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Improving the Performance of Conventional Concrete Using Multi-Walled Carbon Nanotubes

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Article

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Abstract (row height 0.8 cm)

Today, one of the main aspects of nanotechnology is its interdisciplinary nature and the interaction of this science with concrete science which can create a turning point in the construction industry. The goal of nanoscale concrete research is to discover a new generation of high-performance building materials with new and different properties than traditional materials. The present study aims to investigate and compare the mechanical and strength properties of cement concrete samples and concrete samples mixed with nanotubes. Also, the compressive strength changes in three mixtures with 0.045, 0.15, and 0.2 percentage of the nanotube to cement weight in the concrete matrix is another goal that was pursued in this study. By performing the necessary tests based on the relevant standards, different ratio of nanomaterials in the main concrete mix design were compared and analyzed. In all tests, better performance of nano concrete than cement concrete was observed. Averagely, at 90 days of age, a more than 30% increase in compressive strength in carbon nanotube concrete samples was recognized in comparison with the concrete control samples.

1. Introduction

Since the beginning of the 1980s, the range of design and construction of buildings has witnessed innovations in the field of more efficient and effective materials in strength, ductility, durability and greater ability to traditional materials. In recent years, the rapid development of science and technology, especially in the field of nanotechnology, has led to great changes in industry, environment and basic biological sciences. Removal of pollutants Remediation of contaminated soils and the like, nanotechnology is one of the new technologies that has important and valuable applications in various industries, including the construction industry.

Nanotechnology is the ability to fabricate, control and use matter in nanometer dimensions. The ratio of surface to high volume of nanomaterials is one of the most important characteristics of materials produced at the nanoscale. At this scale, the behavior of the surfaces dominates the behavior of the masses of matter. In the nanoscale, the laws of quantum physics make it possible to change the properties of matter, such as melting temperature, magnetic properties, and color.

Among these applications in the construction industry, we can mention the improvement of cement and concrete properties, the use of nanoparticles improves the mechanical properties and increases the quality of cement and concrete. Also, nanoparticles and nano-coatings prevent the penetration of external destructive agents into the concrete, which reduces durability and reliability and increases the rate of degradation. Applications of nanostructures in concretes include their use in high performance concretes and self-compacting concretes.

Carbon nanotubes are another admixture of concrete that, although they are about one-sixth the density of steel, have a yang modulus of 5 times and a strength of 8 times that of steel. The use of nanotechnology in the concrete industry dates back to recent years, since about 80 years ago, micron-sized silica has been widely used in cement-based concretes.

It has been proven that the use of finer particles than microsilica has increased the compressive strength of concrete. However, the lack of knowledge and poor understanding of the effect of fine particles and nanoparticles in concrete technology requires much research in this field.

Carbon nanotubes are made of carbon atoms one atom thick, in the shape of hollow cylinders, and were discovered in 1991 by Iijima (NEC of Japan). In the soot of electrically discharged carbon in an environment containing neon gas, Iijima discovered that these chemical compounds, with atomic structures similar to graphic plates, consisted of cylinders several nanometers in diameter and hundreds of micrometers in diameter.

Among the unique properties of carbon nanotubes, high modulus of elasticity (1200 GPa), and good tensile strength on the one hand and the carbon nature of nanotubes (Because carbon is a lightweight material, it is very stable and easy to perform processes that are cheaper to produce than metals.) have led to important research in the efficiency and productivity of nano in the last decade. The addition of these materials increases the resistance to chemical attacks, which in turn leads to the durability and stability of concrete. Another property of carbon nanotubes is that they can withstand very high bends without breaking.

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One of the most important benefits of carbon nanotube concretes is the reduction of concrete cracks. One of the purposes of these concretes is to eliminate the weaknesses of conventional or traditional concretes. Cracks will be in the early stages of concrete composites. The addition of these materials increases the resistance to chemical attacks, which in turn leads to the durability and stability of concrete. Other properties of this concrete can withstand very high bends without breaking. We compare the properties of carbon nanotubes with other concrete admixtures in the table below:

Table 1. Comparison of carbon nanotubes with other additives

	SWNT	DWNT	MWNT	VGCNF	Carbon Fibre	Zylon	Spectra	Kevlar 49	Steel fibers 0.1 %
Tensile Strength (GPa)	-	23-63	-	3-20	4-7	5.8	3.1	3.6-4.1	500-2000
Tensile Modulus (GPa)	640	-	1060	50-775	150-950	270	105	130	-
Elongation at break (%)	5.8	28	-	-	0.5-2.5	2.5	2.5	2.8	٥-٣٥%
Density (g/cm^3)	1.3-1.5	1.5	1.8-2.0	1.9-2.1	1.7-2.2	1.56	0.97	1.44	7۹00
Electrical Conductivity (S/m)	~10^6			5.5*10^4 to 9 * 10^5			<10^{-13}		-
Typical diameter	1 nm	~5 nm	~20 nm	60-100 nm	5-10 µm				0.3-0.7 mm

Previous studies have shown that small amounts of nanotubes can improve the desired resistances if they are effectively dispersed at the matrix surface. It can be noted that in order for nanotubes to have a beneficial effect on the mechanical properties of cement composites, their dispersion is very necessary.

In a study by malgorzata lelusz (2015), the effect of increasing carbon nanotubes on the compressive strength of concrete at 7 and 28 days of age was investigated.

The important point in this study is that if a small amount of nanotubes are effectively dispersed in the concrete matrix, they can significantly increase the flexural strength. It should be noted that even better results on compressive strength have been obtained. In this study, polycarboxylate (superplasticizer) and 1% by weight of CNT cement were used in weight percentages of 0.06% and 0.12%. The results of the samples are shown in the following figure:

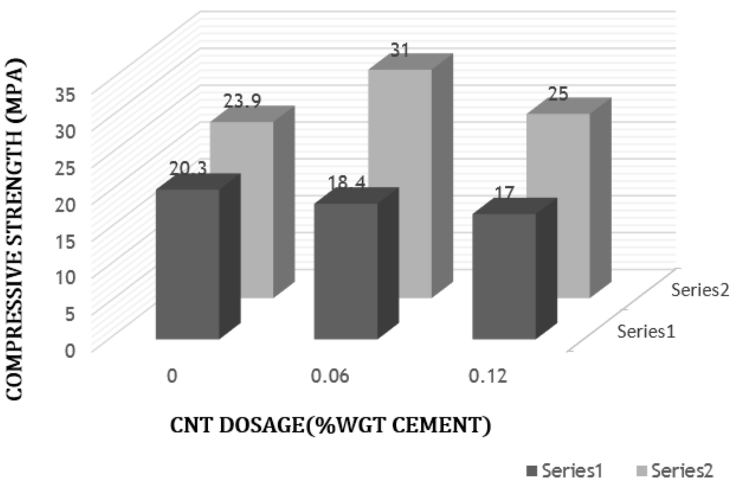

Figure 1: Compression strength diagram and percentage of carbon nanotubes

As shown in the diagram above, the compressive strength of the 7-day sample decreased by 0.06 and 0.12 percent of nanotubes. Meanwhile, the 28-day compressive strength of the samples was 0.06 and 0.12%, respectively, 29.7% and 4.6% higher than the compressive strength of concrete without nanotubes.

In a study conducted at the University of Ramapuram by a group of students, this study was performed on 36 concrete samples, some of which were ordinary concrete and 27 experimental samples containing concrete with multi-walled nanotubes. It is worth mentioning that surfactant (carboxylic) superplasticizer was used in the samples. The weight percentages of nanotubes are 0.015%, 0.03% and 0.045% according to the weight percentage of cement, M30 grade concrete used, 4.75 mm sieve sand and 20 mm coarse grains and 0.4 water to cement ratio. The increase in compressive strength of the 28-day sample with 0.045% nanotubes increased by 27%, while the tensile strength increased by 45%. Crack emission is reduced, and water uptake is reduced by 17%.

In a study conducted by A. Sobolkina et al. (2012), in addition to using short multi-walled nanotubes with a length to diameter ratio of 700, it led to a 35% increase in flexural strength. Using nanotubes with a length to diameter ratio of 1600 improved Similar mechanical properties were obtained.

The use of nanotubes with a concentration of 0.5% by weight of cement increased the compressive and flexural strength of mortar by 19% and 25%, respectively (Akhnoukh, A. K. , 2013).

In a study conducted by Abinayaa et al. (2014), The compressive strength of non-nanotube concretes was 18 MPa and that of nanotube concretes was 30.6 MPa. The following table shows the results of this experiment:

Table 2. Percentage of nanotubes and compressive strength

No	CNT % based on the composition mass	Average density (Kg/m^3)	Compressive strength (MPa)
1	0	330	18
2	0.05	309	30.6

The main purpose of this study was to investigate the changes in compressive strength and tensile strength of nanotube concrete, as well as cement concrete control samples that were processed without these fibers in similar conditions and times, which were finally compared.

Therefore, the main parameter that was examined is the compressive strength, which was considered in each of the mix-designs.

2. Materials and methods

2.1. Aggregates

In this research, mountain sand in Arak city has been used. The sand was also purchased from a well-known company in the form of granulation. In the case of coarse sand, it was first thoroughly washed and tested after drying.

2.2. Coarse aggregates

Granulation according to ASTM C136-849 was performed for mountain aggregate with a maximum dimension of 12.5 mm. The granulation curve is shown in the figure below:

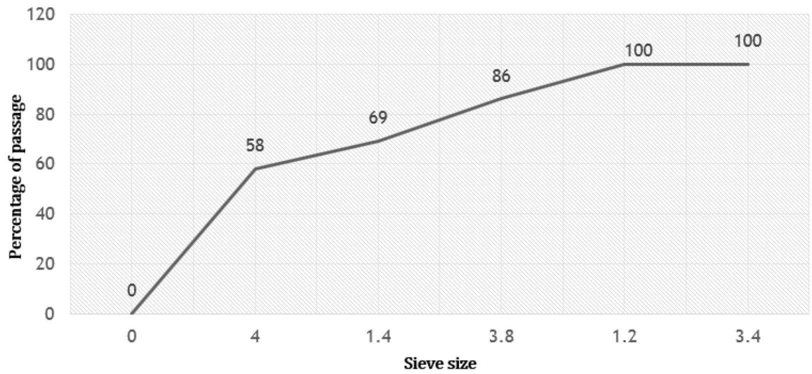

Figure 1. Coarse-grained curve

The specific gravity of coarse grain was 2.71 g/cm3 in accordance with ASTM C127-88. Coarse water uptake of consumed grains was 5.1%. The specific dry weight of crushed rods for sand was 1594 kg/m3, in accordance with ASTM C29-78.

2.3. Fine aggregates

The sand was prepared in granular form to meet the requirements of ASTM C33-84. In the figure below, you can see the prepared granulation sand.

Figure 2. Granulated fine aggregate

Specific gravity and water absorption of sand in accordance with ASTM C128-88 were 2.59 g/cm3 and 4.7%, respectively.

It should be noted that the experiments were performed with sand with SE=98.4 and a modulus of the softness of 2.79. The following table displays the percentage of coarse aggregate passing each sieve, for optimum aggregate gradation to a maximum of 12.5 mm after we see.

Table 3. Percentage of each sieve for optimal aggregate granulation

sieve (mm)	N											
	0.67	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1
12.5	100	100	100	100	100	100	100	100	100	100	100	100
9.5	83	84	85	86	87	88	89	90	91	92	92	93
6.35	62	65	67	69	71	73	75	77	78	80	82	84
4.75	51	54	56	58	61	63	66	68	70	73	75	77
2.38	31	34	36	39	42	44	47	50	53	56	59	62
1.19	18	21	23	25	27	30	33	35	38	41	45	48
0.6	10	12	14	15	17	19	21	24	26	29	32	35
0.3	5	6	7	8	10	11	13	14	16	18	20	22
0.15	2	3	3	3	4	5	5	6	7	8	9	11
Fineness modulus	5	4.86	4.76	4.66	4.52	4.4	4.26	4.13	3.99	3.83	3.68	3.52

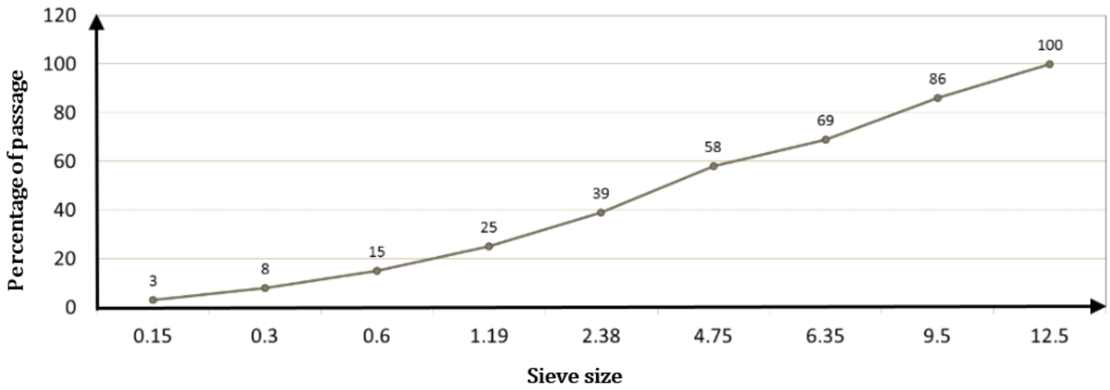

Figure 3. Aggregates' granulation curve

2.4. Carbon nanotube fibers

These fibers were prepared in powder form. The following figure shows an example of fibers.

Figure 4. Carbon nanotube fibers

2.5. Cement

In this study, Portland cement type 2 with a grain density of 3.1 g/cm^3 and with the specifications listed in the table below was used to make concrete samples.

Nanotube concrete is made like cement concrete. As nanotube powder does not homogenize with water, before the mixing process is done, the carbon nanotube powder would be homogenized with water in the ultrasonic bath for 30 minutes.

Table 4. Chemical characteristics of cement used

Ingredients	Percent	Ingredients	Percent
K_2O	0.6	SiO_2	20.9
Cl	0.013	Al_2O_3	5.5
Loi	0.93	Fe_2O_3	4.3
C_3S	60.8	CaO	65.02
C_3A	6	SO_3	1.8
C_4Af	13	MgO	1.02

After the nanotube powder is homogenized with water, cement will be added to the mixture. The reason for this is that the mixture of water and nanotubes must penetrate the cement particles. The materials are then poured in 3 to 4 layers in a mold that has already been well lubricated with oil on the inside surface, and vibrating operations are performed by rods and pounding. After filling the molds, we perform the surface polishing operation of the samples, then we place the samples in a metal mold and under plastic coatings for 24 hours in order to maintain the moisture of the concrete.

In this study, the ages of the samples are 7, 28, and 90 days. For example, for 7-day samples, on the seventh day, we take the sample out of the water and after the sample dries, we put it under the pressure jack device and perform the compressive strength test. The 28-day and 90-day samples were similarly taken out of the water one day before the test and stored in the laboratory. They were taken out of the water and tested for compressive strength testing. Nano-tube concrete samples are similar to cement concrete at the ages of 7, 28 and 90 days and are processed and tested under the same conditions. After 24 hours, the concrete samples are taken out of the mold and placed in a pool of water, and according to the desired age, the samples are taken out of the water and tested. Nano concrete samples were taken out of the mold after 24 hours and stored in the laboratory to be tested at a specified time.

The following mixing scheme is used for concrete with nanotubes:

Table 5. Design of experiments

Sample	Cement (kg)	Water (kg)	Water/cement	Coarse Aggregate (kg)	Fine Aggregate (kg)	CNTS
TCNT1	350	157.5	0.45	757	1045	0.045
TCNT2	350	157.5	0.45	757	1045	0.15
TCNT3	350	157.5	0.45	757	1045	0.20

Considering that in the present study, all compressive strength tests have been performed on cubic specimens (10×10×10 cm) and due to the existence of comprehensive information about the types of specimens, only the cubic specimen is described here.

3. Results and discussions

3.1. Compressive strength test and its results

For this experiment, cubic specimens measuring 10 x 10 cm at 7, 28 and 90 days of age were tested. It is worth noting that all samples were placed in the laboratory at about 25 ° C for 24 hours before being placed under the compressive strength jack.

The following table shows the results of 7, 28 and 90 days compressive strength tests.

Table 6. Compressive strength

Samples	**Compressive strength kg/cm^3**		
	90 days	28 days	7 days
CNT1	440	437	335
CNT2	535	470	337
CNT3	543	486	334
C	390	380	340

In the following bar charts, quantitative changes in the compressive strength of the samples at different ages can be seen.

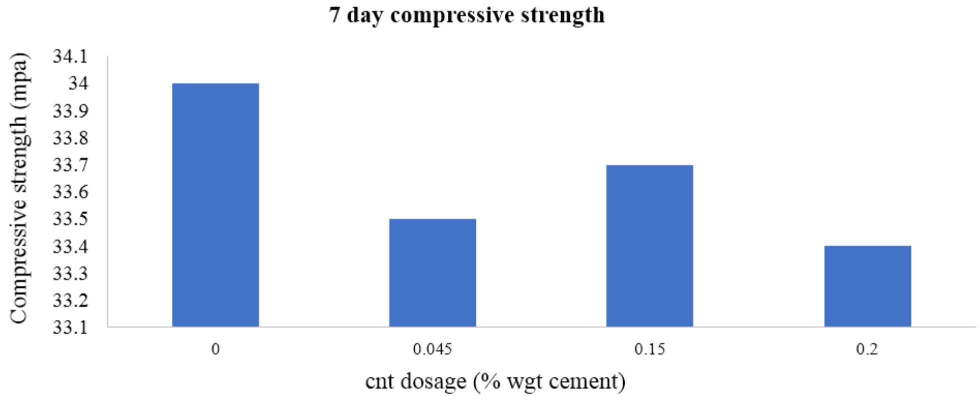

Figure 5: 7 day compressive strength diagram with different percentages of carbon nanotubes

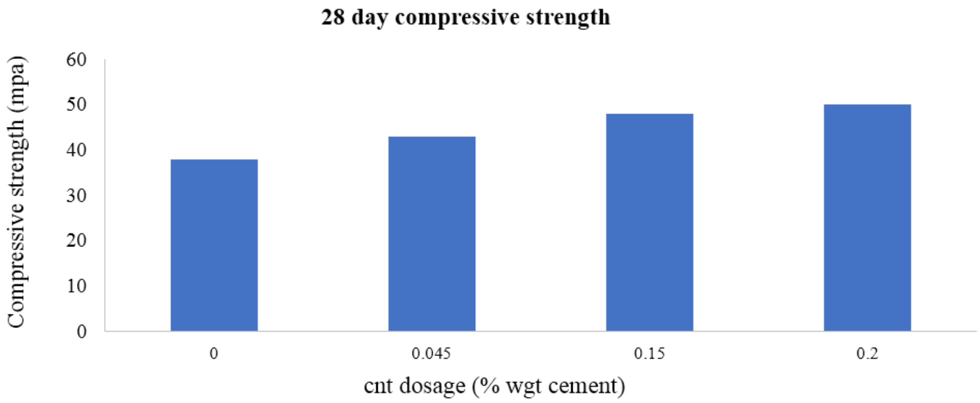

Figure 6: 28 day compressive strength diagram with different percentages of carbon nanotubes

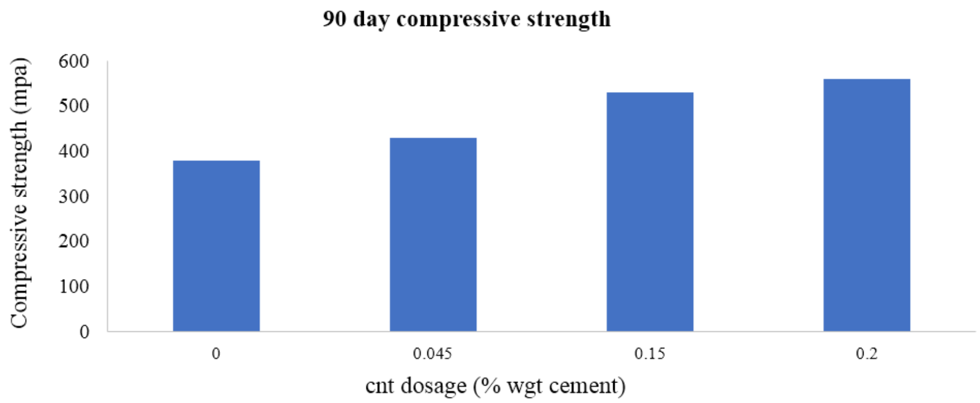

Figure *8*: 90 day compressive strength diagram with different percentages of carbon nanotubes

In the compressive strengths of 7-day samples with all 3 designs made (0.045, 0.15 and 0.2% of weight of cement), leads to decrease in compressive strength. In 28-day compressive strengths in 0.045, 0.15 and 0.2 design have 15%, 25% and 28% increase in compressive strength respectively. For 90-day compressive strengths in 0.045 design, almost 12% increase in compressive strength and in 0.15 design, 37% increase and for 0.2%, 40% increase in compressive strength of concrete samples is observed.

The test results show that nanotube concrete samples show higher performance over a longer period of time, and as it can be seen 90-day samples shows a significant increase compared to 28-day samples.

4. Conclusion

At 7 days of age, the lowest compressive strength was for cement concrete control samples.

At 28 and 90 days, the best performance was related to the concrete sample with carbon nanotubes with 0.15% of cement weight and 0.2% of nanotube cement weight and by considering the economic efficiency, the sample with 0.15% nanotube has the best performance.

It is worth mentioning that 90-day samples showed a significant increase in strength even compared to 28-day samples. It can be said that the reason for this increase in strength is the reactions that do not appear over time in the concrete samples.

Based on the results, it is clear that the carbon nanotubes have a significant impact over a longer period of time, so it is suggested that experiments be investigated over longer periods of time.

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