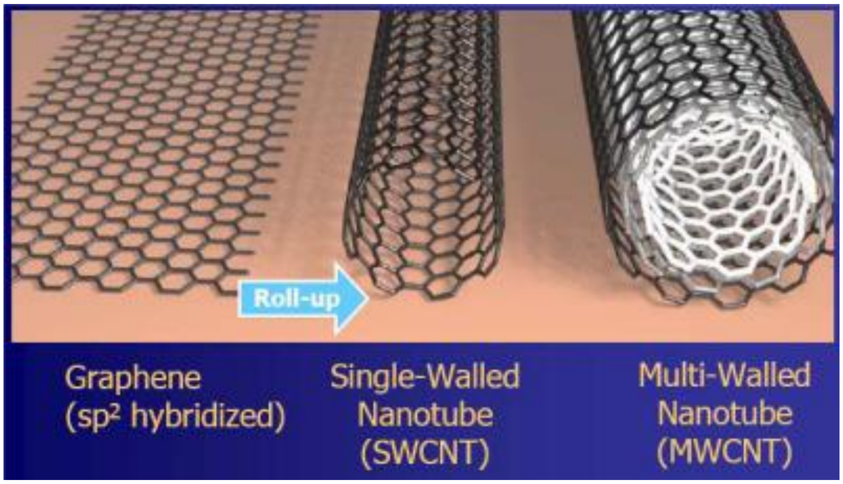

Figure 1. Representation of Single Walled and Multiwall Carbon Nanotube [6]

Using treated carbon nanotube and good dispersion technique in concrete mixes causes increasing compressive strength and epecially tensile and flexural strength of concrete and cement mortars. Because the carbon nanotube is grouped as COOH, they can be connected to CSH and calcium hydroxide shown in Figure 1. Figure 2 shows the chemical interaction between C-S-H gel and –COOH of Carbon Nanotube. CNTs might also act as nucleating sites of high stiffness C-S-H phases. Nanocarbon tube (CNT) provided a bridge cracking. The size of the Nanocarbon tube is very small, but the ratio of surface/diameter is very high. These causes bridge cracking.

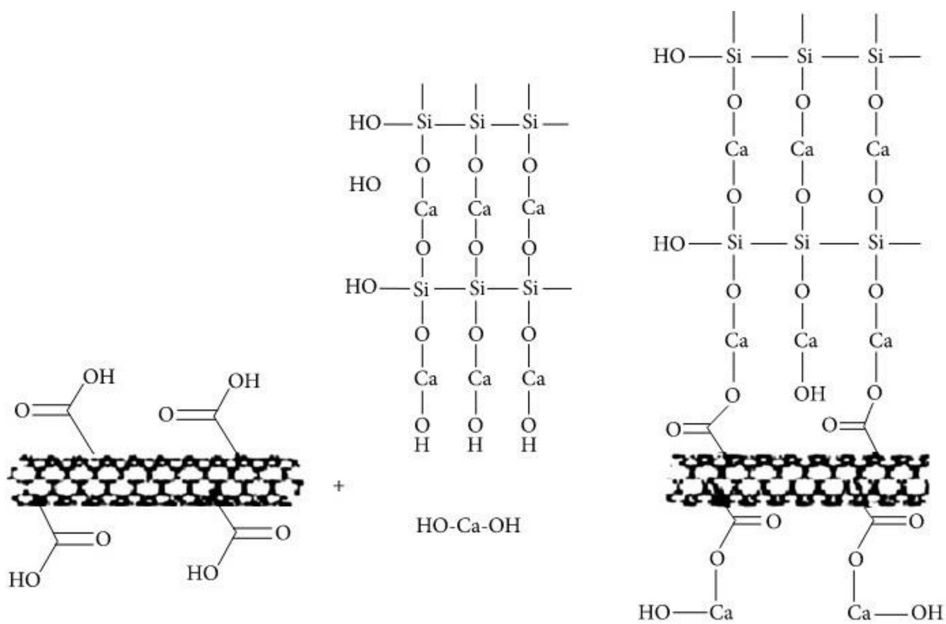

Figure 2. Interaction of –COOH and C-S-H gel [6]

The CNTs have characteristic same as water retarder, in the mix with low water/cement ratio, therefore is suggested to use super-plasticizer.

2.2. EXPERIMENTAL WORK

In this research, an ultrasonic bath EURONDA model made in Germany and a mixer ELE International made in England and humidity small room for control temperature and humidity made in Iran were used. The compressive test was carried out on the sample 50 x 50 x 50 mm concrete. The compressive test on mortars is based on standards, is carried out on this size of sample (50x50x50mm), as shown in Figure 3.

Figure 3. compression tests on 50mm cube

For comparison, two mixes have constructed the specimens contain CNT and a control specimen concrete. Type 5 cement (anti sulfate) with chemical characteristics is shown in Table 1.

Table 1. Chemical composition of cement used in this research

Cement Oxide	%
LOI	1.38
Na_2o	0.16
K2O	0.86
SO_3	2.76
MgO	1.56
CaO	63.75
Fe_2O_3	3.45
Al_2O_3	5.74
SiO_2	20.34

The river sand and CNT multi-wall treated carboxylic for uniform dispersion of water were provided by the laboratory research center Oil industry with characteristics given in Table 2. Water used in this experiment was drinkable water.

Table 2. The properties obtained from research center at Oil Company

characteristic	size
external diameter	10-20nm
length	10 µm
Ash %	0.2%
Purity	95%
Specific area	250-280 m2/g
Amorphous carbon	3%

2.3. MIXES DESIGN

In this research, the ratio of cement/sand was 1:3 (one part in weight cement and 3 part sand), and W/C ratio was 0.5. The details of the mixes are given in Table 3.

Table 3. Mix designed presented and environmental temperature at the time of casting specimens

Dimension (mm)	No. of sample	Sand gr	Cement gr	water gr	CNT gr	Temperature ºC	Type of cement	Density Kg/m3
50*50*50	5	600	200	100	-	24	5	2100
50*50*50	5	600	200	100	0.24	23	5	2100

The traditional mortars with cement/sand ratio of 1/3 and w/c=0.5 were used.

2.4. DISPERSION OF CNTS IN WATER

In case of dispersing CNTs in the concrete base was done properly, the mechanical characteristics are increased.
For this reason, CNTs Nanocomposite by 0.03% in weight of dry materials (cement and sand), is added to the water of the mix in 60 minutes in the ultrasonic bath with the frequency of 40 Hertz and dispersed uniformly.

2.5. THE CONDITION OF CURING SPECIMENS

After constructing the specimens, they kept in the humidity room at a relative humidity of 98% and temperature of 21ºC for 24 days. The specimens were removed after 24 days from the molds and again inserted in the humidity room for 28 days at temperature 21ºC immersed water. After curing, specimens were folded in a cotton sheet under laboratory conditions (temperature of 26ºC and relative Humidity (RH) of %25).
After elapsing the curing period, the compressive tests were carried out.

2.6 WATER ABSORPTION

The water absorption test is carried out based on ASTM C 642-97 [22]. The samples were dried in the oven for 24 hours at the temperature of 100-110 ºC and weighed, then samples were removed from the oven and kept in dry temperature to reach 20-25 ºC and again weighed (A). Then the dry specimens are saturated in water for 48 hours and weighed (B). Water absorption% = {[A-B]/A} x100
The result of this test is shown in Figure 6.

2.7 FLEXURAL STRENGTH TEST BASED ON ASTM C348-M08 [23]

Three points bending test on the specimens 4x4x16cm was carried out at age 28 days, as shown in Figure 4. The loading rate in this test was 9kN/s. Three control and 3 CNTs specimens were provided. The mix proportion was the same as the compression test given in Table 3.

Figure 4. Flexural strength test setup for concrete specimens

2.8. ELECTRICAL RESISTANCE OF CONCRETE

ASTM C1202-10 [24] standard was used to determine the electrical resistance of samples at 28 days of age. The apparatus used in this study to measure the electrical resistance of the specimens was a four-probe resistor called resisto-meter, which is a common tool for the electrical conductivity of concrete. The two end electrodes are used to inject current; the voltage is measured between the two inner electrodes. The effective length of the sample being measured is the distance between the two inner electrodes. Modern voltage meters draw very little current, so there is no significant current through the voltage electrodes, and hence no voltage drops across the contact resistances.

Concrete electrical resistance can provide good information about concrete resistance in the face of aggressive factors. The method of reading the numbers in this experiment was that three readings were made on each side of the sample, and the average obtained electrical resistance criterion was considered. How to read and use the device is illustrated in Figure 5.

Figure 5. Electrical resistivity meter and the method to use it

Correlation of electrical resistance of concrete with corrosion rate based on ASTM C1202-10 (Table 6) is presented to compare the results.

3. RESULTS AND DISCUSSION

For comparison between the control sample and composite samples (CNT), two mixes were used, each consisted of 3 samples; these samples were cured in a humidity room. Tests were carried out using an axial compressive test machine with rig speed of 0.8 kN/sec. The results are shown in Tables 4 and 5.

For abbreviation, the samples with cement and sand only (control) are known as “PC” and samples with carbon Nanotube or composite specimens are named as PCNT.

As shown in Tables 4 and 5, that mean ultimate strength at 28 days strength of PC and PCNT, is 37/3 MPa and 51.8MPa, respectively. Evaluation of the compressive strength shows 39% increases in the composite samples in comparison with control.

The water absorption test is shown in Figure 6. The water absorption in CNTs samples is about 18% lower than control. This reduction can be attributed to the effect of CNTs.

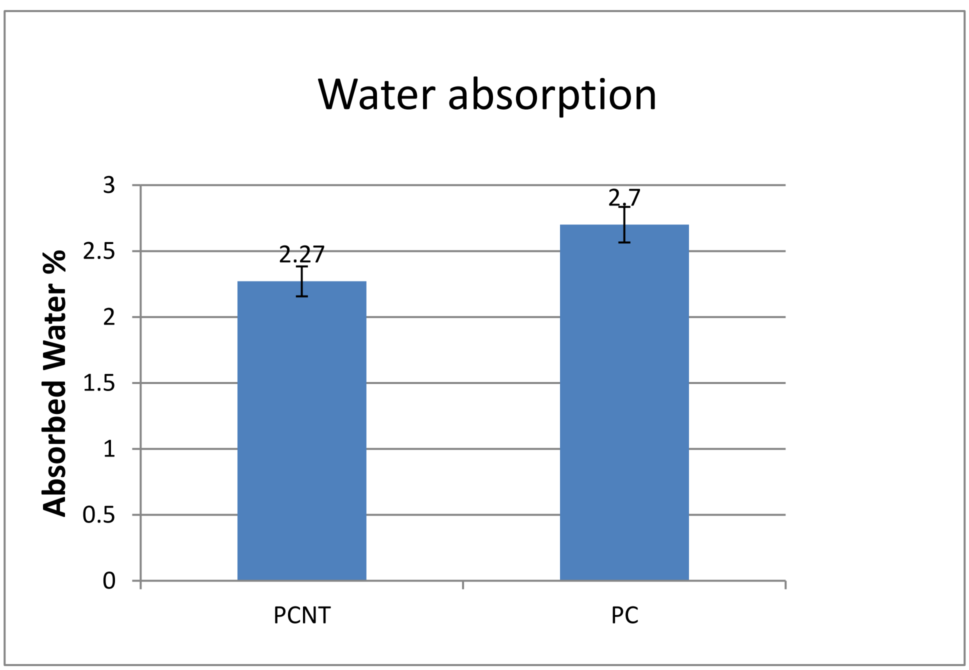

Figure 6. The water absorption test on control and 0.03% CNTs sample

Table 4. Results of compressive strength at 28 days-control specimens (PC)

Samples	Max compressive force (kN)	Max. compressive stress (MPa)	Laboratory temperature ℃	RH%
1	93.1	37.24	24	20
2	93.1	37.25	24	20
3	93.7	37.46	24	20
sum	279.9	111.95	-	-
Mean	93.3	37.3	-	-
Variance(SD)	0.24	0.1	-	-

Table 5. Results of compressive strength at 28 days specimens reinforced with %0.03 carbon nanotubes (PCNT)

sample	Max compressive Force (kN)	Max. compressive stress (MPa)	Laboratory temperature ℃	RH%
1	129.7	37.24	24	20
2	129.1	51.7	24	20
3	129.3	51.7	24	20
sum	388.1	155.3	-	-
mean	129.4	51.8	-	-
Variance(SD)	0.3	0.1	-	-

Considering the results obtained from the experiment, the 0.03% CNT multi-wall added to the mortar the strength increased by 39%, and this can be attributed to the dispersion of CNT in concrete and protecting concrete from progressive cracks. In other words, treated CNT in the composite concrete matrix, provided more surface connection due to high specific areas resulted transferring more forces, so they provided better connection, therefore preventing matrix surrounding from any damages.

In Figure 3, the results obtained from this research are summarized and compared with other similar research. In these researches, other supplementary cementing materials and other percentage used of CNT were compared by the results obtained by other researchers [5, 6, 7, 25].

As shown in Figure 3, the highest strength is obtained with 0.03% CNT. For analyzing this result, it can be mentioned that the viscosity of the solution of water-CNT (is higher than 4) after using ultrasonic dispersion technique [9], due to electromagnetic reaction between graphene sheets, the CNT particles were attached and formed as a group that their diameters are much more than CNT. This causes a significantly higher compressive strength, and the Nanometer voids are left emptied in concrete in the structure of concrete. Therefore the optimized addition used of multi-wall CNT is 0.03%. These results can be compared with the results obtained by another researcher, ie. Abbasi and Moghadam 2011 [21], as shown in Figure 3. The results can also be compared by Bryan et al. [5], which used 0.2% of CNT as the weight of cement. Other researchers such as Shubham Ashish Jha et al. [2] concluded 0.05 to 0.5% addition of CNTs to cement enhance the properties greatly. The results obtained by Marcondes et al. [1] give the amount of CNT added was 0.30% with respect to cement mass.

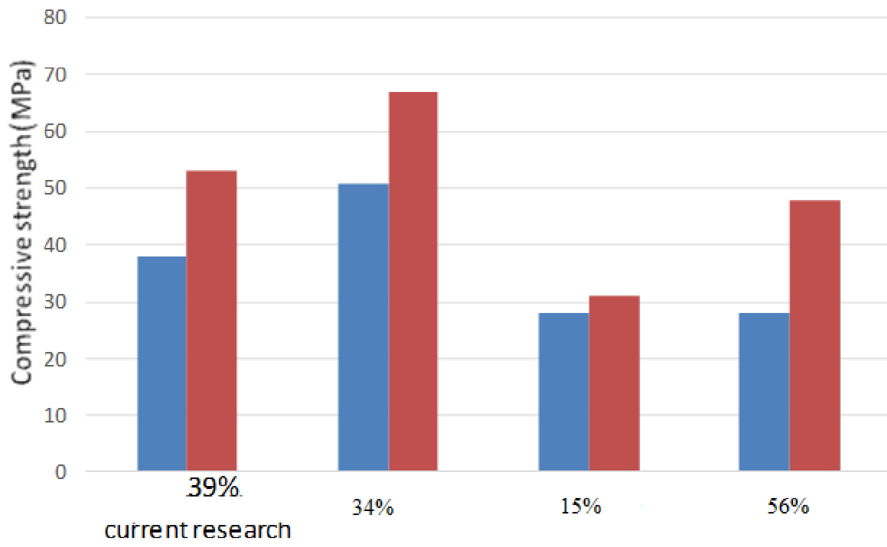

Figure 7. Comparison between compressive strength in various researches

As shown in Figure 3 for 0.03% CNT in this research, the increase of compressive strength is 39% in comparison with the control specimen, while for 0.02% and 0.5% adding CNTs, the strength increased by 34% and 15%, respectively. Also, the result is compared with concrete made by micro silica gel in concrete, which shows 56% strength increased.

3.1 Result from flexural strength tests is given in Table 6.

Table 6. Mean results of flexural strength test

Control	**3.70 MPa**
0.03% CNTs	**4.18 MPa**

As is given in Table 6, the 13% increase of flexural strength is obtained in 0.03% CNTs in comparison with control specimens. Also, this result can be compared by [21], which used 0.2% – 0.5% CNTs and increased flexural strength by 6%. 3.2 Result from the electrical resistance test is given in Table 7.

Table 7. Average results obtained from resisto-meter

Control	**49 Ω-m**
0.03% CNTs	**87 Ω-m**

Table 8. Influence of electrical resistance of concrete on reinforcement corrosion rate ASTM C1202-10

The corrosion rate	Electric resistance (Ω. m)
corrosion is unlikely	**ρ ≥ 120 Ω-m**
corrosion is possible	**ρ = 80 to 120 Ω-m**
corrosion is fairly certain	**ρ ≤ 80 Ω-m**

The results of this study show that with the addition of CNTs, the electrical resistance is increased, which may be due to the decrease in porosity and permeability of concrete, and the corrosion rate decreased. Therefore durability is enhanced.

3.1. SEM (SCAN ELECTRON MICROSCOPE) IMAGES

CNTs are nanoscale particles and can be effectively used as fillers for gaps and voids, resulting in more efficient reinforcement. Also, crack bridging has been observed in CNT-cement which inhibiting the crack propagation [Fig. 8A and. Fig. 8B].

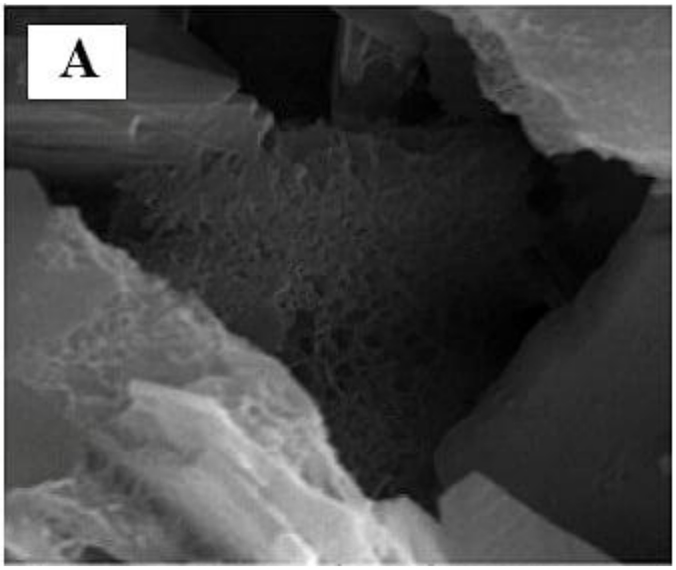

Figure 8. (A) The mode of failure of control mortar after compressive force

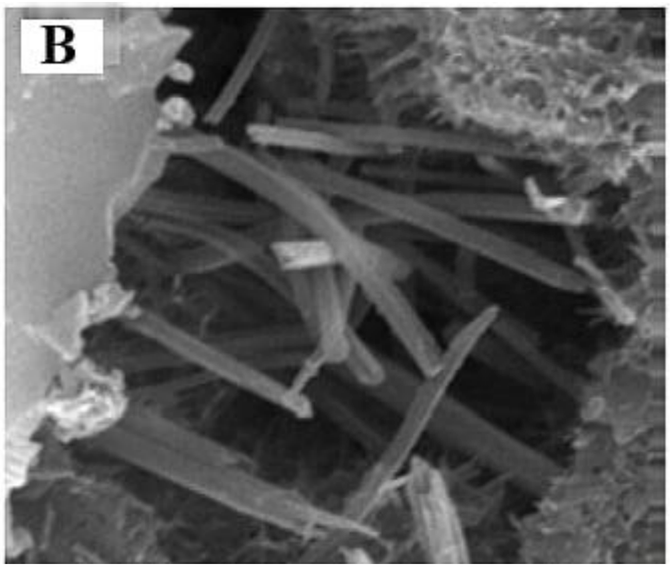

Figure 8. (B) The mode of failure of CNTs mortar after compressive force shows crack bridging effect of Carbon Nanotubes

4. CONCLUSION

In this research, the effect of multi-wall carbon Nanotube (MCNT) on mortar properties were investigated, and the following conclusion can be listed:

- A review of the research shows that the using CNT is in the laboratory research field at present, and may need more initial cost. Their positive effects on the strength concrete can cover this initial cost.
- This research is in the initial stage but, by doing more research in this field, more efficient concrete can be provided.
- Using CNT in concrete repair materials can be considered for further research.
- The absorbed water in CNTs specimens is reduced by about 18% in comparison with control samples, which show the effect of using CNTs.
- As is investigated in this paper, the application of CNTs reinforcement is useful (39% increasing compressive strength) and is required more research in the more suitable dispersion technique in this field.
- Results obtained from flexural strength show that the strength of the mortar mix by adding 0.03% CNT enhanced the strength in comparison with control specimens i.e., 3.70MPa to 4.18MPa.
- Results obtained from the electrical resistance test show, the corrosion rate in the CNTs samples is lower than the control specimen hence more durable.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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