

Effect of Nanoparticles on Mechanical Properties of Cement-Sand Mortar Applications

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Abstract

Cement-sand mortar is a construction material widely used; tile adhesive is one of the main applications where the compressive strength is the key performance metric. Nanoparticles like MWCNTs and HNTs are currently being used to improve the mechanical performance of the cement mortar due to their properties. The cost of MWCNTs has limited their application in the construction industry. This study focuses on the effect of two different concentrations of MWCNTs and HNTs in cement mortar; HNTs are proposed in this study to compare performance and cost overall benefits. A common problem with MWCNTs is agglomeration; to achieve a proper dispersion an ultrasonic processor was utilized. Mechanical properties of a cement mortar modified with nanoparticles were investigated with compression and bending tests on specimens performed at the age of 7 days. Results showed that concentrations of 0.1% of MWCNTs increase in compression strength by 56% and concentrations of 0.1% of HNTs performance increased by 31%, both compared to plain cement mortar.

Keywords

Mechanical Properties, Compressive Strength, Cement, Cement Manufacture

1. Introduction

Cement-sand mortars are used in many applications in the construction industry such as tiles adhesive, interior and exterior coatings, texture, and leveling.

Mortars in tile adhesive applications have high compression strength; to improve mortar mechanical properties several solutions have been proposed in micro

and macro fibers like Dramix[®] fibers and glass fibers. In nanoscale, solutions have been used mainly in tubular form like Multi-wall Carbon nanotubes and Halloysite nanotubes, also in the form of flakes like Graphene [1].

In actuality, MWCNTs usage as engineering reinforcement is expanding due to their mechanical properties. MWCNTs have a Young modulus ranging from 270 to 950 GPa and a tensile strength ranging from 11 to 63 GPa [2], making this an ideal reinforcement for cement mortar.

As an alternative for MWCNTs, HNTs are proposed base on mechanical properties, lower cost and present no health risk compared to CNTs. HNTs have a Young modulus ranging from 1 to 1000 GPa and a tensile strength ranging from 0.03 to 4.0 GPa [3].

Studies of MWCNTs on cement mortar reported an improvement in mechanical properties; MWCNT reported in [4] showed 15% improvement in compression strength and 36% in tensile strength at concentrations of 0.5%. HNTs reported in [5] showed an improvement in compressive strength of 24% at concentrations of 3%

To measure the improvement in mechanical properties a mix design was proposed. It consists of a base formula without any nanoparticle addition and two samples with two concentrations of MWCNTs and HNTs. Mechanical properties of a cement mortar modified with nanoparticles were evaluated with compression and bending tests at 7 days; three specimens were performed for each concentration.

2. Materials

Cement mortar specimens were prepared using: Portland Cement CPO 30 RB, sand, water and chemical additives.

MWCNTs-Ni were provided by Dr. Oxana Vasilievna Kharissova and Dr. Beatriz Ortega Garcia from UANL. HNTs were provided by Dr. Laura Peña Parás from UDEM, physical properties for both nanoparticles shown in **Table 1**.

For an appropriate dispersion, a super plasticizer Sika Viscocrete 7300 HE and a 500 W and 20 KHZ Cole-Parmer Tip Ultrasonic processor were used.

3. Dispersion of Nanoparticles

A common problem with MWCNTs is agglomerations, nanoparticles present a high ratio of surface area/volume coupled with a relatively high Van der Waals energy. To avoid this problem was proposed the first sample of MWCNTs was dissolved in 100 gr of water and 2.45 gr of super plasticizer, and then it was so-

Table 1. Physical properties of nanoparticles.

	MWCNT-Ni	HNTs
Diameter (nm)	50 - 80	30 - 70
Length (microns)	10 - 20	1 - 3
Appearance/Form	Black/Powder	White/Powder



Figure 1. MWCNTs and HNTs sonicated dispersions.

nicated for intervals of 5 minutes, with the ultrasonic processor using a power of 100 W at 20 KHz.

Samples were taken every 5 minutes and observed under an optical microscope at 20× zoom and observed looking for agglomerations of MWCNTs, continued this process until a similar manner as mentioned dispersion in [6], was determined a time of 30 minutes the ideal, same time used for dispersion is mentioned in [7]. On this basis specimens with two concentrations of MWCNTs and HNTs were sonicated as shown in **Figure 1**.

4. Mixing and Specimens Preparation

The base formula comprises Portland white cement CPO 30 RB, sand, and chemical additives. For the preparation of the specimens shown in **Table 2**, were added in a planetary mixer first water, then the powder mortar, in the case of plain cement mortar. For mixtures with nanoparticles water is added first, then the solution of water + SP and nanoparticles, at last, dust mortar is added as shown in **Figure 2**. The mixing procedure is according to NMX-C-420, in all mixtures, 26% water is retained powder mortar. After the mixing is allowed to stand for 10 minutes to remove the air to each mixture. Mix density is reviewed in a bronze glass with a specific volume, the glass is according to ASTM C185 for each formula shown in **Table 3**. Later proceed to prepare the specimens in the molds for mechanical testing as shown in **Figure 2**. Specimens cured in a room controlled conditions for 7 days at 45% relative humidity and a temperature of 23°C according to NMX-C-420.

5. Mechanical Testing Equipment

The scope of this article had the purpose of investigating the mechanical properties of a cement mortar modified with nanoparticles such as compression and bending tests. Specimens were removed from metal molds at 72 hours and then tested at the age of 7 days. The equipment used for testing is a machine by company Controls Dual 15 KN for bending 300 KN compression. Automatic digital model 65-L27D1x, shown on **Figure 3** is equipped with two load cells to measure forces with high precision The machine has 2 devices, the first consists of a fixture for standard bending for beams 4 × 4 × 16 cm mortar dimensions according to EN 196-1 the second it is for testing standard compression

Table 2. Mixture proportions.

Mixture	Code of mixture	Mixture portions of mortar (grams)					Water
		White portland cement CPO 30 RB	Sand + Chemical additives	Superplasticizer	MWCNTs Ni	HNTs Ni	
0	Control formula	611.4	1888.6	0	0	0	650
1	Cement mortar with 0.10% MWCNT Ni	611.4	1888.6	2.45	0.6114	0	650
2	Cement mortar with 0.25% MWCNT Ni	611.4	1888.6	2.45	1.5285	0	650
3	Cement mortar with 0.10% HNTs	611.4	1888.6	2.45		0.6114	650
4	Cement mortar with 0.25% HNTs	611.4	1888.6	2.45		1.5285	650



Figure 2. Mixture and specimen preparation.

Table 3. Densities of cement mortar paste.

Mixture	Code of mixture	Density gr/cc
0	Control formula	1.54
1	Cement mortar with 0.10% MWCNTs Ni	1.46
2	Cement mortar with 0.25% MWCNTs Ni	1.47
3	Cement mortar with 0.10% HNTs	1.48
4	Cement mortar with 0.25% HNTs	1.48



Figure 3. Bending/Compression equipment and specimens.

Table 4. Mechanical properties at 7 days.

Mixture	Code of mixture	Mechanical properties	
		Compressive strength kg/cm ²	Flexural strength kg/cm ²
0	Control formula (Plain cement mortar)	44.5	15.3
1	Cement mortar with 0.10% MWCNTs Ni	69.1	16.0
2	Cement mortar with 0.25% MWCNTs Ni	60.4	13.4
3	Cement mortar with 0.10% HNTs	57.8	15.5
4	Cement mortar with 0.25% HNTs	56.5	15.8

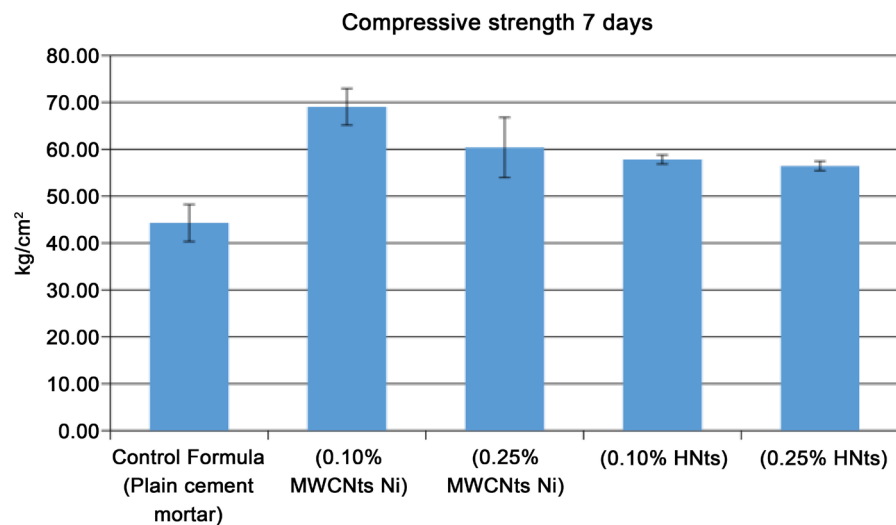


Figure 4. A Chart of compressive strength of specimens at 7 days.

according to EN 196-1, bending previously broken.

6. Results

Bending tests and conducted over an area of mortar 640 mm² at a loading rate of 15 kg/s using the bending device, for compression test contact area of 1600 mm² is used, and a load speed 15 kg/s, results shown in **Table 4** and Charts of Compressive and Flexural strength shown in **Figure 4** and **Figure 5**.

7. Discussion of Results

- Sample MWCNTs mortar with 0.10% on cement mortar, exhibits an increase in the mechanical properties of compression at the age of 7 days of 56% compared with the control formula, in terms of flexion, there is an improvement of 4% with respect to control formula.
- Sample MWCNTs mortar with 0.25% on cement mortar, showed an increase in compressive strength of 36% at the age of 7 days with relation to the control formula, but a decrease of 12% in flexural strength at the age of 7 days.
- Sample mortar with 0.10% HNTs on cement, exhibits a 31% increase in compressive strength at the age of 7 days, regarding flexural strength at the

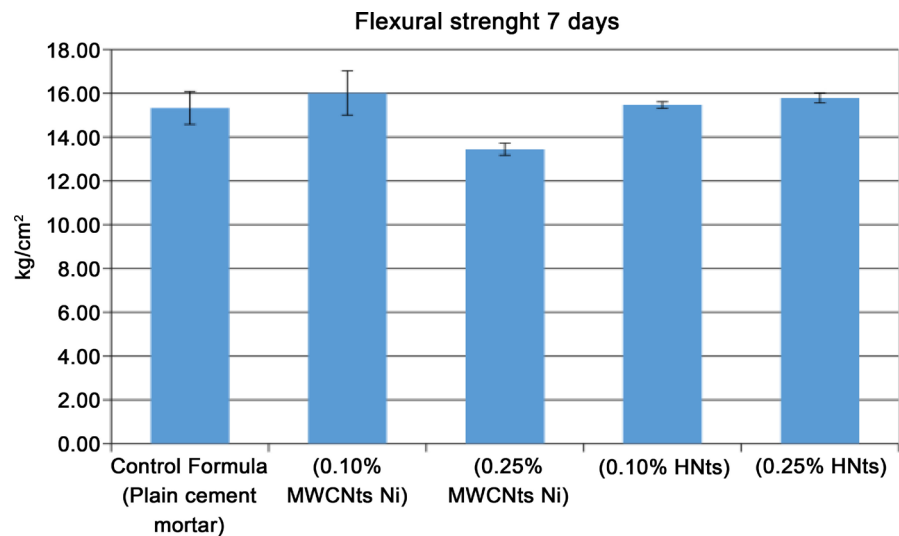


Figure 5. A Chart of flexural strength of specimens at 7 days.

age of 7 days, there was a small improvement of 0.8% compared with control formula.

- Sample with 0.25% HNTs mortar on cement, showed a 28% increase in compressive strength at the age of 7 days and an increase of 3% in terms of flexion at the age of 7 days.

8. Conclusions

Based on the results obtained, we can determine that the lower the concentration of nanoparticles was in cement mortar, the better performance in mechanical properties was achieved. According to the observed standard deviation, in HNTs it was more reduced than with MWCNTs and plain cement mortar; this was due to a better dispersion within the cement matrix.

The impact on the cost as a reference was from Sigma-Aldrich [8]; HNTs cost \$59.10 USD/100g or \$0.59 USD/g. and for MWCNTs \$116 USD/gram.

The 0.1% specimens of HNTs gave an improvement in compressive strength 16% lower than MWCNTs with same concentration, but it was noticed that the cost in the industry played an important role in decision-making. An evaluation based on the cost/performance ratio showed that HNTs were a better overall solution for cement mortar performance increase.

Studies are needed in order to review the properties at the age of 28 days and also to evaluate lower concentrations to find the optimal minimum for HNTs.

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