INFLUENCE OF CARBON NANOTUBES CONCENTRATION ON THE MECHANICAL PROPERTIES OF CEMENT MORTARS

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Abstract: *In recent decades, mechanical properties of composite materials containing carbon nanoparticles, in particular single-walled or multi-walled carbon nanotubes (SWCNTs or MWCNTs), have been researched, taking into account their excellent physical and mechanical characteristics. In this work, the influence of the concentration of MWCNTs (0.1, 0.2, 0.3, 0.35 wt.%) on compressive and flexural strengths of the cement mortar was investigated. The results of the research show that the compressive and flexural strength of the 7 and 28 days curing period samples reach their maximum value at 0.3% of nanotube concentration. In comparison to the control sample the compressive strength increased by 10.93% within 7 and by 32.0% within 28 days. And in the case of flexure, the strength of the test samples increased by 33.67% within 7 and by 36.50% within 28 days. It can be concluded that in the case of the selected carbon nanotubes and the material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.*
Keywords: *carbon nanotubes, cement mortar, compressive and flexural strengths.*

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Introduction

In recent decades, the mechanical properties of composite materials containing carbon nanoparticles, in particular single-walled or multi-walled carbon nanotubes (SWCNTs or MWCNTs), have been researched, taking into account their excellent physical and mechanical characteristics [1,2,3].

Carbon nanotubes (CNTs) are cylindrical fibrous nanomaterials with a diameter from 0.4-3 nm to 1.4-100 nm (depending on the wall layers quantity) and a very high aspect ratio (100-1000). Depending on the number of wall layers, nanotubes can be SWCNTs and MWCNTs. They have high tensile strength (50-200 GPa) and high Young's modulus (1 TPa), which significantly increases the strength, rigidity and crack resistance of the composite material [1]. They have excellent electrical conductivity, due to which the composite gets self-sensing property [4].

CNTs are able to improve cement materials properties because of their excellent mechanical characteristics [3,7]. Many researches have indicated that CNTs are able to increase the mechanical properties [8,9] and durability [10-13] of cement materials. CNTs effectively improve both stiffness [14] and crack resistance of cement-based materials [3,15]. Usually, the quantity of CNTs used by researchers in the cement materials is 0.01 – 0.5 wt.% [16,17], suggesting an increase in strength of 15% - 50% [3,7,8].

At the same time, depending on the CNTs' properties and type of material composition (physical, chemical properties of sand and cement, ratios of w/c and s/c) the optimal amount of CNTs for the cement composite changes. In this work, the influence of the concentration of MWCNTs (0.1, 0.2, 0.3, 0.35 wt.%) on the cement mortar's compressive and flexural strengths were investigated.

The aim of this work is to determine the optimal amount of MWCNTs for the compressive and flexural strength of the cement mortar, depending on the selected material composition and type of MWCNTs used in this study, as well as to increase and develop the physical and mechanical properties of cement mortar of the same composition.

Materials and Methods

Materials

In this work, Portland cement 52.5 (GOST 31108-2020, available in Hrazdancement Factory) was used as a binder in the composite. Tables 1 and 2 show the physical and mechanical characteristics of selected Portland cement and sand, respectively.

In Fig. 1 MWCNTs were obtained from Zhengzhou University of China, which were synthesized using a chemical vapor deposition method (CVD)[1]. The necessary physical and mechanical properties of nanotubes are shown in Table 3.

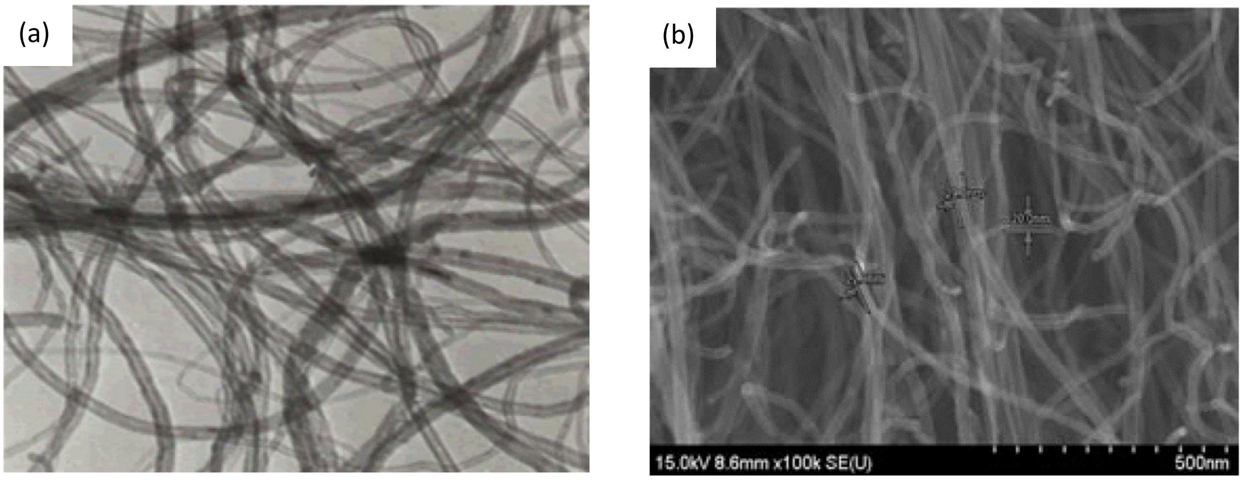

Fig. 1. *(a) Transmission Electron Microscopy (TEM),*
(b) Scanning Electron Microscopy (SEM), × 50.000 of MWCNTs

Table 1. Physical properties and chemical composition of the cement

<table>
<tr><td colspan="9">Physical properties of cement</td></tr>
<tr><td colspan="4">Properties</td><td colspan="5">Results</td></tr>
<tr><td colspan="4">Norm consistency (%)</td><td colspan="5">27</td></tr>
<tr><td colspan="4">Specific gravity (g/sm^3)</td><td colspan="5">3.1</td></tr>
<tr><td colspan="4">Blain's fineness (m^2/kg)</td><td colspan="5">328.3</td></tr>
<tr><td colspan="3" rowspan="3">Compressive strength (MPa)</td><td>3 days</td><td colspan="5">20</td></tr>
<tr><td>7 days</td><td colspan="5">36</td></tr>
<tr><td>28 days</td><td colspan="5">52</td></tr>
<tr><td colspan="3" rowspan="2">Setting time (min)</td><td>Initial</td><td colspan="5">45</td></tr>
<tr><td>Final</td><td colspan="5">315</td></tr>
<tr><td colspan="9">Chemical composition of cement (wt.%)</td></tr>
<tr><td>SiO_2</td><td>Al_2O_3</td><td>Fe_2O_3</td><td>MgO</td><td>CaO</td><td>SO_3</td><td>Loss of ignition</td><td>Insol. Resid.</td><td>Free CaO</td></tr>
<tr><td>21.6</td><td>4.5</td><td>2.2</td><td>1.1</td><td>61.9</td><td>2.1</td><td>3.2</td><td>1.9</td><td>1.5</td></tr>
</table>

Table 2. Physical characteristics and chemical composition of the sand

Fineness modulus	Specific gravity	Bulk density in Loose state (kg/m^3)	Bulk density in Compact state (kg/m^3)
3.4	2.45	1700	1925

[1] Technical data, TNM5. Chengdu Zhongke Times Nano Energy Tech Co., Ltd., 1-5.

Table 3. Physical properties of MWCNT

Outer Diameter	Length	Purity
20 – 30 nm	20 – 30 μm	> 98 wt.%

Dispersion of MWCNTs

According to the literature reviewed, there are many methods for dispersing multi-walled carbon nanotubes. In this paper, MWCNTs and water in the needed concentration and amount were continuously mixed with each other to ensure proper mixing by ultrasonic dispersion. The sonication process was carried out using an ultrasonic device UP400S at room temperature. The sonication time was considered 30 minutes. The dispersion method was carried out at all concentrations (0.1, 0.2, 0.3, 0.35 wt.%) selected in this study.

Mixing and Sample Preparation

The w/c ratio and c/s ratio used in this work were 0.47 and 0.25, respectively. Portland cement and sand were mixed by E095 Mortar mixer for 2 min, then the nanotubes/water mixture was added and blended for 5 min. The sample molds were chosen with dimensions of 4 cm × 4 cm × 16 cm. The composite was vibrated using a vibrating table C278 for 30 s. The process of mortar mixing and preparing without nanotubes occurred in the same way. After 24 h, the specimens were de-molded and were submerged in water at 20.0 ± 0.2°C temperature (Fig.2).

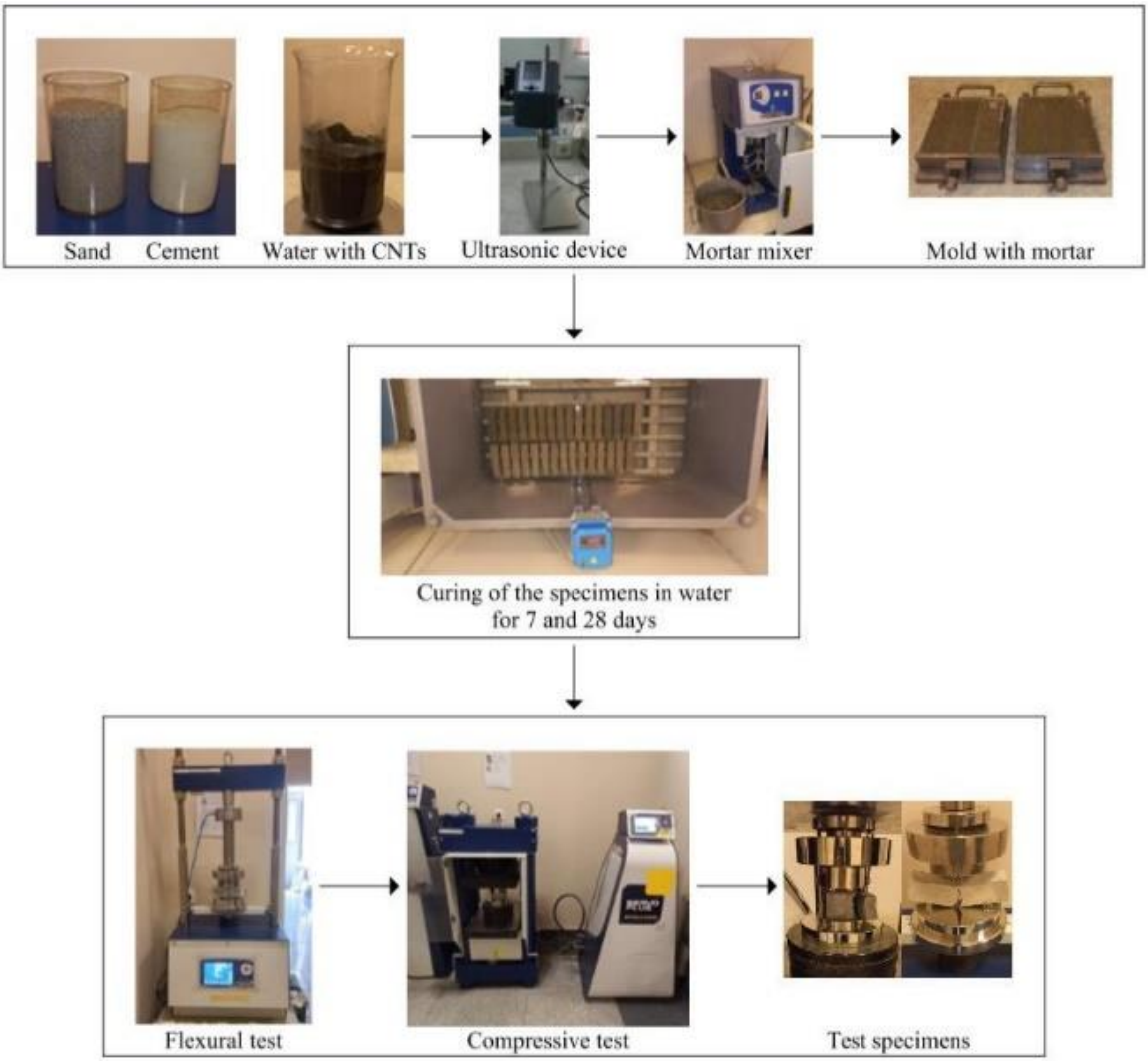

Fig. 2. *Diagram of experimental procedure*

Experiment

Compressive and flexural strength testing

Three specimens were randomly selected from each batch to test their average compressive and flexural strength.

Compressive tests were carried out on an automatic pressure machine (C089) (Matest, Treviolo, Italy) with a loading rate of 0.5 kN/s at the age of 7 days and 28 days, according to the standard EN 196-1, and specimen sizes were 4 cm × 4 cm.

The flexural strength of 4 cm × 4 cm × 16 cm samples were tested by Unitronic Compression/Tensile 50 kN testing machine within its maximum by standard test method. The experiment was based on a three-point bending test of the poured prism. Specimens aged 7 and 28 days were subjected to three-point bending at a loading rate of 0.05 kN/s.

Results and Discussion

Figs. 3,4 show the compressive and flexural strength of the composite samples with different wt.% of nanotubes for 7 and 28 days, respectively. C0 - C4 correspond to 0%, 0.1%, 0.2%, 0.3% and 0.35% of MWCNTs by weight of cement, respectively.

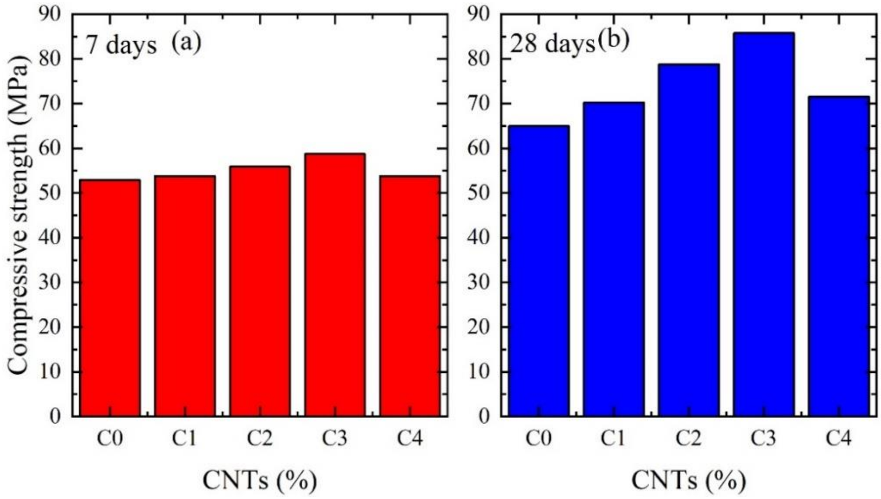

Fig. 3. *Compressive strength of cement specimens with different wt.% of MWCNTs. (a) for 7 days, (b) for 28 days*

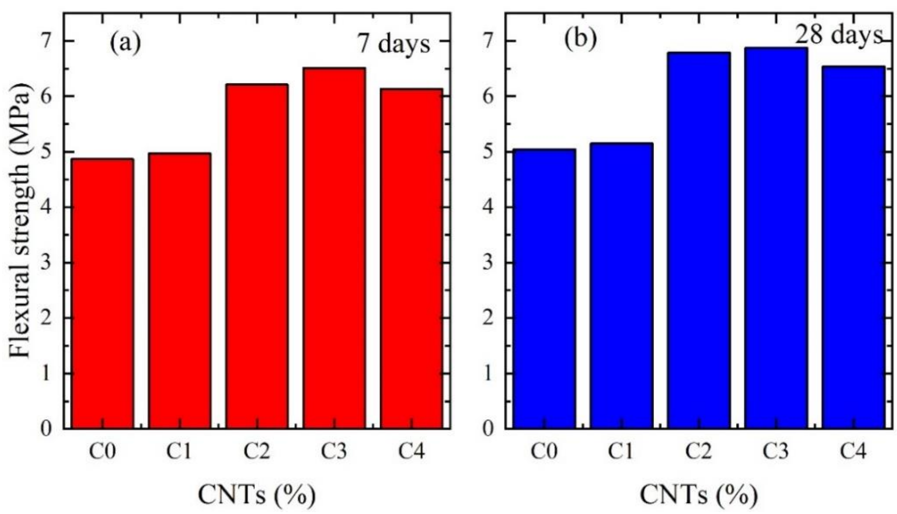

Fig. 4. *Flexural strength of cement specimens with different wt.% of MWCNTs. (a) for 7 days, (b) for 28 days*

The results indicate that the compressive strength of the cement specimens aged 7 and 28 days obtains its maximum value at 0.3% of nanotubes. It is clear from the figures that the strength of the test samples increased by 10.93% within 7 days and by 32.0% within 28 days.

In the flexural case, maximum strength of the 7 and 28 days curing period specimens was reached at 0.3% of MWCNTs. In particular, the strength of the test samples increased by 33.67% within 7 days and by 36.50% within 28 days.

From the Figs. 3,4 it can be concluded that in the case of the selected carbon nanotubes and material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.

On the other hand, in the case of 0.35 wt.% both compressive and flexural strength decreases. The reason is the low-efficiency dispersion of the nanotubes in the water, which will decrease the hydration degree. From the results it can be visible that the compressive strength grows with growing curing period, which can be explained by increasing hydration with time [2].

The increase of flexural strength is explained by increasing of crack resistance, due to the fact, that the CNTs bridge the cracks at the mid-span of specimens by moving the tensile stresses across the cracks and preventing the cracks from growing [1,18].

Conclusion

In this work, the influence of the concentration (0.1, 0.2, 0.3 and 0.35 wt.%) of multi-waled carbon nanotubes (MWCNTs) on the compressive and flexural strength of the mortar was researched. The results of the research indicate that the compressive and flexural strength of composite samples at 7 and 28 days reaches its maximum value at 0.3% concentration of nanotubes. Compressive strength increased by 10.93% within 7 and by 32.0% within 28 days. And in the case of flexion, the strength of the specimens increased by 33.67% within 7 and by 36.50% within 28 days.

It can be concluded that in the case of the selected carbon nanotubes and material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.

Acknowledgments

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