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# Enhancing the Mechanical Properties of Concrete Pavement Using Steel Fibers (SFs) and Carbon Nanotubes (CNTs)

\*Abeer Hassan<sup>1,2</sup>, Sameh Galal<sup>3</sup>, Ahmed Hassan<sup>4</sup>

<sup>\*1</sup> Ph.D. Student, Dept. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt

<sup>2</sup>Lecturer, Dept. of Civil Engineering, Faculty of Engineering, Nahda University, BeniSuef, Egypt.

<sup>3</sup>Professor, Dept. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt.

<sup>4</sup>Professor, Dept. of Civil Engineering, Faculty of Engineering, Beni-Suef University, BeniSuef, Egypt.

\*Corresponding author

**ABSTRACT:** In the last few years, much interest has been carried out in nanomaterial applications to improve the mechanical performance of construction materials, which can also be used for rigid pavement constructions. Also, various types of fibers have been used to improve the performance of concrete constructions. Carbon nanotubes (CNTs) are used to improve the performance of nanocomposites due to their high strength and physical properties. When applied, this shows good effects on cement mortars' mechanical properties. Also, including fibers in a concrete mixture significantly improves its strength and brittleness.

Consequently, this study examines the impact of carbon nanotubes (CNTs) and steel fibers (SFs) on concrete pavements to assess their influence when subjected to vehicular loads and achieve an improved composition compared to traditional pavements. The study investigated the compressive, tensile, and flexural strengths of the tested samples, both with and without the inclusion of these additive materials.

**KEYWORDS:** *Carbon Nanotubes (CNTs); Steel Fibers (SFs); Rigid Pavement.*

## I. INTRODUCTION

Concrete pavement is commonly used in many areas; however, it has a major cracking problem. The interactive harmful effects of traffic and the environment cause pavement deterioration. Traffic loads, especially those from heavy vehicles, cause stress/strain in road pavements, the effects of which accumulate over time, causing deterioration of the pavement, such as asphalt concrete plastic deformation or cracking in portland concrete.

Materials used for road construction have developed over time. Developments have followed this advancement in materials in the methods by which these materials are applied to pavement structural design [1]. Many reinforcement techniques are based on fillers for filling the pores, joining the components, and transferring concrete stresses.

Nanotechnology has progressed quickly in recent years. The configuration of the next industrial revolution, or nanotechnology, was first presented in the famous lecture by Nobel laureate Richard P. Feynman, "There's Plenty of Room at the Bottom," given at the California Institute of Technology in 1959 [2].

Using carbon nanotubes (CNTs) enhances concrete mechanical properties as concrete is a cement-based material with a complex binding article network known as calcium silicate hydrate (C-S-H). Because of their nano-scale characteristics, CNTs shall interact most intimately with (C-S-H). A large number of atoms on the nanotube surface achieve the interface of CNTs with (C-S-H) [3]. CNTs have a high degree of flexibility, and their microstructure as

tubes can bend in circles and form bridges across the micro and nano cracks formed in the cement composites, which in turn increases the strength of the cement composites [4]. CNTs can be widely distributed in a concrete paste and, as a nanomaterial, their interaction with the paste is more intense than the other larger fibers. CNTs have high tensile strength, yield strain, and high modulus of elasticity. These properties make the CNTs an attractive concrete reinforcement material. The unique characteristics offered by CNTs provide an excellent opportunity to develop CNT-enhanced structural concrete [5]. CNTs increase the tensile strength of cement composites because of their ability to prevent the creation of micro-cracks in cement matrix [6].

As reported by Hassan et al. [7], the addition of carbon nanotubes (CNTs) to concrete resulted in noticeable improvements in both compressive and tensile strengths compared to control specimens made of regular concrete. The increase in strength ranged from 7% to 20% for compressive strength and from 10% to 20% for tensile strength. Scanning electron microscopy analysis of these specimens revealed that the CNT specimens exhibited a well-structured and evenly distributed nature, contrasting with the control specimens. This observation confirms that CNTs function as bridges across microcracks, enhancing the bond strength of the concrete. Furthermore, it was found that the inclusion of CNTs significantly enhanced the load-bearing capacity and ductility index of concrete, ultimately leading to an increase in flexural strength [3], [8].

On the other hand, concrete shows fragile behaviors under compression. A way to enhance concrete's strength, ductility, and deformity is by adding steel fibers to concrete [9], [10]. Multiple experimental and analytical studies have been carried out to improve the mechanical characteristics of fiber-reinforced concrete [11], [12].

Steel fiber reinforced concrete (SFRC) has recently received much interest because of its better mechanical response to dynamic and impact loads. Steel is the main component of FRC and the most used material. Many studies have been carried out over the last three decades on the effects of steel fibers on the mechanical properties and impact resistance of concrete. It has been shown that steel fibers can significantly improve concrete's mechanical properties and impact strength [13]. High-strength steel fibers placed in a concrete matrix have a strong bridging effect, which improves the bonding between fiber and matrix and contributes directly to the enhancement of SFRC post-cracking performance and residual strength [14]. As well as mechanical behavior, thermo-physical parameters, such as thermal conductivity, are the main analysis and design parameters governing heat transport in multi-phase systems. Due to the importance of thermal conductivity properties, there is a wide framework of experimental methods for estimating the thermal response of fiber-reinforced concrete [15].

Short fibers with a particular aspect ratio (length/diameter) are generally used for concrete reinforcement. Also, the distribution of short fibers within concrete is usually random. Currently, a model has yet to be suggested to the best of the knowledge of authors that simultaneously considers such factors as fiber aspect ratio and random dispersion and estimates the thermal conductivity of fiber-reinforced concrete [16]. Today, high-performance modified concrete reinforced with fiber and carbon nanotubes (CNTs) has drawn significant scientific interest [17]–[19].

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

## **II. RESEARCH OBJECTIVE**

The main objective of this paper is to propose new types of concrete pavement by including the parameters SFs and CNTs in the concrete mix and observing the results to optimize concrete behavior compared to the traditional concrete. The proposed rigid pavements are anticipated to be more durable, with increased serviceability and lower life cycle maintenance costs, as well as improving traffic safety.

### III. EXPERIMENTAL WORK

The concrete mixture employed in this study consisted of cement, sand, and gravel, as depicted in Figure 1. As per the guidelines outlined in the ASTM C150 standard [20], ordinary portland cement (type II 42.5) was used in all the mixtures investigated in this study. Figure 2 displays the results of a sieve analysis conducted on the coarse and fine aggregates utilized in this study. The relative specific gravity of coarse and fine aggregates used are 2.77 and 2.75 respectively.

Potable water was employed during the mixing process, aiming to achieve a target concrete strength of 25MPa. Table 1 presents the proportions of the control mix. Figure 3 illustrates the morphology of the carbon nanotubes and steel fibers utilized in the study. Carbon nanotubes were incorporated in the mixture at a concentration of 0.05% by weight of cement, while steel fibers were added at a rate of 1% by weight of cement. Table 2 presents the specific characteristics of the steel fibers utilized in the study. The dry aggregate, cement, and steel fibers were combined in a laboratory mixer with a capacity of 0.125 m<sup>3</sup> for a duration of 2 minutes. Following this, the water containing carbon nanotubes (CNTs) was added, and the mixing process continued for an additional 2 minutes.



**Figure 1.** The Concrete Components, Cement, Sand, and Basalt

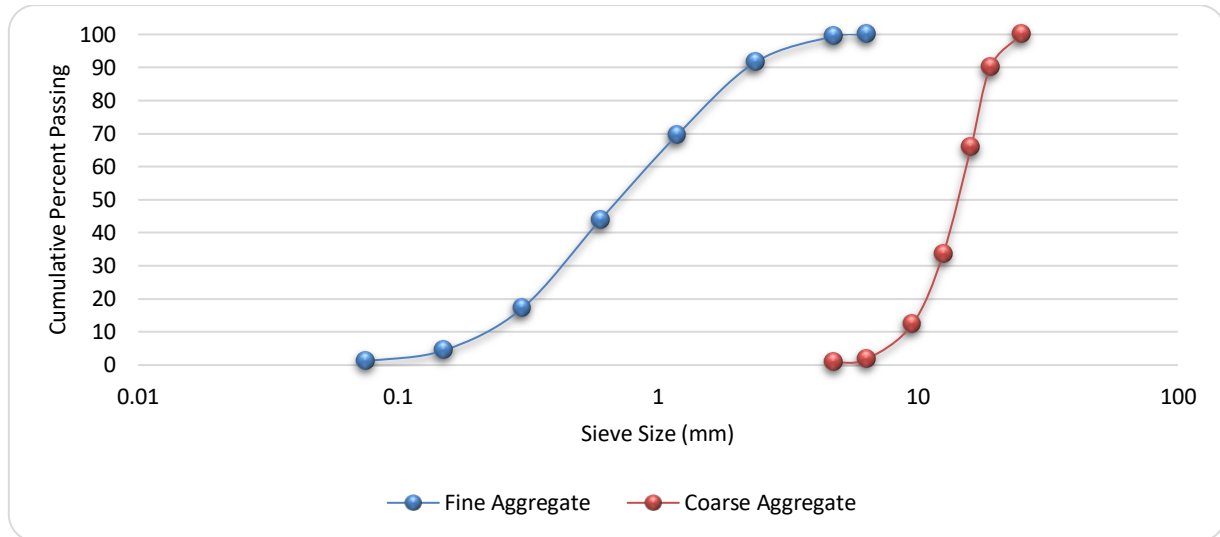


Figure 2. Gradation of Used Aggregates

Table 1. Proportions of the Control Mix

| Fc (MPa) | Cement (kg/m <sup>3</sup> ) | Water (kg/m <sup>3</sup> ) | Fine Aggregate (kg/m <sup>3</sup> ) | Coarse Aggregate (kg/m <sup>3</sup> ) |
|----------|-----------------------------|----------------------------|-------------------------------------|---------------------------------------|
| 25       | 350                         | 175                        | (kg/m <sup>3</sup> )                | 1200                                  |

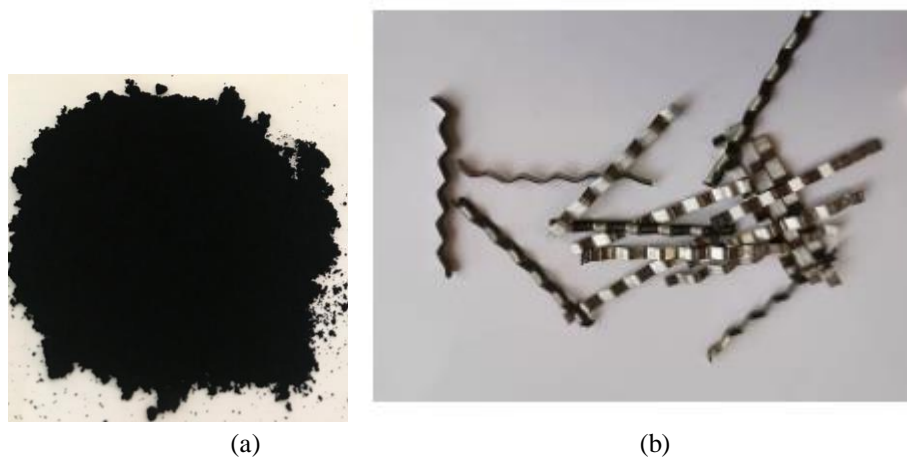


Figure 3. The Additive Materials (a) CNTs, (b) Steel Fiber

Table 2. Steel Fiber Properties

| Length (mm) | Thickness (mm) | Width (mm) | Tensile Strength (MPa) | Young's Modulus (GPa) |
|-------------|----------------|------------|------------------------|-----------------------|
| 50          | 0.5            | 3          | 532                    | 210                   |

A total of twelve concrete cubes with dimensions of 100 mm, twelve cylinders measuring 100 mm x 200 mm, and twelve beams measuring 100 mm x 100 mm x 500 mm were produced in order to evaluate the compressive strength, tensile strength, and flexural strength of the concrete after a 28-day period. Figure 4 includes a specimen sample for each mix. The testing procedures followed the guidelines specified in ASTM C 496 [21]. The testing involved three

control samples, three samples with 1% steel fibers by cement weight, three samples with 0.05% CNTs (Carbon Nanotubes), and three samples with a mixture of 0.05% CNTs and 1 percent steel fibers. Each batch comprised three cubes used for testing compressive strength, three cylinders utilized for determining tensile strength, and three beams employed for measuring flexural strength. After being molded at one day old, the specimens underwent curing in normal pure water at 27°C until the testing age. Consequently, the experimental investigation involved the examination of the compressive, tensile, and flexural strengths at each stage.



Figure 4. Specimen Sample of Each Mix

#### IV. RESULTS AND DISCUSSION

##### The Mechanical Properties of the mixtures

The compressive, tensile, and flexural strength of specimens containing 1% steel fibers were assessed. The results of the strength tests were analyzed after 28 days of curing and are presented in Table 5. The inclusion of steel fibers in the samples led to a significant improvement in compressive strength by 19.5%, tensile strength by 25.9%, and flexural strength by 59.3%. These findings are consistent with similar studies conducted previously.

As reported by Sahin and Köksal[22], the inclusion of fibers resulted in a noteworthy 36.3% increase in splitting tensile strength, indicating improved ductility in the samples. Another study conducted by Vikrant et al.[23] found that the addition of 0.5% of 50mm copper-coated crimped round steel fibers with an aspect ratio of 53.85 to concrete with a compressive strength of 25MPa resulted in a remarkable 61.1% improvement in split tensile strength.

After the 28-day curing period, the compressive, tensile, and flexural strength of four different specimens were examined, including the control sample, sample with 1% steel fibers, sample with 0.05% carbon nanotubes, and sample with both 1% steel fibers and 0.05% carbon nanotubes. The outcomes are presented in Table 3, while Figure 5 visually demonstrates the enhanced behavior of concrete mixtures resulting from the addition of both steel fibers (SF) and carbon nanotubes (CNTs). The addition of both carbon nanotubes and steel fibers to concrete mixtures can lead to an increase in strength due to the favorable properties of both materials. This results in an increase of 22.7% in compressive strength, 29.3% in tensile strength, and 70.8% in flexural strength when compared to the control specimen.

Table 3. Strengths of Control, CNTs, and Steel Fibers Samples

| Concrete Type       | Compressive Strength (MPa) | Tensile Strength (MPa) | Flexure Strength (MPa) |
|---------------------|----------------------------|------------------------|------------------------|
| Control             | 25.1                       | 2.3                    | 9.2                    |
| 0.050% CNTs         | 29.6                       | 2.79                   | 11.8                   |
| 1% SF               | 29.65                      | 2.95                   | 14.65                  |
| 0.050% CNTs + 1% SF | 30.8                       | 3.1                    | 15.7                   |

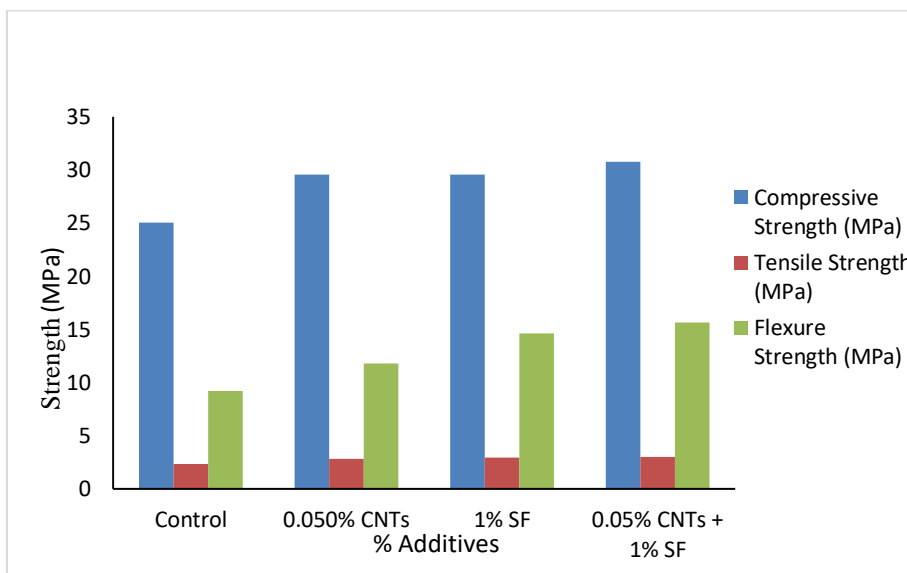


Figure 5. Test Results of Compression, Tensile, and Flexural Strengths

### Loading Test of the Mixtures

An experiment was conducted to obtain stress-strain curves by testing twelve cylinders made of four concrete mixtures. Each cylinder had a radius of 150 mm and a length of 300 mm. Figure 6 shows some specimen samples and test setup. The specimens were divided into four groups. The first group comprised three plain concrete specimens, while the second group consisted of three specimens with a concrete mix containing 0.05% CNTs. The third group included three cylinders with 1% SFs (Short Fibers), and the fourth group comprised three cylinders with 0.05% CNTs and 1% SFs added to the concrete mix. The specimens were removed from their molds after 24 hours and subjected to a curing process in water until they were tested after 28 days. All specimens were tested using a load-testing machine with a 1000-kN capacity and a loading rate controller, adhering to the guidelines outlined in the ASTM C-39 standard. The testing apparatus was gradually brought down until it made contact with the specimen. At this point, the dial gauge was calibrated to zero. Subsequently, the load was progressively incremented. Measurements of deformations were recorded at a frequency of 50 measurements per second. The average values of these measurements were calculated after capturing the deformations and corresponding loads. The obtained stress-strain curves are depicted in Figure 7. Observing the results, it is evident that the peak stress exhibited an increase of 19.7%, 26.8%, and 30.6% in the samples containing CNTs, SFs, and a combination of CNTs and SFs in the mixtures, respectively, compared to the control specimens. Furthermore, it is worth mentioning that the inclusion of SFs and CNTs in the standard concrete mix enhances ductility and raises the modulus of elasticity in the resulting sample.



Figure 6. Cylinders Specimens and Test Setup

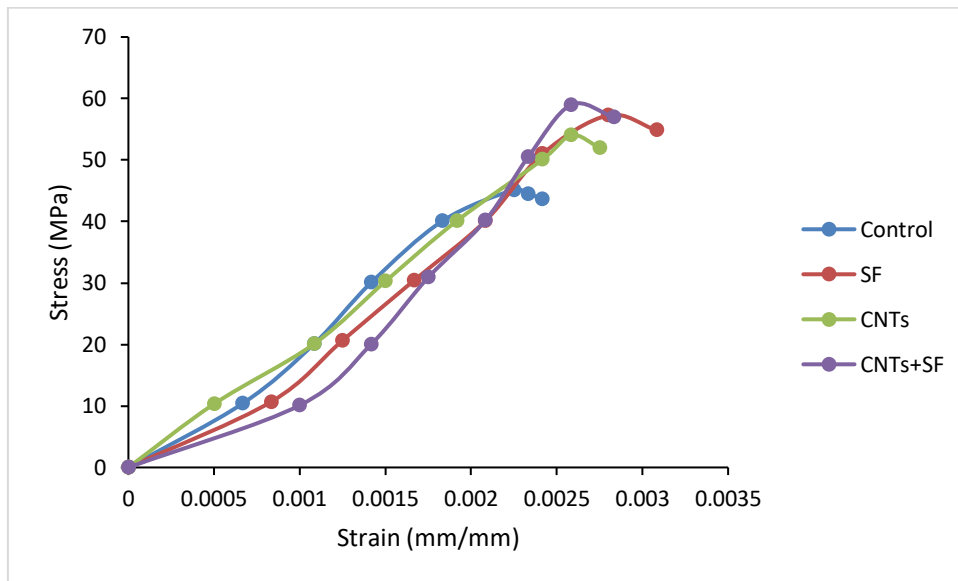


Figure 7. Stress-Strain Curve of the Different Concrete Mixtures.

## V. CONCLUSION

The objective of this study was to assess how the addition of carbon nanotubes and steel fibers to concrete influenced the mechanical properties of the material. The primary findings of this investigation are summarized as follows:

1. The inclusion of steel fibers in concrete yields notable improvements in compressive strength, splitting tensile strength, and flexural strength. It leads to a 19.5% enhancement in compressive strength, a 25.9% increase in tensile strength, and a substantial 59.3% increase in flexural strength. Consequently, incorporating steel fibers in concrete enhances its toughness and ductility.
2. Incorporating the optimal percentages of carbon nanotubes along with an appropriate ratio of steel fibers into the concrete mixture has a more significant impact on strength. This combination resulted in a notable increase



of 22.7% in compressive strength, 29.3% in tensile strength, and a substantial 70.8% increase in flexural strength.

3. The stress-strain curves demonstrate that when carbon nanotubes and steel fibers are combined, the ultimate stress achieved at the same strain level is higher. This combination imparts a higher modulus of elasticity to the concrete.

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