



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 5, May 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

 9940 572 462

 6381 907 438

 ijrset@gmail.com

 www.ijrset.com

Using the Carbon Nanotubes (CNTs) to Improve the Properties of the Concrete Rigid Pavement

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ABSTRACT: Concrete pavements are widely used to construct long-lasting roads as they provide a better distribution of load on the subgrade and allow a lower structural depth than flexible asphalt pavements. Especially for high axle loads, the option of concrete pavement is preferred because it has considerable flexural strength or flexural rigidity. On the other hand, heavy vehicles are primarily responsible for the pavement's deterioration. It damages highways that reflect their effect on their performance, lifetime, and fuel consumption.

This study discusses the effect of using carbon nanotubes as an advanced material to improve the mechanical properties and durability of rigid pavements. A series of experiments were carried out on the concrete mixes with various percentages of CNTs to determine the best cost and amount of CNTs. Compressive, tensile, and flexure strength characteristics were investigated.

KEYWORDS: Carbon Nanotubes (CNTs); Rigid Pavement; Concrete Pavement

I. INTRODUCTION

Rigid pavements have become urgent in recent years, as they need less maintenance and renovation than other types. Because of the importance of pavements everywhere in the world, a lot of money and effort is spent annually on their design, construction, repairs, and rehabilitation. Sometimes, while the pavement construction expense is low, the expense of maintenance is very high, and time is wasted due to regular resurfacing and replacement. And, because of depleting resources, it has become necessary to develop designs based on materials with higher stiffness along transportation system life. The design of pavements is mainly controlled by the need to withstand the forces of heavy vehicles.

To improve the performance of the pavement, it is important to adjust it with suitable modifications. Today, pavement innovations have focused on nanotechnology and found that nanocomposites have changed their efficacy by modifying pavement with nanomaterials.

Nanotechnology development has increased rapidly since 1990 in more fields such as science, construction, electronics, manufacturing, medicine, and energy. This is because of the special properties of materials on the nanoscale. The construction field may be one of these research's beneficiaries, with applications that improve the properties of concrete, steel, and isolating materials. Researchers have already put their interests in nanotechnology, and many studies have shown that nanomaterials significantly improve concrete mixture properties [1].

Nanotechnology started to change our views, perceptions, and ability to influence the material world. Nanotechnology can be classified as the science that deals with materials and devices with a small functional dimension on the nanometer scale, which is one billionth of a meter (10^{-9} m) [2]. The properties of the nanomaterial may differ greatly from the same

material's properties at the macro (10^{-6} : 10^{-3} m) or micro (10^{-6} m) scale. It is done by controlling the shape and size of the material's nanoscale [3].

When nanomaterials are mixed into portland-cement paste or concrete, they produce materials with distinct properties from ordinary materials. The performance of these cement-based materials is considerably influenced by Nano-sized solid calcium–silicate–hydrates (C–S–H) particles or nano-sized porosity at the cement–aggregate particle interface. Strength, durability, shrinkage, and steel bond are some of the characteristics affected by nano-sized particles [4].

Carbon nanotubes are a shaped carbon that has a cylindrical shape; their name comes from their nanometer diameter. Carbon cylinders are seamless and have unique electronic and mechanical characteristics. They may be several millimeters in length and may have one "layer" or wall (single-walled nanotube) or more than one wall (multi-walled nanotube) [5].

CNTs have unusually high strength and stiffness and are chemically stable and electrically conductive. These characteristics make using CNTs desirable for constructing composite materials based on various matrices [6], [7]. The impact of CNT addition to cement-based materials has been investigated in recent years. However, some of the literature results are conflicting [8]. Several CNT-based constructions have recently been investigated [9]–[11] due to their unique characteristics (mechanical and magnetic properties; high electronic; high aspect ratios, etc.), which are cylindrical rolled-up carbon atom sheets [12]. However, there are few examples of practical applications. CNTs mixed with ordinary Portland cement (OPC) provide good mechanical characteristics but fragility in tension [13].

According to Hassan et al. [14], adding CNTs into concrete resulted in an increase in the specimens' compressive and tensile strengths relative to the control specimens made of regular concrete, with increases ranging from 7 to 20% and from 10 to 20%, respectively. These specimens' study using scanning electron microscopy revealed that the CNT specimen is well-structured and distributed in comparison to the control specimen. This confirms that CNTs operate as bridges across microcracks, which is beneficial to increase the bond ability. At normal temperatures, CNT significantly increased the load-bearing capacity and ductility index of concrete, which in turn increased the flexure strength [15], [16].

Konsta-Gdoutos et al., 2010 [17] studied the development of high-performance cemented nanoparticles supported with multiwall carbon nanotubes (MWCNTs). It was observed that small quantities of effectively distributed MWCNTs (0.025–0.08% by wt. of cement) would increase the strength and rigidity of the cement matrix significantly as lower quantities of long MWCNTs (0.025–0.08% by wt. of cement) provide effective reinforcement. In comparison, higher quantities of short MWCNTs (close to 0.08%) are needed to achieve the same reinforcements. The nano indentation results indicate that MWCNTs can greatly modify and improve cementitious matrix nanostructure compared to plain cement matrix because of their small diameters (20–40 nm); the MWCNTs appear to reduce the number of fine pores in particular. These phenomena contribute to a decrease in capillary stresses, which benefits the nano composites' early strain ability.

The impact of CNTs on the properties of microencapsulated phase-change materials (MPCM) cement paste has been evaluated. Evaluation results indicated that adding CNTs in MPCM cement paste accelerated the cement hydration reaction. The SEM micrograph revealed that CNTs had been closely bound to cement hydration materials. The percentage rise in flexural and compressive strength with various dosages of CNTs was observed to be up to 41% and 5%, respectively, at 28 days. It was observed that the optimal dose of CNTs used in MPCM cement paste was 0.5 wt. % [18].

The use of CNTs ferrocement improved the general performance of the beams containing small openings by raising the ultimate load to 17%, improving ductility by roughly 45%, and decreasing crack width and deflections [19].

According to Musso et al. 2009 [20], mortar modification with functionalized CNTs (0.5 % by cement weight) decreased compressive strength by approximately 80 % and rupture modulus by approximately 60 %. The different effects of CNT

additives on cement materials' mechanical efficiency can be explained by the various CNT type, quantity choices, and nanotube dispersion methods [8].

In this study, CNTs was used to the concrete rigid pavement mix in order to reach the best mechanical properties of the cement mortar of rigid pavement slab.

II. RESEARCH OBJECTIVE

The purpose of this study is finding the optimal CNTs content that will enhance the behaviour of the concrete mix as a whole to enhance the performance of concrete pavement by adding different ratios of CNTs into the mix.

III. MATERIALS PROPERTIES

To meet the aim of this investigation, a series of experiments were set up to determine the suitable CNTs content that will enhance the mechanical characteristics of rigid concrete pavement .

Type II ordinary Portland cement was used in all the mixtures considered in this work. Table 1 illustrates cement's physical and mechanical characteristics. The concrete mix prepared in this investigation consists of cement, sand as a fine aggregate, and basalt as a coarse aggregate, as seen in Figure 1.

Table 1. Ordinary Portland cements Properties.

Element	Property	Element	Property
SiO ₂	21.20%	MgO	2.39%
Al ₂ O ₃	4.52%	SO ₃	2.80%
Fe ₂ O ₃	3.60%	Na ₂ O	0.36%
CaO	61.63%	K ₂ O	0.21%
Initial setting time (min)		97.00	
Final setting time (min)		193.00	
Compressive strength (7-days)		35.0 N/mm ²	
Compressive strength (28-days)		52.5 N/mm ²	



Figure 1. Concrete mix components

Sieve analysis of the aggregates used in this investigation is presented in Figure 2. The maximum aggregate size of basalt used is 19mm. A specific gravity test was carried out on the aggregate used, as seen in Figure 3, and the test results of both fine and coarse aggregates are presented in Table 2. Potable fresh water is used. Carbon nanotubes (CNTs) in sizes of 8-22 nm diameters were used in this study. Figure 4 illustrates the appearance of CNTs before and after dissolved in water and the micrograph of this material.

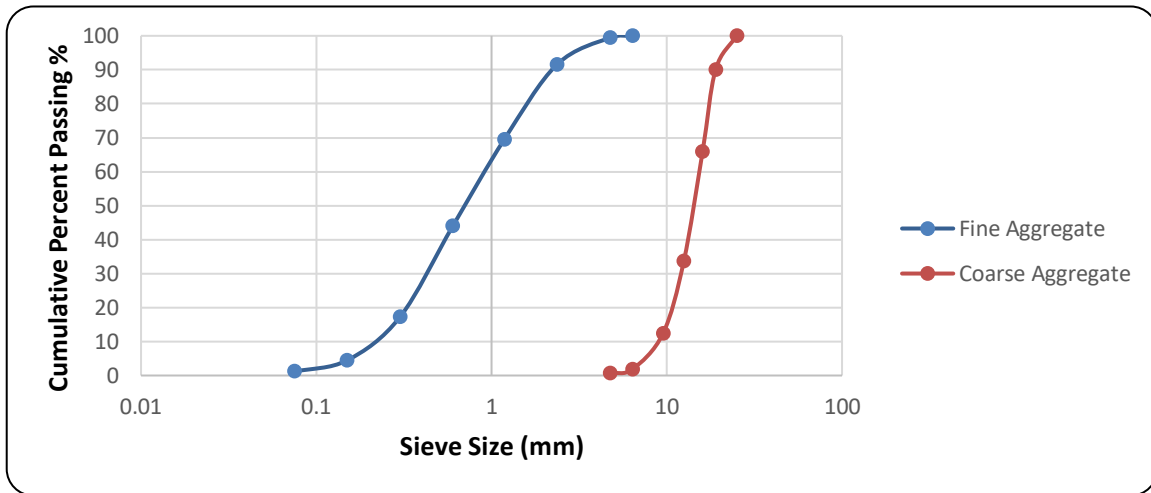


Figure 2. Sieve analysis of the fine and coarse aggregates

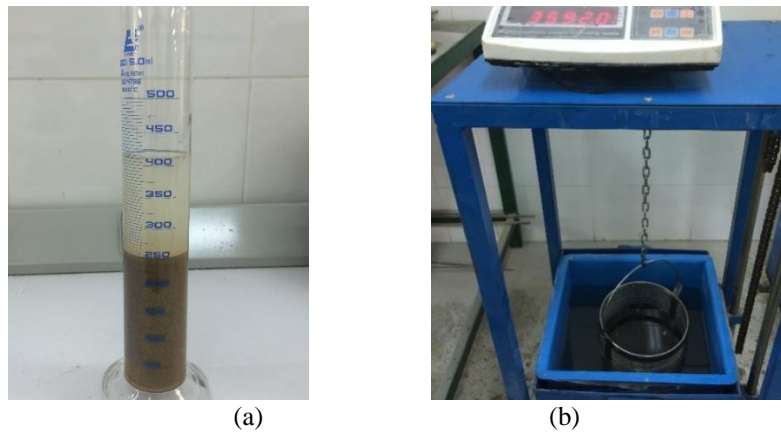


Figure 3. Specific weight of (a) coarse aggregate and (b) fine aggregate

Table 2. Specific gravities and absorption of coarse and fine aggregates

SG (g/cm ³)	Coarse Agg.	Fine Agg.
Relative SG (OD)	2.67	2.65
Relative SG (SSD)	2.70	2.69
Apparent SG	2.77	2.75
Absorption	1.82%	1.48%

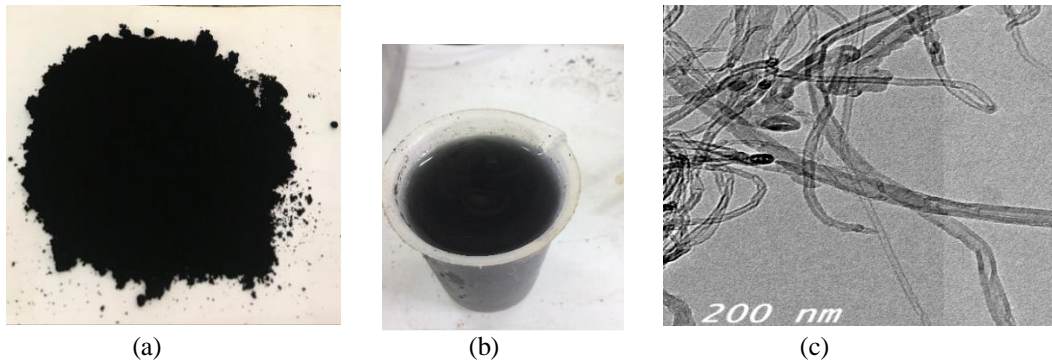


Figure 4. CNTs (a) Powder and (b) Dissolved in Water, and (c) CNTs Micrograph

The dry components of the mixture were blended for 2 minutes in a laboratory mixer with a 0.125 m³ capacity, shown in Figure 5. The CNTs ratio was dissolved in 150 mm of the required amount of water for the dispersion and removed surface tension forces, using a magnetic stirrer, and mixed with the dry contents. The remained water was added, and the mixing continued for another 2 min. Table 3 presented the amounts of additives in the mix.



Figure 5. Specimen Preparation

Table 3. Proportions of the Control Mix

Cement (kg/m ³)	Water (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	F _{cu} (MPa)
350	175	600	1200	25

IV. TESTING SPECIMENS

According to ASTM C 496 [20], twelve concrete cubes measuring 100 mm, twelve cylinders measuring 100 mm* 200 mm, and twelve beams measuring 100 mm* 100 mm* 500 mm were cast to test the concrete's compressive, tensile, and flexure strengths after 28 days. Four mixes were prepared, a control mix and three mixes containing CNTs with different percentages, 0.025%, 0.050%, and 0.075%, by the cement weight.

The workability of the fresh concrete was measured with a standard slump cone using the slump test according to ASTM-C 143 [23]. Figure 6 shows the slump test, and Table 4 presents the results. Figure 7 shows the test samples after preparation.



Figure 6. Slump Test

Table 4. Slump Test Results for The Mixture

CNTs %	0	0.025%	0.050%	0.075%
slump value (mm)	37	29	11	18



Figure 7. Test Samples

V. RESULTS AND DISCUSSION

The specimens were examined for compressive, tensile, and flexure strength using 1000kN universal testing equipment. Table 5 and Figure 8 illustrate the test results after 28 days.

Table 5. The results of the compressive, tensile and flexure strength of concrete

Concrete Type	Compressive Strength (MPa)	Tensile Strength (MPa)	Flexure Strength (MPa)
Control	25.1	2.3	9.2
0.025% CNTs	26.7	2.65	10.94
0.050% CNTs	29.6	2.79	11.8
0.075% CNTs	29.5	2.81	11.3

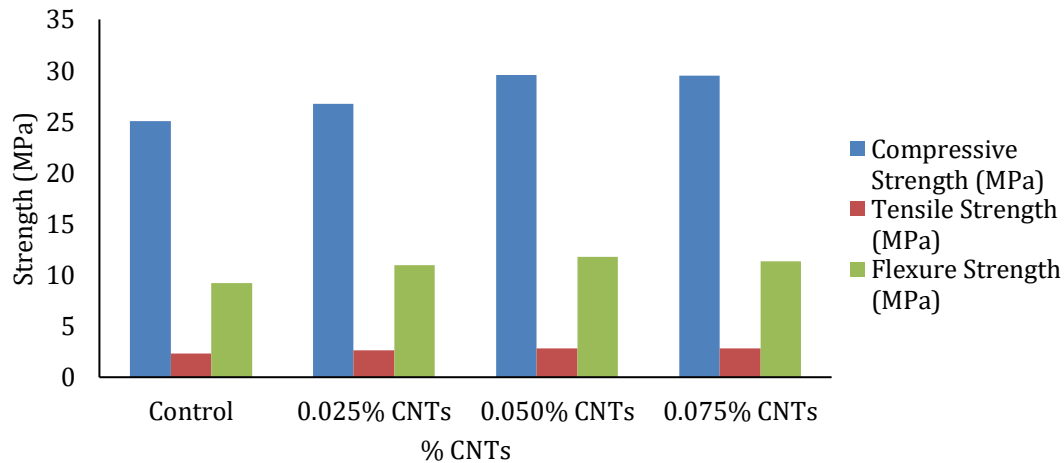


Figure 8. Compressive strength, tensile strength, and flexure strength of the control and CNTs Concrete

Compressive Strength Results

When CNTs are added to the concrete mix, the compressive strength of the specimens increases when compared to the control specimens. The increase in compressive strength was 6.7% for the sample containing 0.025% CNTs, 17.9% for the sample containing 0.05% CNTs, and 17.6% for the sample containing 0.075% CNTs. The high mechanical properties of CNTs can significantly influence the compressive strength [24]. According to Hawreen and Bogas [25], the filling, nucleation, and bridging actions of the CNTs are responsible for the increase in compressive strength of concrete with CNTs compared to ordinary concrete. A study by Camacho and Konsta [26], [27] discovered that 0.06% CNTs added to concrete mixtures boosted strength by up to 20%.

Splitting Tensile Strength

Compared to the control specimen, the tested specimens' splitting tensile strength increased when CNTs were mixed into the concrete mix. Tensile strength increased by 14.3%, 20.4%, and 21%, respectively, for 0.025%, 0.05%, and 0.075% CNTs. Qissab and Abbas [28] evaluated that including 0.06% CNTs into the mix enhances the tensile strength by 3 to 38% using long and short CNTs in their study. Also, Hunashyal et al. [29] investigated that samples containing 0.5% CNTs increase tensile strength by 19%.

Flexural Strength

According to the test's results, using carbon nanotubes enhances flexural strength by 19.2%, 28.2%, and 23.3% at 0.025%, 0.05%, and 0.075% CNTs, respectively. Konsta et al. [27] determined that adding 0.08% short, multi-walled CNTs (MWCNTs) to cement mix enhanced flexural strength and young modulus by 35%. Another study by Li et al. [30]; determined that including 0.05% of MWCNTs in the concrete mix enhances flexural strength by 25%.

VI. CONCLUSION

This study's objective was to examine the impact of including carbon nanotubes in concrete for use as pavement concrete. The following are the main findings:

1. The addition of CNTs to the concrete mix has a major influence on the mechanical characteristics of mortars. It relatively enhanced the compressive, tensile, and flexural strengths when compared to the control specimen.
2. There were increases in the compressive strength of 6.7%, 17.9%, and 17.6%, the tensile strength of 14.3%, 20.4%, and 21%, and the flexural strength of 19.2%, 28.2%, and 23.3% for the samples containing 0.025%, 0.05%, and 0.075% CNTs, respectively.
3. The optimum CNT concentration to add to the concrete mix is 0.05% since the compressive and flexural strengths were better than the other samples; the tensile strength was marginally higher for 0.075% CNTs than the sample with 0.05% CNTs. This was clarified by the reason that CNTs rapidly agglomerate at high doses.

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