# The Effect of Plastic Shrinkage on Mechanical Properties of Nano-Material Cement Mortar

Haider K. Ahmed , Mohammed A.Abdulrehman

Department of Materials Engineering,

College of Engineering, University of Mustansiriyah,

# Abstract

In this research, two nanomaterial types have been used such as $Tio_2$ nanoparticles (NPs) and carbon black NPs to study their effect on compressive strength and flexural strength of cement mortars when exposed to the plastic shrinkage condition. The mixing ratio was 1:2.75:0.485 (cement: sand: water/cement ratio). The two nanoparticles ratios are (0%, 0.25%, 0.75%, 1.25 % and 1.75%) by weight of the Portland cement. The test results show When the samples are exposed to normal conditions that the highest value of compressive strength and flexural strength was obtained by using titanium oxide at 1.25% wt. of cement and the maximum value of compressive strength and flexural strength was obtained when using carbon black at 1.75%,1.25% wt. of cement respectively. But when the samples are exposed to the phenomenon of plastic shrinkage, the compressive strength and flexural strength decreasing when increasing the nanoparticles percent.

Key words: compressive strength, flexural strength, Portland cement, Nano-particle, plastic shrinkage.

## 1. Introduction

Recently, nanoparticles have attracted great interest due to their four major effects, including size effect, quantum effect, surface effect and interface effect. By adding nano-particles into cement, the performance and properties of materials could be improved [1][2].

Nanotechnology has been increasingly brought into the study of cement and concrete in recent years, Various nanomaterials (including Nano sized powders, tubes, and fibers) have been developed and incorporated into cement-based materials. Much of the work to date has been with nano-silica (nano-$SiO_2$) and nano-titanium oxide [3]. Nanoparticles which show the high activity in cement-based materials have huge surface areas, Moreover, nanoparticles can also be nucleation sites for the generation and growth of hydration products, which can promote the early-term cement hydration at different levels [4]. There are many researchers who have presented studies on white cement, such as, Ta-Peng Chang *et al*, had studied compressive strength and permeability coefficient of the cement mortar that contains silicon dioxide ($SiO_2$) [5], Ali Nazari and Shadi Riahi had studied the investigate the percentage of water absorption, rate of water absorption, coefficient of water absorption, workability, and setting time of binary blended concrete with partial replacement of cement [6], Ding Siang Ng *et al*. had studied the effects of different types of nanoparticles, namely nano-$SiO_2$(NS),nano-$TiO_2$ (NT),and nano-$Fe_2O_3$ (NF) on the fresh properties, mechanical properties, and microstructure of cement mortar containing fly ash as a supplementary cementitious material[7], Magdalena Janus *et al*, had studied the mechanical properties and photocatalytic activity of new photoactive cement mortars are presented by measuring the flexural and the compressive strength, the hydration heat, the zeta potential of the fresh state, and the initial and final setting time[8], Yanqun Sun *et al*, had studied the investigates the combined effects of nano-$CaCO_3$ and fly ash on the mechanical properties and durability of concrete[9], T.R. Praveenkumar et al. had studied the concrete designed with Titanium oxide ($TiO_2$) Nanoparticles and rice husk ash (RHA) as pozzolanic materials used in a partial replacement of Portland cement (PC) [10]. In this research, we shall be focused on the effect of plastic shrinkage on compressive strength and flexural strength of cement mortar modified by nanoparticles.

# 2. EXPERIMENTAL

## 2.1. Materials

All the material input in this study was purchased from local markets in Baghdad and some materials were imported and checked to make sure that they conform to the standard specifications.

### 2.1.1. Nano Materials

Available Nanomaterial was chosen according to its vast uses in the manufacturing of Nano cement mortar. The gradient of particle size and they have different chemical composition, these Nanomaterial is:

1. Carbon Black Nano powder

2. Titanium Oxide Nano powder ($TiO_2$).

The physical and chemical characteristics of both materials have been given in Tables **1.**

**Table 1.**The Chemical and Physical Characteristics of Titanium Oxide and carbon black Nano powder

| Name | Titanium Oxide Nano powder | Carbon Black Nano powder |
|---|---|---|
| Chemical composition | $TiO_2$ | - |
| pH | 6.70 | 15-20 |
| Particle size(nm) | 10-20 | 6.5 |
| Appearance | White powder | 640 |
| Specific surface area (m2/g) | 20-30 | Black powder |

| | | |
|---|---|---|
| Stability | Completely stable | Completely stable |
| Purity | >99.90 | >99.90 |
| Reactivity | Non-reactive | Non-reactive |

*Both materials manufacturing by (NANOSHEL - INTELLIGENT MATERIALS PVT. LTD) company/USA.

## 2.1.2. Cement

The cement which has been utilized in the present work has been the OPC type I, which is known commercially as the MASS, and produced at Al-Mass Company, Sulaimaniya, Iraq. The physical and the chemical analysis have been carried out and the results of the tests have indicated that the sample comply with Iraqi specifications (IQS No5 /1984) [11].The physical characteristics and the chemical composition of Al- Geser have been listed in Table **3** and 4.

**Table 3.** Physical properties and characteristics of cement

| Properties | Test result | Spec. Limit according to IQS No5:1984 |
|---|---|---|
| Setting time (h:min)<br>-Initial setting<br>-Final setting | <br>115min<br>4:33 | <br>≥ 45 min. |
| Compressive strength (MPa)<br>-3days<br>-7days | <br>16.59<br>24.4 | <br>15<br>23 |
| Soundness (Autoclave) | 0.31 | ≤ 0.8 |
| Fineness (m2/Kg) (blains method) | 277 | ≥ 230 |

**Table 4.** Chemical composition of cement

| Properties | Test result | Spec. Limit according to IQS No5:1984 |
|---|---|---|
| $SiO_2$ (wt. %) | 19.34 | - |
| $Al_2O_3$ (wt. %) | 4.32 | - |
| $Fe_2O_3$ (wt. %) | 4.42 | - |
| CaO (wt. %) | 61.08 | - |
| Lime saturation factor (LSF.) (%) | 0.96 | 0.66–1.022 |

| | | |
|---|---|---|
| MgO (wt. %) | 2.18 | ≤ 5 |
| $SO_3$ (wt. %) | 1.82 | ≤ 2.5 |
| Loss on ignition (wt. %) | 2.54 | ≤ 4 |
| Insoluble residue (wt. %) | 0.44 | ≤ 1.5 |

## 2.1.3. Fine aggregate

Standard sand was used in this research depend on ASTM C778[12], table **4** shows grading of fine aggregate.

**Table 4** Grading of fine aggregate

| **Sieve size** | **Passing percent %** |
|---|---|
| 1.18 mm | 100 |
| 0.600 mm | 98.6 |
| 0.425 mm | 74.1 |
| 0.300 mm | 24.3 |
| 0.150 mm | 0.12 |

## 2.1.4. Water

Distilled water was used in this study.

## 2.2. Distinguish of Mixtures

Table **5** shows in details distinguish of all mortar mixtures that were used in this study.

**Table 5** Mix proportion of white cement mortar

| Mixtures | $TiO_2$ NPs % wt. of cement | Carbon black NPs % wt. of cement |
|---|---|---|
| WC | - | - |
| WT02 | 0.25 | - |
| WT07 | 0.75 | - |
| WT12 | 1.25 | - |
| WT17 | 1.75 | - |
| WB02 | - | 0.25 |
| WB07 | - | 0.75 |
| WB12 | - | 1.25 |
| WB17 | - | 1.75 |

## 2.3. Methods:-

For each percentage of nanomaterials that are added to the cement mortar, six samples were used to procedure mechanical tests. Three of them are exposed to natural conditions and the other three were subjected to the phenomenon of plastic shrinkage. All samples were used curing by immersion into the water and tested at 28 days age.

**2.3.1. The compressive strength test** is determined according to ASTM: C150 [13] by using cubes with dimensions of 50 x 50 x 50 mm. The compressive strength cubes were tested using a digital compressive machine of 250kN capacity. The tests were performed at age of 28 days and an average of three test results was adopted at each test.

**2.3.2. Flexural strength test** was measured according to ASTM: C 348[14]. Prisms for test specimens shall provide for with dimensions of 40 x 40 x 160 mm are molded by tamping in two layers. Prisms are cured one day in the molds and stripped until tested by center-point loading. The tests were performed at age of 28 days and an average of three test results was adopted at each test.

**2.3.3. Plastic shrinkage** occurs in freshly mixed concrete, with loss of water by evaporation from its surface, after placing and before hardening of the concrete. This can lead to plastic shrinkage cracking if the rate of evaporation is higher than that of the bleeding water rising to the surface of the concrete test [15], plastic shrinkage without any specification, Model is used for plastic shrinkage test, the samples placed inside the model and exposed to a wind speed of 40 km/h controlling by the regulator of the fan and exposed to the temperature of 40°C and controlled by using a thermostat (Maintaining the required ambient temperature of the samples) and exposed for a period of five hours (first 5 hours when mortar is the fresh case). As shown in fig

Figure (1): Model of samples is exposed to the plastic shrinkage

# 4. Results and discussion

## 2.4.1 Compressive strength (fc)

Table **6** shows the results of compressive strength for each samples under ordinary condition

**Table 6** results of compressive strength test

| Mixtures | compressive strength for nano-cement mortar under normal conditions fc (MPa) |
|---|---|
| WC | 27.44 |
| WT02 | 27.51 |
| WT07 | 28.28 |
| WT12 | 29.41 |
| WT17 | 29.39 |
| WB02 | 27.81 |
| WB07 | 28.48 |
| WB12 | 29.70 |
| WB17 | 30.02 |

In general, it has been observed that there is an increase in the compressive strength for the samples exposed to normal conditions when increasing the addition of nanomaterials due to their ability to fill the pores in the cement mortar. Likewise, the highest value of compressive strength was obtained when using titanium oxide at 1.25% wt. of cement and the maximum value of compressive strength was obtained when using carbon black at 1.75% wt. of cement.

## 2.4.2 flexural strength

Table **7** shows the results of flexural strength for each samples under ordinary condition

**Table 7** results of flexural strength test

| Mixtures | flexural strength for nano-cement mortar under normal conditions (MPa) |
|---|---|
| WC | 5.38 |
| WT02 | 5.40 |
| WT07 | 5.79 |
| WT12 | 6.11 |
| WT17 | 5.93 |
| WB02 | 5.61 |
| WB07 | 5.98 |
| WB12 | 6.17 |
| WB17 | 6.06 |

In general, it has been observed that there is an increase in the flexural strength samples at the exposed to normal conditions when increasing the addition of nanomaterials due to their ability to fill the pores in the cement mortar., the highest value of flexural strength was obtained when using titanium oxide at 1.25% wt. of cement, after when using titanium oxide at 1.75% wt. of cement decreasing value of flexural strength comparing with using titanium oxide at 1.25%wt. of cement. The maximum value of flexural strength was obtained when using black carbon at 1.25% wt. of cement. When using carbon black at 1.75% wt. of cement that tends to decrease the value of flexural strength comparing with using black carbon at 1.25% wt. of cement.

## 2.4.3 plastic shrinkage

Table **8** shows the results of compressive strength and flexural strength for each samples was exposed to plastic shrinkage

**Table 8.** results of compressive and flexural strength test for samples was exposed to plastic shrinkage

| Mixtures | compressive strength (MPa) | Percentage of compressive strength decrease | flexural strength (MPa) | Percentage of flexural strength decrease |
|---|---|---|---|---|
| WC | 24.60 | 10.34 | 4.62 | 14.12 |
| WT02 | 24.21 | 11.99 | 4.42 | 18.14 |
| WT07 | 23.78 | 15.91 | 4.51 | 22.10 |
| WT12 | 24.07 | 18.15 | 4.52 | 26.02 |
| WT17 | 23.42 | 20.31 | 4.15 | 30.01 |
| WB02 | 24.40 | 12.26 | 4.62 | 17.64 |
| WB07 | 24.21 | 15.30 | 4.61 | 22.90 |
| WB12 | 24.58 | 17.23 | 4.50 | 27.06 |
| WB17 | 23.73 | 20.95 | 4.18 | 31.02 |

In general, when the samples were subjected to plastic shrinkage, it was observed that there was a deterioration in the compressive strength and flexural strength in all proportions of nanomaterials added (0.25%, 0.75%, 1.25% and 1.75%) by weight of Portland cement. It was also noted that the negative effect of plastic shrinkage increases on mechanical properties with the increase in the percentage of nanomaterials used.

## Conclusion

Although the addition of nanomaterials has improved the value of compressive strength and flexural strength, but when samples of the same mixtures are subjected to conditions of plastic shrinkage, these nanomaterials were added to cement mortar have a negative impact on the value of compressive strength and flexural strength due to their small size relative to the cement mortar components, thus fills the voids and hinders the rise of water molecules from the bottom of the mixture to the top when the cement mortar is exposed to wind speed and high-temperature while the upper layer dries out than it is in the lower layer, causing defects at the upper layer, and this is called the phenomenon of plastic shrinkage.

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