Study the Effects of Nano-Materials Addition on Some Mechanical Properties of Cement Mortar

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Abstract-*This research involves nano-materials addition and interaction with cement mortar behavior for many mortar samples under variable curing time with constant water to cement ratio (W/C = 0.5). Some mechanical properties such as (compressive and flexural strength tests), durability (by water absorption test) were studied. The effect on the (Al-Mass cement) Ordinary Portland Cement (OPC) type (I) by additives with small amounts of nano-particles (SiO_2) and (Al_2O_3) were investigated in this research. The nano materials additives were added on the mixture of mortar with the percentages (1, 2, 3, 4 and 5%) for both nano materials with constant (W/C) ratio and also the amount of the fine aggregate used three times the amount of cement. The results shows that, the strength of the mortar consist both nano materials give better properties than mortar without nano materials in all tests. But nano silica additive gives good properties up to (3%) than mortar with nano alumina additive which give proprietress up to (2%).*

Keywords- *Compressive strength, flexural strength, nano-(Al_2O_3), nano-(SiO_2), water absorption.*

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1. Introduction

Nano technology is taken into account as a brand new field of science in materials science and materials engineering. This technology forms the idea for evolution of novel technological materials. Such technology enhances engineering product in varied fields. Enhancement of sustainable materials in the construction industry and study the pore filling effects and the pozzolanic activity with cement by adding nano silica is an important subject which must be focused to determine all the effects of such additives on the improvement of mechanical and durability specifications. Thus, there is a scope of study on the development of cracks in concrete towards sustainable construction [1].

Several methods of mortars characterization like: (The fourier transform infrared spectrometer -FTIR), thermo gravimeter-differential thermo gravimeter (TG-DTG) and scanning electron microscope (SEM) were used to study the influences of additives like: nano silica (NS), silica fume (SF) and fly ash (FA) on the mortars properties. All specimens mechanical strength were determined at early (7^{th} day) and standard (28^{th} day) curing ages [2]. Investigations were concern on how agglomeration of nano silica can affect the compressive strength and workability of normal strength concrete [3]. Nano silica influences on properties of: concretes, cement mortars, cement and other cementitious materials were studied to report all the enhancements in: pore filling, rheological behavior of cement pastes, workability increment, the pozzolanic activity or reactions, micro structure analysis, reduction of (CH) leaching, permeability, heat of hydration and durability [4]. Two different concrete samples were investigated, these samples were made of waste ceramics as a pozzolan. First samples were made of (10 to 40%) of ceramic powder substitution while the second samples were made of (10% to 25%) of ceramic powder and (0.5 to 1%) of nano-(SiO_2) were added to them. Both samples were exposed to water absorption and compressive strength tests. It was found that adding waste ceramics up to (20%) does not have great significant effects on concreate compressive strength, also adding ground ceramic with any amounts in the concrete reduces the water absorption capacity of it. It was also found that using (nano-SiO_2) and pozzolan improves the compressive strength of it but reduces the water absorption capacity. According to that, (nano-SiO_2) can improve the effects of ceramic powder on the properties of concrete [5]. A mixed of (M60) and (M80) with

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mineral combined admixture like: fume condensed silica with (OPC) and nano silica (SiO_2) were studied with different proportions which might be used as replacement to cement and gives high mechanical strength. So mechanical properties for such mixtures where studied with details, also a combination of fly ash with (OPC) and nano silica (SiO_2) was studied for determining the strength properties. From all these studies, a gradual increase in the strength up to (2%) of nano silica (SiO_2) with (10% CSF) in the mix was noticed and above (10% CSF) a gradual decrease in in the strength was determine. Similarly results were found in the combination of fly ash with (1.5 % nano silica) in the mix for the strengths [6]. After (7 and 28 days) of curing time, compressive strength was determined and water absorption after (28 days). The results of the experiments showed that the (nano-silica-SiO_2) additives enhances the strength of cement mortar at (28 days) clearly. Moreover, the study reveals that water absorption of cement mortar reduces with addition of Nano-Silica due to reduction of minute pores present in cement mortar [7]. Different types of nano silica (SiO_2) were added to self-compacting concrete (SCC). Same particle size distribution (PSD) were for the self-compacting concreate (SCC) and the nano silica (SiO_2) added. This was done in two different methods by using fumed powder silica and precipitated silica in colloidal suspension. The properties of concrete in fresh (workability) and hardened state (mechanical properties and durability) were studied by adding nano silica (SiO_2) to self-compacting concreate (SCC). Also, the microstructure of the hardened concrete was characterized by (SEM) and (EDS) analyses. Results showed the mechanical properties improved by the added nano silica (SiO_2) to (SCC) and the durability also improved. Considering the reactivity of the two applied (Nano-silica's), a higher reactivity at early age was showed, which influenced the final (SCC) properties [8]. The properties and the durability of self compacting concrete (SCC) containing alginate in variety values with artificial stone resin, micro and nano silica were studied. The values of (0.5 and 1%) alginate, (10%) micro silica, (0.5%) nano silica and (0.5%) artificial stone resin were used. Artificial stone resin was used as the super plasticizer. Properties of hardened (SCC) such as flexural strength, split tensile, copressive and water absorption were assessed and represented graphically. In general the use of alginate improved the performance of (SCC) in fresh state and also avoided the use of viscosity modifying admixtures. Adding nano silica to samples increased (SCC) workability and results showed that the split tensile strength of concrete decreased in (0.5%) alginate and in all mixes receptacle (0.5%) alginate. Adding micro silica to alginate increase the split tensile strength, but Adding nano and micro silica decreased the values of water absorption [9].

2. Experimental Work

I. Materials

The materials used to prepare the specimens in this research are:

1. Water

Water is very important in all specimens forming operations. It is used for the preparations of all specimens that had been tested by physical tests and all the mechanical tests that have been carried out. The used water must be free of oils, acids, alkaline and any other particles. This is can be reached when the used water is suitable for drinking purpose.

2. Fine aggregate

Fine aggregates generally consist of natural sand or crushed stones with most particles smaller than (5 mm). Most fine grading aggregate based on the research requirements. Fine aggregate grading is in the limits range mentioned in (ASTM C 33) which is generally suitable for most concretes. The (ASTM C 33) limits is with respect to sieve size. The sand used in this research is according to the mentioned standard specification that has been used.

3. Nano materials

Two types of nano materials are used. The first type is nano silica particles (SiO_2) and the other one is nano alumina particles (Al_2O_3). Both have high purity approach to (99.9%) and particle size rounded range between (15 to 20 nm). (Nano Shell Company) is the source of nano particles improved from the (Arrege Alfurat) Company.

4. Cement

In this research, Ordinary Portland cement (type I) was used. The physical properties of the used cement and its chemical composition are listed in Table (1). The cement conforms to the Iraqi specification (No.5/1984) ordinary Portland cement (type I) from (Al Mass Iraqi cement factory), the test in the table (1) was achieved in (National Centre for Construction Materials (NCCM)) laboratory and research.

Table 1: The chemical composition of ordinary Portland cement (OPC).

Oxides Composition	Oxide content %	Limits of Iraqi Specification No.5/1984
SiO_2	20.26	-
Al_2O_3	5.50	-
Fe_2O_3	2.19	-
CaO	61.39	-
MgO	1.99	< 5.00
SO_3	2.7	< 2.8
Free CaO	1.12	-
Loss on Ignition	3.2	< 4.00
Insoluble Residue	0.73	< 1.50
Lime Saturation Factor	0.94	0.66-1.02

II. ***Tests on specimens***

1. Compressive strength test

A (50 mm) cube specimens were tested by using (300 KN) on compressive machine with the type (Tecno-test machine device). The loading rate on the cubes was (0.5 mm/min).Three samples were tested for each examination stage and the average strength was recorded.

2. Flexural strength test

The flexural test machine was achieved by (Tinius Olsen universal material machine device) with (100 KN) applied load in strength of materials laboratory / materials engineering department / Al-Mustansiryiah University.

3. Surface hardness strength test

The device used to measure the hardness is (HPE II) which works with digital decimal precision. The force can be applied on the specimen through the help of a centered patented force grip exist on the center of the instrument. Shore hardness tester is used for (Non-destructive) test. The final results of hardness recorded were the average of the all three result.

III. Mortar preparation

Cement-sand ratio of (1:3) and (water/cement ratio (0.5 %)) were used in mortar preparations in this research. Mortar ingredient homogeneity was achieved through the using of an electric mixer. For compressive strength tests, a (50 mm) cube molds were used for mortar pastes and molds with the dimensions (40*40*160 mm) were used for flexural strength tests. The specimens were kept at (100 %) relative humidity in the molds for (24 hours) and then cured in water for (3, 7, 14, 21, 28, 60 and 91 days).

2. Result and Discussion

I- Compressive results

The results of compressive strength specimen's tests without and with nano materials addition to mortars are illustrated in figures together in order to show the effect of nano materials addition on the compressive strength behavior. Figure 1 shows the variation of days (3, 7, 14, 21, 28, 60 and 91 days) with compressive strength of blended mortar for (1%) nano silica (SiO_2) addition. With (2%) nano-silica replacement the compressive strength increases with curing time increase with the same (W/C) ratio and the compressive strength properties has improved than the control cement mortar at different curing time, this behavior was shown in Figure 2. Slow increase of compressive strength with increasing nano silica loading with the increasing quantity of nano particles (nano (SiO_2)) up to (3%). The mechanism of (SiO_2) nano-particles effect was shown in Figure 3 which increases the strength of mortar with nano particles, this can be described as adding (SiO_2) Nano-particles reduces the amount and size of ($Ca(OH)_2$) crystals and fills the voids of (C-S-H gel) structure. The structures of hydrated becomes denser and compact. The pozzolanic reaction by consumption of ($Ca(OH)_2$) which led to the formation of an additional (C-S-H) that fills the pores system and causing densification effect which improve the microstructure of mortar.

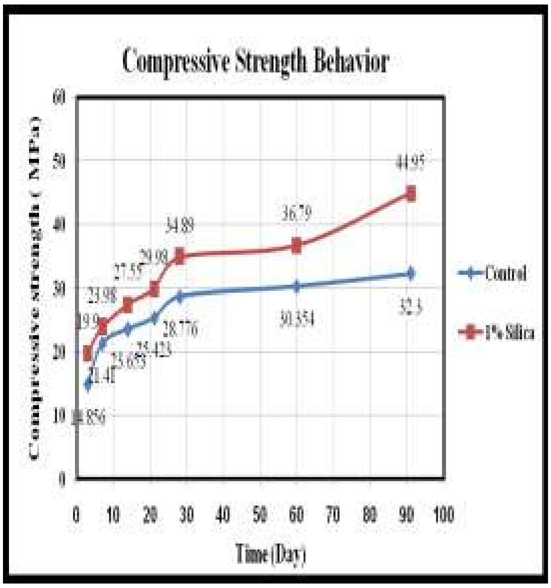

Figure 1: Compressive strength for (1%) nano (SiO_2) addition

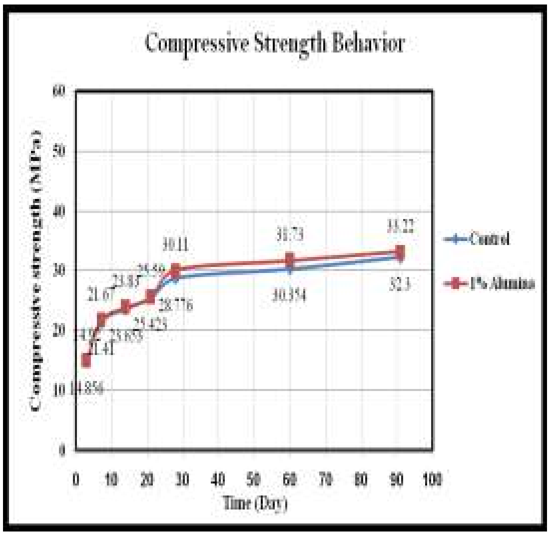

Figure 2: Compressive strength for (1%) nano (Al_2O_3) addition

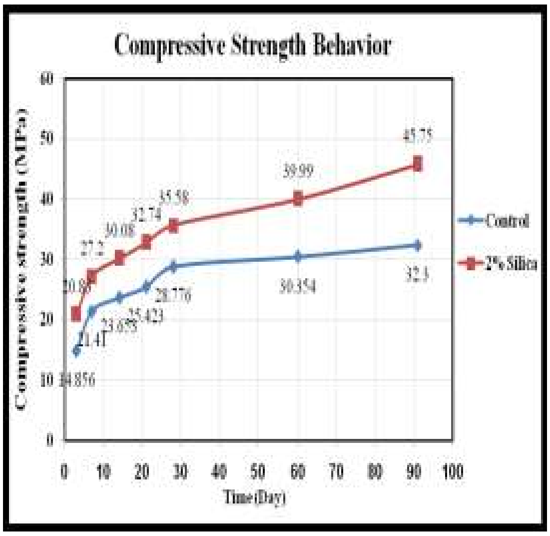

Figure 3: Compressive strength for (2%) nano (SiO_2) addition

The compressive behavior for samples containing (4 & 5 %) nano-particles can be seen in Figures 4 and 5, adding nano (SiO_2) to the mortar with more than (3%) will lead to un uniform distribution in cement mortar and will cause agglomeration, this agglomeration will cause to appear weak zones in the cement mortar. This is because of the formation of voids.

Figure 6 illustrate the compressive strength behavior of (1%) nano-alumina (Al_2O_3) addition, the compressive strength appear a few increment in compression strength compare with different curing time. Small increase in compressive strength than control samples with the same (W/C) ratio was noticed. But, when adding nano alumina (nano-Al_2O_3) replacement reaches (2%) the compressive strength of mortar with nano addition begin to give better compressive strength behavior compared with control. The mechanical property (compressive strength) development at (2%) nano alumina replacement addition is can be seen in figure (7). Basically the enhancement in compressive strength is because packing effect of filling the voids that create during the hydration reactions, so the materials become denser and the compressive strength increase. But when the amount of nano alumina increases up to (5%) the compressive strength began to decrease at the percentages (3, 4 and 5%) which can be seen in figures (8, 9 and 10) because adding more nano particles will create small distances between the nano particles and prevent ($Ca(OH)_2$) to growth and accelerate (voids creation and nucleate spaces) which prevent ($Ca(OH)_2$) growth also.

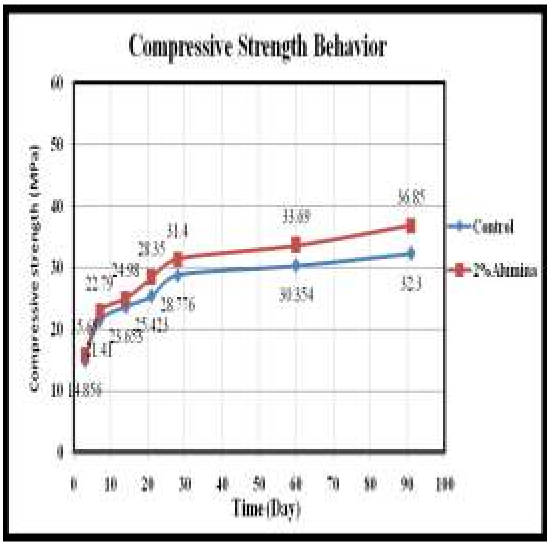

Figure 4: Compressive strength for (2%) nano (Al_2O_3) addition

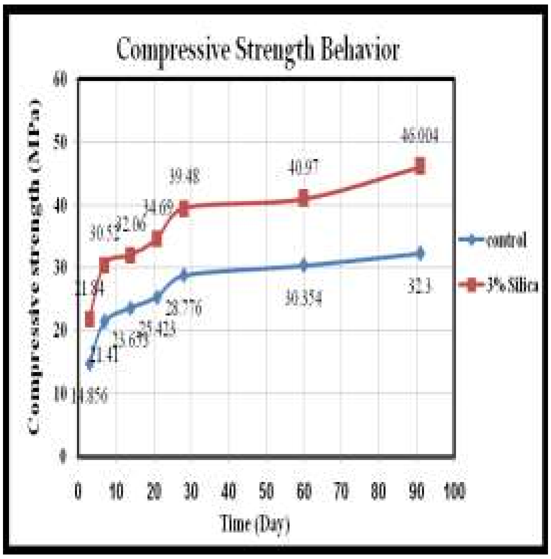

Figure 5: Compressive strength for (3%) nano (SiO_2) addition.

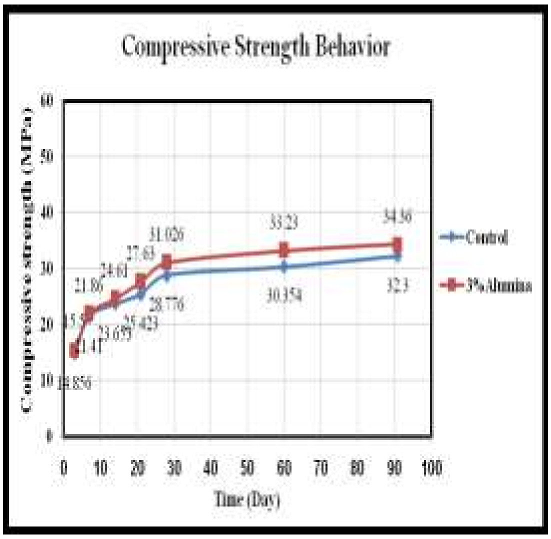

Figure 6: Compressive strength for (3%) nano (Al_2O_3) addition.

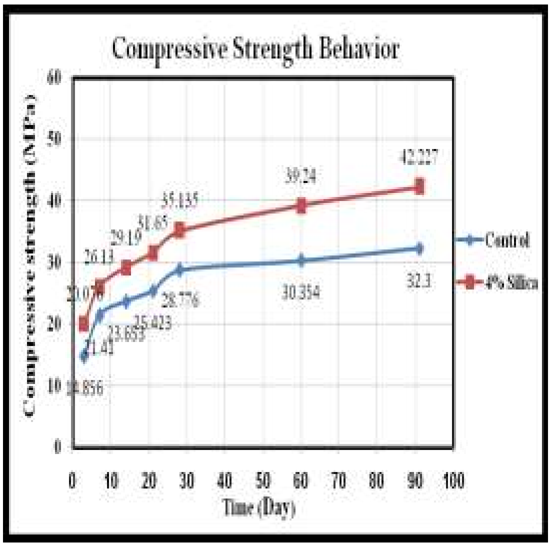

Figure 7: Compressive strength for (4%) nano (SiO_2) addition.

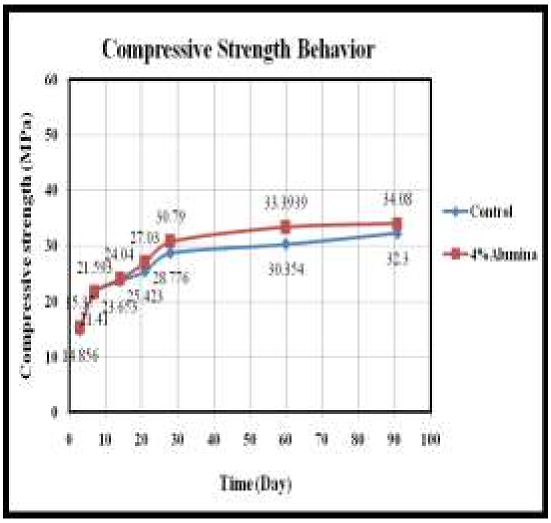

Figure 8: Compressive strength for (4%) nano (Al_2O_3) addition.

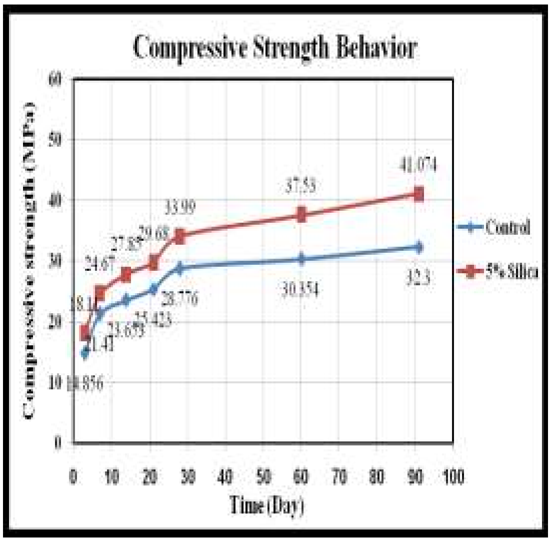

Figure 9: Compressive strength for (5%) nano (SiO_2) addition

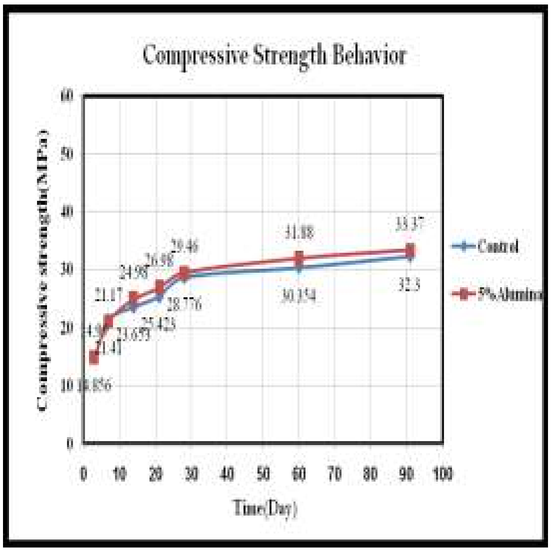

Figure 10: Compressive strength for (5%) nano (Al_2O_3) addition

II- Flexural strength results

Mortar prisms were tested according to the specification (EN 196-1) which found the flexural strength and compare between control and specimens with nano materials addition. Flexural strength of control mortar with (1%) nano-silica (SiO_2) mortar is slightly higher than that for control mortar (about 3%). Increasing nano silica up to (2 and 3%) improve the flexural strength, these behaviors can be seen in Figures 11, 12, 13, 14 and 15 respectively. Then the behaviors of flexural strength decreases when the nano silica addition increases up to (5%). This is shown in Figures 16 -19.

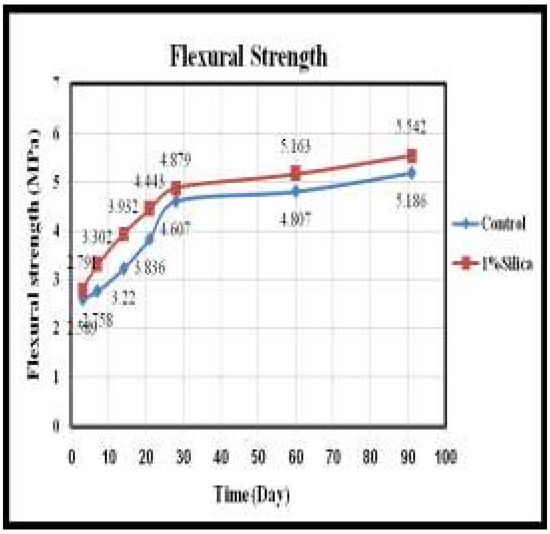

Figure 11: Flexural strength for (1%) nano (SiO_2) addition

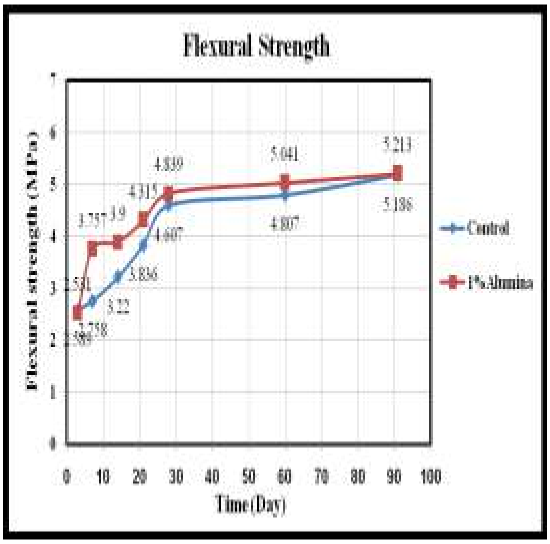

Figure 12: Flexural strength for (1%) nano (Al_2O_3) addition

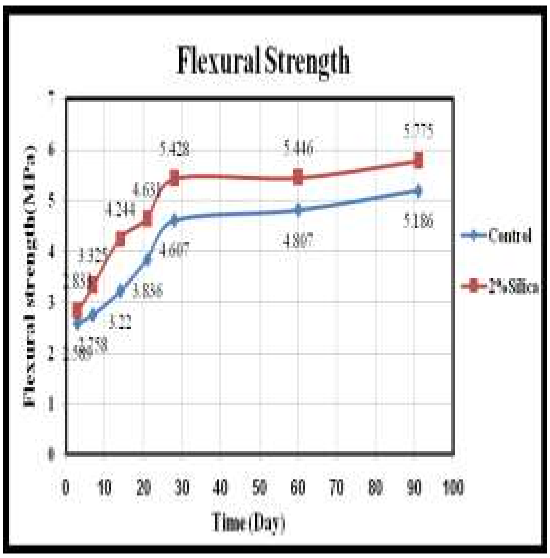

Figure 13: Flexural strength for (2%) nano (SiO_2) addition

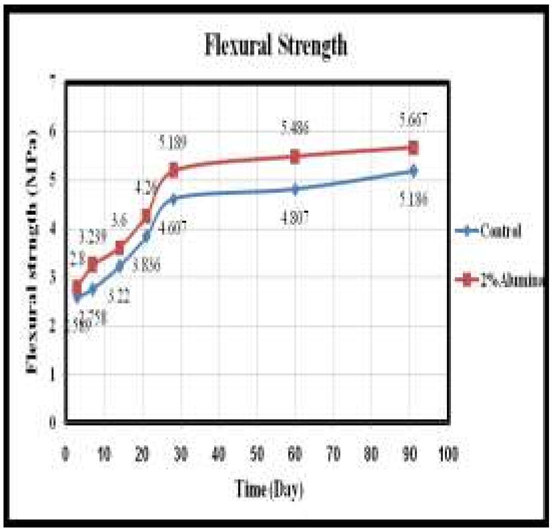

Figure 14: Flexural strength for (2%) nano (Al_2O_3) addition

The increasing in the flexural strength is because of rapid consuming of ($Ca(OH)_2$) which had happened during the hydration of Portland cement at early ages related to the high reactivity of nano-(SiO_2) particles. This was happened because of extreme pozzolanic characteristic reaction of silica nanostructures and formation of the dense gel of (calcium-silicate-hydrate (C-S-H)) and high micro-filling characteristic of these particles. So, when the proportion of nano-silica addition up to (3%) an ideal behavior will be noticed. For the case of adding (nano-Al_2O_3), the flexural strength of mortar will be improved, this can be seen in Figures 12 and 13 respectively. Then with nano alumina loaded more up to (5%) the flexural strength begin decreases but the amount of strength remain more than control samples. The decreases can be considered because of agglomeration caused by nano particles addition.

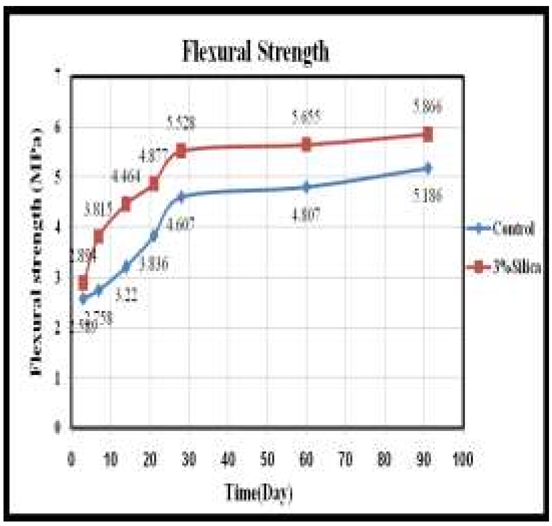

Figure 15: Flexural strength for (3%) nano (SiO_2) addition

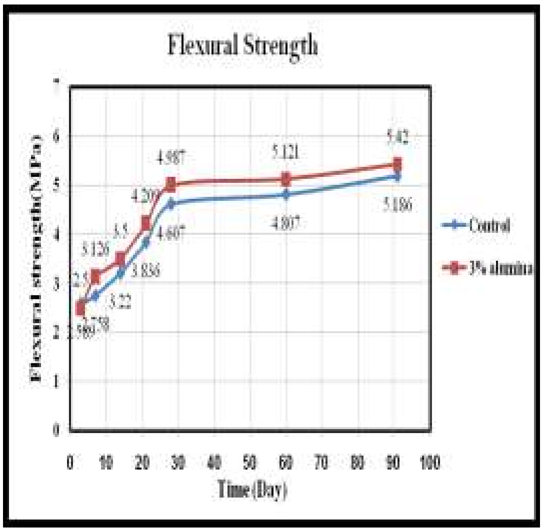

Figure 16: Flexural strength for (3%) nano (Al_2O_3) addition.

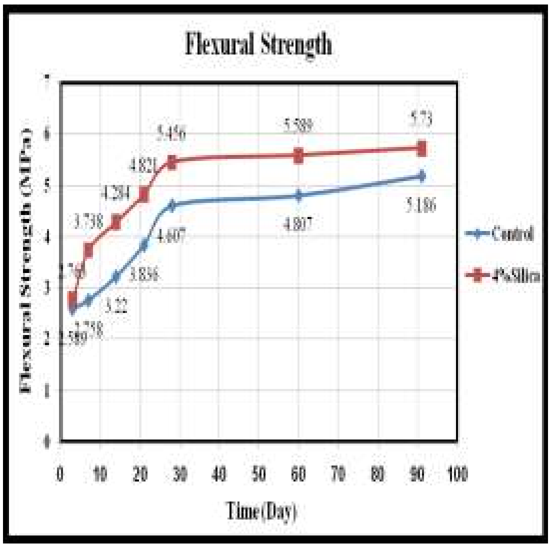

Figure 17: Flexural strength for (4 %) nano (SiO_2) addition.

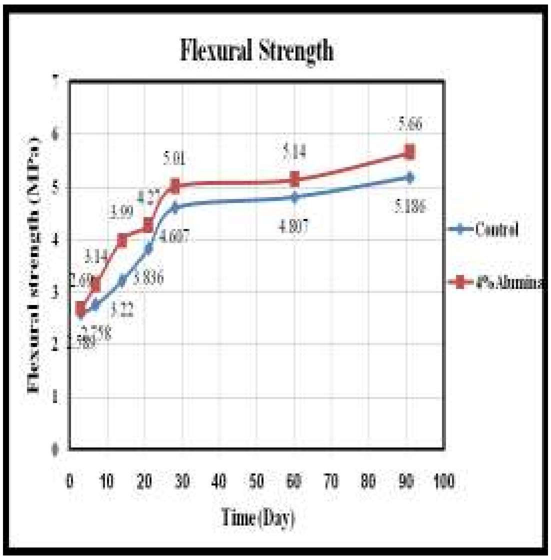

Figure 18: Flexural strength for (4%) nano (Al_2O_3) addition.

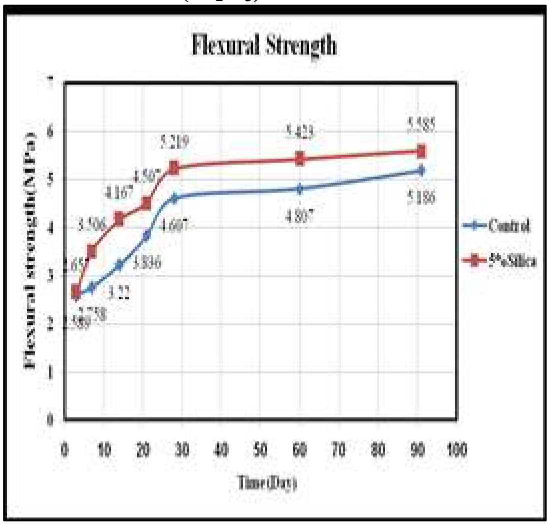

Figure 19: Flexural strength for (5%) nano (SiO_2) addition.

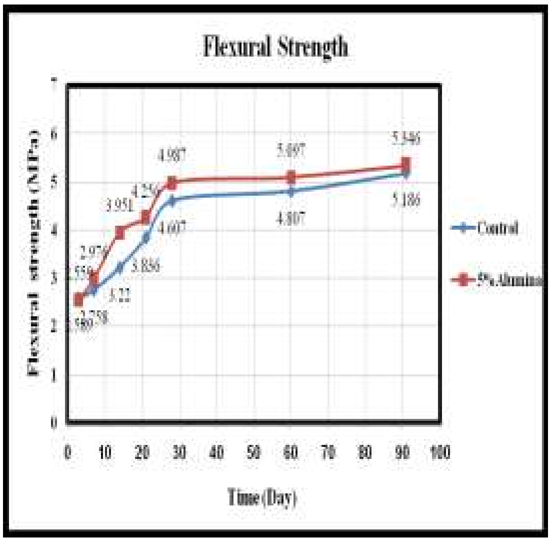

Figure 20: Flexural strength for (5%) nano (Al_2O_3) addition.

4. Conclusions

According to the results from the tests, the following points can be concluded:

1. The pozzolanic reactions were affected by the nano silica (SiO_2) additives which helps in the formation of additional (C-S-H) and the consumption of ($Ca(OH)_2$).
2. At all curing ages, Compressive strength of mortar cubes cast contain nano silica (SiO_2) was higher than containing the same amount of nano Alumina (Al_2O_3).
3. The enhancement of compressive strength was (42%) above control mortar at (91 days) by adding nano (SiO_2); whereas the enhancement of

compressive strength was (3%) by adding nano (Al_2O_3) for same curing time.
4. The enhancement of flexural strength was (13%) at (91 days) above control mortar by adding nano (SiO_2); whereas the enhancement of flexural strength was (3%) by adding nano (Al_2O_3) for same curing time.
5. Nano particles improve flexural strength, compressive strength of all specimens containing both nano materials (nano silica and alumina).
6. Nano (SiO_2) is better than nano (Al_2O_3) as additives to mortars in enhancement of some mechanical properties of these mortars.

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