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Influence of Using Nano-Clay Hydrophilic Bentonite on Mechanical Properties of Concrete

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Abstract

The properties of concrete are strongly influenced by its microstructure. The addition of nano-clay to cement can control the calcium-silicate hydrate reaction, leading to improvements in the mechanical properties. So, in this study, the effect of adding hydrophilic nano-clay on the concrete fresh and hardened properties of Portland cement mortar was investigated. The main objective of this research is to figure out the optimum replacement percentage of cement by nano clay that gives the highest compressive strength and flexural strength. Four percentages of nano clay were used to replace cement content by 0%, 3%, 5%, and 7%. The tests conducted in this study were compressive strength and flexural strength for 7 and 28 days of moist curing, and the load deflection curve of each concrete mix was drawn. Absorption and specific gravity were determined for all concrete mortar samples with nano-clay of different percentages. The results showed that the compressive strength and the flexural strength of the concrete mortars with nano-clay were higher than the control sample. The highest enhancement in both compressive strength and flexural strength of mortar was when using 3% nano-clay to replace Portland cement.

Keywords— cement, compressive strength, concrete mortars, flexural strength, Nano clay.

I. INTRODUCTION

Concrete is one of the most important and widely used building materials, so many researchers have recently attempted to improve the environmental aspect of concrete to make it more environmentally friendly by using pozzolanic materials such as fly ash, silica fume, and metakaolin as partial substitutes for cement, resulting in a reduction in cement while maintaining the concrete's mechanical properties [1-5]. Using nanomaterials in concrete can reduce the permeability and enhance the strength of concrete due to the small paricle size of these materials, which results in a large surface area with high reactivity with cement [6].

Some researchers studied the use of different nanoclay materials in concrete since it is available and contains high silica content. Before considering these materials for large-scale applications, more research and experiments on the use of various types of nano clay in concrete and their impact on durability and mechanical properties are required.

The size of nano materials which makes it very effective has encouraged researchers to incorporate these materials in concrete [7]. Micro-scaled contents, as well as nano-sized particles, have a significant impact on the performance of concrete [8].

Mohamed (2015) investigated about how nanosilica and nanoclay affect concrete. The findings indicate that these nanoparticles can significantly improve the mechanical characteristics of concrete. Nanomaterials react with calcium hydroxide Ca(OH)2 crystals at the interfacial zone (ITZ) between solidified cement paste and aggregates to form C-S-H gel, as well as the filling action of nanoparticles, resulting in a more densified microstructure. The optimum mechanical characteristics were found in a 3% nanoparticle mixture composed of 25% NS and 75% NC, as measured by compressive and flexural strengths, among other percentages. He also discovered that having a high percentage of nanoparticles in concrete had a negative impact on its mechanical qualities. Also Langaroudi, and Mohammadi, (2018) found that the same percentage of 3% nano clay achieves the optimum mechanical properties.

The effect different percentages of nano-clay including (5, 7.5, and 10%) as cement partial replacements was studied [11]. The tests that were conducted including compressive strength, split tensile strength, flexural strength, with XRD and SEM. The optimum percentage of nano clay was 7.5 % by cement content.

Although there are few studies on the effect of incorporating Nano clays in concrete on mechanical properties and durability, according to [12], the effect of the Halloysite nanoclay type on concrete is investigated in this study by conducting compressive strength and permeability tests on mortars with 1, 2, and 3% replacement of cement by halloysite nanoclay. The results demonstrate that a 2% replacement resulted in a 56 percent improvement in compressive strength.

The objective of this study is to see how nanoclay hydrophilic bentonite improves the mechanical characteristics of mortar concrete and to figure out what the best nanoclay replacement percentage is. The physical properties of mortar concrete with different percentages of nano clay were compared to a control sample with no nano clay material.

II. MATERIALS AND METHODS

A. Cement

The cement that is used for this study is manufactured according to the European Standard EN 197-1:2011. It is a type of Portland cement with limited amount of C3A (maximum of 3.5%) it complies with Iraqi standard IQS 5-1984 type V.

B. Fine aggregates

The used aggregates for preparing all the concrete mortar samples were fine aggregates passing through sieve No.4 and mixed with cement in SSD condition.

C. Nanoclay montmorillonite

The most common natural nanomaterial used by industry is nanoclay montmorillonite hydrophilic bentonite, which is a smectite clay substance made from bentonite ore [13]. With a single layer thickness of 1 nm, it comprises a layered structure with a silica tetrahedron connected to an alumina octahedron, coordinated by oxygen atoms or hydroxyl groups [14]. For quicker dissipation of the nanoclay hydrophilic particles in asphalt, the raw nanoclays are altered by replacing metal cations for the interlayer and layered in a multilayer. Figure 1 and Table 1 show the X-Ray analysis as well as the chemical composition of the nanoclay material used.

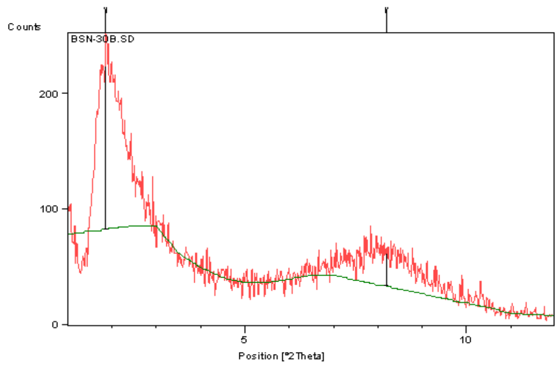

Figure 1: Nanoclay analysis X-Ray.

Table 1: Physical and chemical properties.

Physical properties	
Appearance	Powder
pH	2,5 - 3,5
Bulk density	300 - 370 kg/m3
Chemical composition	
O	52.6%
Si	**18.5%**
Fe	**10.0%**
Al	**9.4%**
Mg	**2.3%**
Na	**2.0%**
Ca	**1.9%**
K	**1.7%**
Ti	**1.6%**

D. Testing Methods

Compressive strength, flexural strength, toughness measured from the load deflection curve, absorption, specific gravity, and workability measured from the flow table test were all performed on concrete mortar samples with varying nanoclay percentages.

The standards for the tests conducted in this study are listed in Table 2

Table 2: The mechanical tests that were performed in this study.

Mechanical tests	Specifications
Compressive strength	*ASTM C109*
Flexural strength	*ASTM C348*
Workability (flow table)	ASTM C1437
Load deflection curve (toughness)	ASTM C-1018
Absorption	ASTM C1403
specific gravity	ASTM C127

E. Test samples

Mortar samples were prepared for four replacement percentages of nanoclay including (0%, 3%, 5%, and 7%). Six cubes and six prisms were casted for each percentage tested for 7 days and 28 days moist curing.

III.RESULTS AND DISCUSSION

A. Compressive strength

For the compressive strength, three mortar cubes of a size equal to 5 cm x 5 cm x 5 cm were tested in the compressive testing machine for each concrete mix of different percentages of nano clay, including the control samples. Figure 2 illustrates the comparison of the compressive strengths of all the concrete mixes in this study.

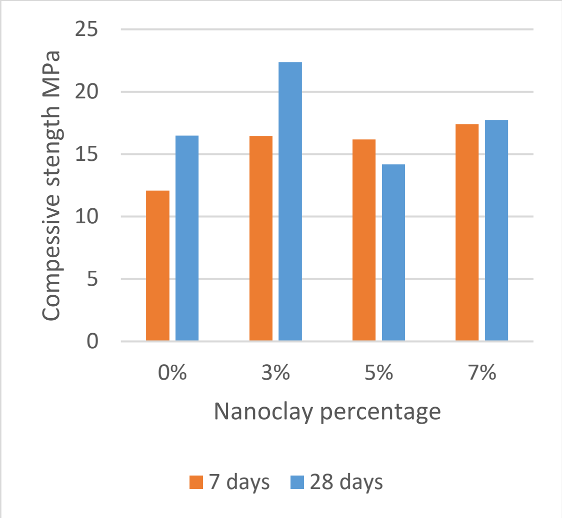

Figure 2: concrete compressive strengths

It can be figured out in general from this figure that using nano clay in replacement of cement content in mortar modifies the compressive strength even when using large percentages. Also, the best percentage of replacement was 3% nanoclay for 7 and 28 days of moist curing, which resulted in increasing the compressive strength by 36.3% and 35.7%, respectively.

B. Flexural strength

In the flexural strength test, three mortar prisms measuring 4 cm x 4 cm x 16 cm were evaluated in the flexural testing machine (three point loading) for each concrete mix containing varying percentages of nano clay, including control samples. Figure 3 shows the flexural strengths of all of the concrete samples.

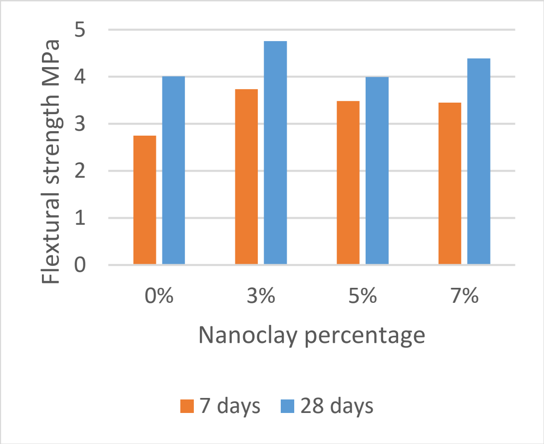

Figure 3: concrete flexural strengths

From this figure, it is obvious that the nano clay enhances the flexural strength for all the studied percentages. Besides that, as well as the compressive strength, 3% nano clay replacement for 7 and 28 days of moist curing has the highest increments in flexural strength among the other percentages, by 36% and 18.7%, respectively.

C. Other mechanical properties

The load deflection curve is drawn from the load of the flexural test with the dial gage recordings. The dial gage was attached to the tested mortar sample. The area under the load deflection curve was calculated to indicate the toughness of the mortar samples as shown in Figure 4 and Figure 5.

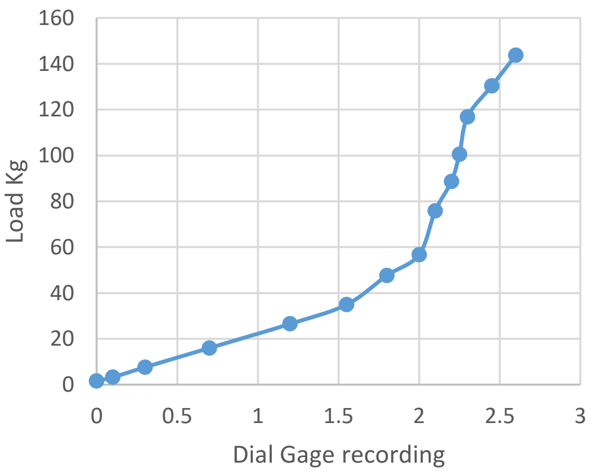

Figure 4: Load deflection curve for mortar mix of 3% nano clay after 28 days curing.

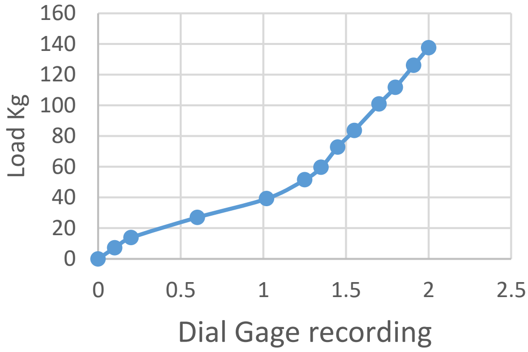

Figure 5: Load deflection curve for control mortar mix after 28 days curing.

Also the other properties were calculated including the absorption and the different types of densities for all mortar samples after 7 and 28 days as listed in Table 3 and Table 4 respectively.

Table 3: Absorption, densities and Toughness of mortar samples after 7 days curing.

Absorption	13.92173	12.61459	13.18109	12.94877
Relative density OD	1.876099	1.887176	1.929648	1.911334
Relative density SSD	2.137285	2.125235	2.183997	2.158828
Apparent RD	2.539337	2.476802	2.587869	2.539959
Toughness	78.86375	100.1785	62.0825	66.82125

Table 4: Absorption, densities and Toughness of mortar samples after 28 days curing.

Absorption	14.48404	12.98266	13.74718	13.71646
Relative density OD	1.845507	1.908271	1.880925	1.877444
Relative density SSD	2.112811	2.156015	2.139499	2.134962
Apparent RD	2.518789	2.536732	2.536902	2.528608
Toughness	101.8803	102.7968	41.1285	42.98725

From Tables 3 and 4, the highest toughness is observed in mortar mix with 3% nano clay in both 7 and 28 days curing. All types of measured densities of 3% nano clay mortar mix was higher than the other mixes for 7 and 28 days. The absorption also of the 3% mortar samples were the minimum for 7 and 28 days curing among the other mortar samples with different percentages.

IV. CONCLUSIONS

From this study it can be concluded that:

1. Using nano clay hydrophilic bentonite as a partial replacement of cement can improve the mechanical properties of concrete even when increasing the replacement percentage to 7%.
2. The optimum replacement percentage of nano clay is 3% according to the compressive and flexural strength results for both 7 and 28 day curing.
3. Based on the other measurements of absorption, density, and toughness, the results indicate that using 3% nano clay has the highest improvements in concrete mechanical properties.
4. Using nano clay in large scale applications can reduce environmental pollution that results from reducing the amount of consumed cement.

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