Performance of Nanoparticles Combination (SiO$_2$, Al$_2$O$_3$) on Highway Concrete Pavement

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Abstract. Nano materials are being used in concrete technology to enhance the sustainability of performance grade for the pavement construction. In this paper, test investigations are conducted to study the addition effect of nanoparticles combination (Al$_2$O$_3$, SiO$_2$) with the average diameter of 20 nm and with different acceptable percentages (Al$_2$O$_3$: 0% and SiO$_2$: 0 %), (Al$_2$O$_3$: 0.5% and SiO$_2$: 0.5 %), (Al$_2$O$_3$: 0.5% and SiO$_2$: 1 %), (Al$_2$O$_3$: 1% and SiO$_2$: 0.5 %), (Al$_2$O$_3$: 1% and SiO$_2$: 1.5 %), (Al$_2$O$_3$: 1% and SiO$_2$: 0.5 %), (Al$_2$O$_3$: 1.5% and SiO$_2$: 0.5 %) and (Al$_2$O$_3$: 1% and SiO$_2$: 1 %) by weight of cement on the mechanical properties (compressive strength, flexural strength and modulus of elasticity) and the thickness design of concrete pavement. The optimal combination which contributed to the highest values of mechanical properties at (28) days in order to maintain the workability requirement of nano concrete mixes was found (Al$_2$O$_3$: 1% and SiO$_2$: 0.5 %) which associated with the decrement in concrete pavement thickness, when all other factors were held constant. It is concluded that cement modification with nano particles (combination of SiO$_2$ and Al$_2$O$_3$) increased compressive strength, flexural strength and modulus of elasticity though decreased concrete pavement thickness.

Keywords: Nanoparticles, Nano SiO$_2$, Nano Al$_2$O$_3$, Pavement Thickness, Mechanical Properties.

1. Introduction

Highways have a significant role in the infrastructure of countries. Their building and maintenance consume large amount of energy. The minimization of the lifetime energy utilized in roads can result in positive outcomes for sustainable development. Durability and safety are the important aspects need to be incorporated in highways concrete pavement for low maintenance which can result in reducing traffic delays, which is a significant benefit on some of the already congested roads.

The physical and mechanical characteristics of concrete (compressive strength, modulus of elasticity, setting time, workability and water absorption) generally depend on the size of each contentious particle which showed a different behaviour in nano scale [1].

The study on the properties of various kinds of nano materials in concrete is significant to compare the results. In most of studies, the compressive strength of concrete has been improved by utilizing nano materials like nano SiO$_2$. Also, it was indicated that nano Al$_2$O$_3$ significantly increased the modulus of elasticity and improved the durability properties.[1]

Cement binder is the primary active part of concrete particles which has recently been used as admixture like Nano silica which can improve the compressive strength of the cement paste. This is because of the
filler effect of nano-size particles making dense composition, and it accelerates the hydration process by the pozzolanic reaction that forming C-S-H gel quietly and strengthen the composite product [2]. The novelty of this paper is the prospect of using combination of nano particles (SiO$_2$ and Al$_2$O$_3$) rather than utilizing each one individually (that are usually adopted in pervious papers) for achieving better concrete pavement performance.

1.1 Mechanical Performance of Nano Concrete Layer

The incorporation of alumina nanoparticles can lower the workability of fresh concrete as well as enhancing the compressive strength of concrete in comparison with the control ones. These were also obtained by nano titanium dioxide, nano zinc oxide and nano silica for sustainable development of concrete layers. However, the nano alumina reduced the initial setting time of concrete composite. Scanning Electronic Microscope (SEM) almost was carried out for micro analysis which indicated that nano particles was uniformly distributed by enhancing the microstructure of concrete [3]. Due to the high surface area of nanoparticles, the pozzolanic activity should be investigated for describing the achieved benefit depending on strength activity index. This index represents the ratio between the strength of control mortar and the strength of mortar incorporating nano particle as a partial substitution (10%) at 28 days normal curing [4].

On the other hand, one of the main problem of incorporating the nano particle is the method of applying due to highly agglomeration. Different methods of de agglomeration should be adopted such as sonication, homogenization, and stirring. Adding the superplasticiser may help the process of nano particles dispersion [5]. Thus, the utilization of nano particles requires special attention.

Concrete is a highly heterogeneous product with inherent chemical, physical and mechanical characteristics because cement and water reacts with each other producing calcium silica hydrate which is responsible for concrete strength. Nano materials are being used in concrete technology to enhance the performance and sustainability of the constituent materials. Nano materials, as mentioned in the most of previous studies, have been used as an admixture for the cementitious material to enhance the mechanical and durability characteristics related to the physico-chemical reactions [6]. Therefore, nano silica technology is an new field of emergency in national science and engineering. This is due to its application in various field such as the development of crack free concrete toward sustainable construction [7].

Nanotechnology has a substantial potential to produce new kind of concrete which is more durable, stronger and has desirable stress-strain behaviour and probably having the entire characteristics. Nanotechnology has huge potential to result in new generation of concrete stronger and more durable with desired stress-strain behaviour and possibly with the whole range of new induced properties. Improved flexural behaviour of the concrete may cause decrease in the thickness of slab utilized in concrete pavement construction. The incorporation of nano materials (such as SiO$_2$) improved the density and strength of concrete since they act not only as a filler to enhance microstructure, but also as active value to spark pozzolanic action [8].

In the nano engineering sector of concrete, new developments are undertaken. One of the most promoting involves the development of high-performance cement binder reinforced with nanoparticles, resulting in concrete with outstanding characteristics of moisture, temperature, stress-sensing capacity. Eco-binder were adjusted with nanoparticles and manufactured with substantial low amount of Portland cement [9].

Therefore, nanoparticles are beneficial for concrete in various applications whether these are in improving hardened properties or in durability ones, in spite of some adders effects on fresh properties. Hence, Nanoparticles have many goals prospect in construction field.

For the beneficial utilization of nanoparticles in concrete, their cost-effectiveness need to be examined. Although nano materials have high initial cost, it is essential to consider the enhanced concrete durability.

The healthy risk of nano-material should also be investigated and should be avoided at all time [10].
1.2 Nano SiO:
Nano silica (N.S) addition in cement paste or concrete can result in different effects. The more rapid cement hydration in the presence of N.S was due to pozzolanic reactivity (chemical reactivity) and considerable surface activity [11]. Nano silica mixed with cement to form CSH (calcium silicate hydrate) which accumulates in the micro pores, making the microstructure more compact and uniform [12]. The utilization of N.S substantially decreased the amount of cement required. The small specific surface of N.S allows it to interface in the voids present in the hydrated cement paste. In addition to the CSH formation responsible for the concrete strength, the permeability also reduced against chloride [13].

1.3 Nano Al2O3:
Nano Al2O3 particles were very effective in enhancing the mechanical characteristics of the concrete. Mixes containing 3% nano Al2O3 (N.A) particles showed better mechanical properties than control concrete [14]. The use of (N.A) resulted in production of C-A-S (calcium- aluminum- silicate) gel in concrete by reaction with calcium hydroxide from hydration and the reaction rate depends on surface area (finesses) thus causing fast increase in number of highly active atoms that resulted in fast hydration [15]. The use of N.S and N.A enhances the compressive strength because the combination of them highly decreases the capillary, so the density of the interfacial zone increases and the compressive strength of the concrete improves higher than the individual use of the N.S and N.A [16].

2. Experimental Work:

2.1. Material:
The material used to prepare the test samples in this research were:
- Water: Tap (drinking) water, free of oils, acids, alkaline, is suitable for samples preparation and curing.
- Fine Agg.: Al-Ekaider natural sand with most particles smaller than 4.75 mm was used based on Iraqi requirements (No.45/1980 - Fine Agg. Zone No.2) [17].
- Coarse Agg.: Crushed gravel of all particles smaller than 20 mm was used based on Iraqi requirements (No.45/1980 - coarse Agg. Zone No. [17].
- Cement: Al-Jeser sulfate resisting cement practiced in Iraq was used. The cement conforms to the Iraqi requirements (No.5/1985 - tyre v) [18].
- Nano materials: Nano silica (SiO2) with high purity reach to (99%), particles size around (30 nm) with pozzolanic active index (P.A.I.) (139%) was used. While nano alumina (Al2O3) used also has high purity (99%) but of particle size (40nm) and with (P.A.I) (143%).
- High range water reducing admixture (superplasticizers).
- Hyperplast (PC 175) is high performance superplasticizer, used as dispersing additives in order to overcome the nano particles agglomeration and to ensure reactive surface for the filling effect and C-S-H formation.
- Colloidal polymer resins admixture.
- Poly Vingle alcohol (PVA) which is colloidal materials (solid white granules) in water that assists in the dispersion of nano materials.

2.2. Concrete Mix:
The concrete mix was prepared to achieve the requirements of concrete layer construction (C30) according to ACI 211.1-C30 [19].

2.2.1. Types of Nano Mixing Methods:
For better performance, the main mixing methods were as follows, which were used to solve the problem of nano admixture agglomeration during addition for cement binder within nano modified concrete mix. **Wet mixing method:** nano combination admixture was mixed with first part of mixing water in the presence of PVA (1% by cementitious binder) by using stirring device as shown in Figure (1-a) for (10 min period). Then, the solution was treated by sonication device for (5 min period) with 50W power and temperature (25°C) as shown in Figure (1-b). The second part of mixing water was mixed with...
superplasticizer (0.5 liter/100 Kg of cementitious material) by using electrical mixer. The final step of preparing nano modified concrete mixture was achieved by adding all mentioned solutions with the residue mixing water to other concrete components (sand, gravel) and compacting using vibrating table.

Figure (1). Devices For Wet Mixing Method

**Dry mixing method:** nano combination material was added to a part of cement binder in small container and mixed by using rotary mixer for (25 min period) as shown in Figure 2. The first part of mixing water was mixed with the superplasticizer (0.5 liter/100 Kg of cementitious material) by using electrical mixer. The final step of preparing nano combination concrete mixes were carried out by adding the solution and modified cement to the other materials (residual cement binder, residual mixing water, sand, and gravel) and compacting using vibrating table.

Figure (2). Rotary Device For Dry Mixing Method

**2-2-2 XRD Test and Nano Admixtures**
The crystallinity of nano particles were determined by X-ray diffraction (XRD) which considers the most useful technique for identification of microstructure as illustrated in Figures (3) & (4). The figures showed the peak values associated with SiO₂ and Al₂O₃ respectively for more insurance.
Figure (3) . XRD Analysis of Nano (SiO$_2$) Particles (Done by Researcher in Germany-Iraqi Lab at College of Science, University of Baghdad)

Figure (4) . XRD Analysis of Al$_2$O$_3$ Nano Particles (Done by Researcher in Germany-Iraqi Lab at College of Science, University of Baghdad)

2.2.3. XRF Test of Nano Admixtures

X-ray - Fluorescence is a simple nondestructive method for testing the quantitative and qualitative analysis of elemental compression of nano silica and nano alumina materials as shown in Tables (1) & (2). The tables indicated the high degree of purity for each of the utilized nano admixtures SiO$_2$ and Al$_2$O$_3$ respectively.
**Table (1): XRF Results of Nano (SiO$_2$) Particles**

| Sample Name Description | SiO$_2$ nano | Date of Receipt Method | 03/11/2019 12:40 TurboQuant-Powder |
|-------------------------|-------------|------------------------|-------------------------------------|
| Z          | Symbol | Element | Norm. Int. | Concentration | Abs. Error |
| 12         | MgO    | Magnesium | 0.0000       | < 0.0034 % | (0.0) % |
| 13         | Al2O3  | Aluminum | 92.1309      | 1.337 % | 0.021 % |
| 14         | SiO2   | Silicon | 3553.9665    | 217.3 % | 0.1 % |
| 15         | P2O5   | Phosphorus | 321.0267      | 0.9260 % | 0.0036 % |
| 16         | SO3    | Sulfur | 30.5036      | < 0.00050 % | (0.0) % |
| 17         | Cl     | Chlorine | 157.2908      | 0.02818 % | 0.00017 % |
| 19         | K2O    | Potassium | 0.0000       | < 0.0012 % | (0.0) % |
| 20         | CaO    | Calcium | 32.8700      | 0.1493 % | 0.0023 % |
| 22         | TiO2   | Titanium | 18.3218      | 0.0745 % | 0.0016 % |
| 23         | V2O5   | Vanadium | 0.6745       | 0.0059 % | 0.0027 % |
| 24         | Cr2O3  | Chromium | 5.3519       | 0.00088 % | 0.00005 % |
| 25         | MnO    | Manganese | 7.9706       | 0.00504 % | 0.00021 % |
| 26         | Fe2O3  | Iron | 343.9652      | 0.1341 % | 0.0005 % |
| 27         | CoO    | Cobalt | 1.6885       | < 0.00090 % | (0.00020) % |
| 28         | NiO    | Nickel | 14.2836      | 0.00205 % | 0.00006 % |
| 29         | CuO    | Copper | 5.7928      | 0.00069 % | 0.00006 % |
| 30         | ZnO    | Zinc | 21.8309      | 0.00190 % | 0.00004 % |
| 31         | Ga     | Gallium | 0.0000       | < 0.00005 % | (0.0) % |
| 32         | Ge     | Germanium | 0.0000       | < 0.00005 % | (0.0) % |
| 33         | As2O3  | Arsenic | 0.0000       | < 0.00007 % | (0.0) % |
| 34         | Se     | Selenium | 0.0000       | < 0.00005 % | (0.0) % |
| 35         | Br     | Bromine | 2.6583      | 0.00007 % | 0.00001 % |
| 37         | Rb2O   | Rubidium | 10.0097      | 0.00178 % | 0.00001 % |
| 38         | SrO    | Strontium | 52.2717      | 0.00086 % | 0.00001 % |
| 39         | Y      | Yttrium | 62.2349      | 0.00085 % | 0.00001 % |
| 40         | ZrO2   | Zirconium | 10.7622      | 0.000327 % | 0.00009 % |
| 41         | Nb2O5  | Niobium | 0.5148      | 0.00013 % | 0.00004 % |
| 42         | Mo     | Molybdenum | 5.2111      | 0.00089 % | 0.00005 % |
| 47         | Ag     | Silver | 1.7532      | 0.00054 % | 0.00013 % |
| 48         | Cd     | Cadmium | 1.9281      | 0.00002 % | 0.00001 % |
| 50         | SnO2   | Tin | 0.0000      | < 0.00039 % | (0.0) % |
| 51         | Sb2O5  | Antimony | 2.1855       | 0.00040 % | (0.0) % |
| 52         | Te     | Tellurium | 0.0000      | < 0.00030 % | (0.0) % |
| 53         | I      | Iodine | 0.0000      | < 0.00030 % | (0.0) % |
| 55         | Cs     | Cesium | 0.0000      | < 0.00040 % | (0.0) % |
| 56         | Ba     | Barium | 2.6371      | 0.00020 % | 0.00002 % |
| 57         | La     | Lanthanum | 2.2632      | 0.00020 % | 0.00002 % |
| 58         | Ce     | Cerium | 2.3554      | 0.00020 % | 0.00002 % |
| 72         | Hf     | Hafnium | 3.1036      | 0.00034 % | 0.00003 % |
| 73         | Ta2O5  | Tantalum | 31.8206      | 0.00795 % | 0.00014 % |
| 74         | WO3    | Tungsten | 2.2527      | 0.00016 % | 0.00002 % |
| 80         | Hg     | Mercury | 3.1389      | 0.00018 % | 0.00002 % |
| 81         | Ti     | Thallium | 4.9419      | 0.00020 % | 0.00002 % |
| 82         | PbO    | Lead | 11.9427      | 0.00073 % | 0.00003 % |
| 83         | Bi     | Bismuth | 0.0000      | < 0.00010 % | (0.0) % |
| 90         | Th     | Thorium | 13.6399      | 0.00056 % | 0.00002 % |
| 92         | U      | Uranium | 12.4055      | 0.00019 % | 0.00001 % |

* Sum of concentration: 220.03 %

* done by researcher in Germany-Iraqi Lab at College of Science, University of Bagdad
Table (2) . XRF Results of Al₂O₃ Nano Particles

| Sample Name Description | Al₂O₃ nano | Date of Receipt Method | 03/11/2019 12:35:23 TurboQuant-Powders |
|-------------------------|------------|------------------------|---------------------------------------|
| Z Symbol Element | Norm. Int. | Concentration | Abs. Error |
| 12 | MgO Magnesium | 30.9113 | 0.584 % | 0.023 % |
| 13 | Al₂O₃ Aluminum | 10468.2744 | 72.36 % | 0.06 % |
| 14 | SiO₂ Silicon | 14.3687 | 0.0603 % | 0.0058 % |
| 15 | P₂O₅ Phosphorus | 277.3465 | 0.4908 % | 0.0036 % |
| 16 | SO₃ Sulfur | 23565.1276 | 22.81 % | 0.02 % |
| 17 | Cl Chlorine | 97.7489 | 0.00933 % | 0.00012 % |
| 19 | K₂O Potassium | 4.3755 | 0.0270 % | 0.0026 % |
| 20 | CaO Calcium | 489.9206 | 0.1974 % | 0.0031 % |
| 21 | TiO₂ Titanium | 11.6765 | 0.0394 % | 0.0014 % |
| 23 | V₂O₅ Vanadium | 0.0000 | < 0.0029 % | (0.0028 %) |
| 24 | Cr₂O₃ Chromium | 9.7836 | 0.00413 % | 0.00017 % |
| 25 | MnO Manganese | 3.8583 | 0.00210 % | 0.00020 % |
| 26 | Fe₂O₃ Iron | 163.9206 | 0.04617 % | 0.00029 % |
| 27 | CoO Cobalt | 0.5567 | < 0.00309 % | (0.0 %) |
| 28 | NiO Nickel | 25.7802 | 0.00346 % | 0.00007 % |
| 29 | CuO Copper | 1.2925 | 0.00014 % | 0.00006 % |
| 30 | ZnO Zinc | 419.8392 | 0.03244 % | 0.00013 % |
| 31 | Ga Gallium | 171.5064 | 0.0053 % | 0.00006 % |
| 32 | Ge Germanium | 0.0000 | < 0.00005 % | (0.0 %) |
| 33 | As₂O₃ Arsenic | 0.0000 | < 0.00070 % | (0.0 %) |
| 34 | Se Selenium | 0.0000 | < 0.00005 % | (0.0 %) |
| 35 | Br Bromine | 0.0000 | < 0.00005 % | (0.0 %) |
| 37 | Rb₂O Rubidium | 7.5965 | 0.00011 % | 0.00001 % |
| 38 | SrO Strontium | 53.2799 | 0.00747 % | 0.00001 % |
| 39 | Y Yttrium | 21.0680 | 0.00024 % | 0.00002 % |
| 41 | ZrO₂ Zirconium | 1.2710 | 0.00029 % | 0.00005 % |
| 42 | Nb₂O₅ Niobium | 0.0000 | < 0.00014 % | (0.0 %) |
| 45 | Mo Molybdenum | 7.2643 | 0.00098 % | 0.00004 % |
| 47 | Ag Silver | 4.0819 | 0.00082 % | 0.00011 % |
| 48 | Cd Cadmium | 3.9744 | 0.00037 % | 0.00005 % |
| 50 | SnO₂ Tin | 5.7733 | 0.00055 % | 0.00004 % |
| 51 | Sb₂O₅ Antimony | 5.9294 | 0.00013 % | 0.00005 % |
| 52 | Te Tellurium | 7.5381 | 0.00057 % | 0.00004 % |
| 53 | I Iodine | 5.9542 | 0.00078 % | 0.00003 % |
| 55 | Cs Cesium | 0.0000 | < 0.00040 % | (0.0 %) |
| 56 | Ba Barium | 8.6282 | 0.00036 % | 0.00004 % |
| 57 | La Lanthanum | 0.0000 | < 0.00020 % | (0.0 %) |
| 58 | Ce Cerium | 0.0000 | < 0.00020 % | (0.0 %) |
| 72 | Hf Hafnium | 1.6750 | 0.00011 % | 0.00003 % |
| 73 | Ta₂O₅ Tantalum | 33.1656 | 0.00738 % | 0.00013 % |
| 74 | WO₃ Tungsten | 1.1037 | < 0.00013 % | (0.0 %) |
| 80 | Hg Mercury | 1.7815 | 0.00007 % | 0.00002 % |
| 81 | Th Thallium | 1.4862 | < 0.00005 % | (0.0 %) |
| 82 | PbO Lead | 5.7850 | 0.00031 % | 0.00003 % |
| 83 | Bi Bismuth | 0.0000 | < 0.00010 % | (0.0 %) |
| 90 | Th Thorium | 3.8728 | 0.00013 % | 0.00003 % |
| 92 | U Uranium | 7.1114 | < 0.00010 % | (0.0 %) |

Sum of concentration: 96.69 %

* done by researcher in Germany-Iraqi Lab at College of Science, University of Bagdad

2.3. Testing Procedure

2.3.1. Fresh Concrete Test
The slump measurement of each mix of natural concrete and nano combination concrete were performed immediately after mixing according to (ASTM C143-89) [20].

2.3.2. Hardened concrete test:
- Compressive strength: The cubic specimens prepared for the compressive strength test were manufactured with dimensions of (150x150x150 mm) according to (ASTM C39-83) [21]. The specimens were examined by utilizing the saturated testing machine having capacity of 2000 kN.
• Flexural strength test: The samples of modulus of rupture were manufactured in accordance with (ASTM C78-02) [22] with dimensions of (100X100X400 mm). These prisms were tested by flexural machine of (2000 kN) capacity.

• Modulus of Elasticity: The related test was carried out in accordance with (ASTM C 469-02) [23]. The cylindrical samples were fabricated with dimensions of (150 D X 300 H mm), fixed in compressive machine with the presence of strain-measuring equipment and the dial gauge of (0.001 mm) accuracy.

• Microstructural analysis: This test was carried out by adopting (SEM) scanning electron microscope and (EDS) energy dispersive spectroscopy for control and nano combination concrete samples. They are of a same contemporary techniques used for phase identification micrograph and chemical channelization of unknown elements in the hardened cement paste of concrete which give a clear idea about the development and distribution of the new hydrated products [24].

3. Results And Discussion

3.1. Fresh Properties of Control And Nano Concrete Mixes

Due to the large surface area (small particle size of nano admixtures), the initial setting time was reduced and the slump value was decreased that effect on workability limitation behavior of nano concrete mixes due to the high degree of agglomeration in which the adopted limitation is (25-75 mm slump). All results were within the accepted limitations except those of M5 (1.5% Al₂O₃ + 0.5% SiO₂) (15-20mm) and M6 (1% Al₂O₃ + 1% SiO₂) (20mm). The results were shown in Figure (5).

![Figure 5](image_url)

Figure (5). Effect of Nano Concrete Mixes Type on The Slump Value For Fresh State

3.2. Hardened Properties of Control And Nano Concrete Mixes

Nano admixtures provides both pozzalanic activities due to high surface area and packing ability with significant role in filling voids, thus it increases the mechanical properties. Moreover, it can participate in hydration process to create C-S-H product through reaction with Ca(OH)₂ [10]. The increase of strength is the most important benefit of using nano materials like nano combination as shown in Table (3) and Figures (6, 7 & 8).

| Concrete Mix | Slump (mm) |
|--------------|------------|
| M1           | 60         |
| M2           | 40         |
| M3           | 20         |
| M4           | 0          |
| M5           | 60         |
| M6           | 40         |

![Table 3](image_url)

Table (3). Tests Values of Fresh Property (Slump) And Hardened Properties at Age 28 Days For Control And Nano Combination Concrete
| Mix Type | Slump (mm) | Compressive Strength (MPa) | Flexural Strength (MPa) | Modulus of Elasticity (GPa) |
|----------|------------|-----------------------------|-------------------------|-----------------------------|
| Control mix (M₀) (0% Al₂O₃ + 0% SiO₂) | 60 | 34.78 | 4.95 | 32.21 |
| Mix with (0.5% Al₂O₃ + 0.5% SiO₂) (M₁) | 45 | 37.51 | 5.11 | 40.31 |
| Mix with (0.5% Al₂O₃ + 1% SiO₂) (M₂) | 40 | 41.15 | 6.66 | 47.87 |
| Mix with (0.5% Al₂O₃ + 1.5% SiO₂) (M₃) | 35 | 36.14 | 5.70 | 42.02 |
| Mix with (1% Al₂O₃ + 0.5% SiO₂) (M₄) | 35 | 45.5 | 8.11 | 54.36 |
| Mix with (1% Al₂O₃ + 0.5% SiO₂) (M₅) | 20 | 42.37 | 7.11 | 51.54 |
| Mix with (1% Al₂O₃ + 1% SiO₂) (M₆) | 20 | 38.6 | 5.99 | 45.37 |

**Figure (6)**. Effect of Nano Concrete Mixes Type on The Compressive Strength at (28 Days Age)

**Figure (7)**. Effect of Nano Concrete Mixes Type on The Flexural Strength at (28 Days Age)
When particles are uniformly distributed in concrete, nano particles fill cement pores and act as concrete core which stick strongly to hydrated concrete. Due to its intense activity, cement hydration is rapid and concrete strength increases.

The SEM pictures and EDS images of concrete mix, demonstrated different comparisons between the control mix $M_0$ (0% Al$_2$O$_3$ + 0% SiO$_2$) and the optimal combination nano concrete mix $M_4$ (1% Al$_2$O$_3$ + 0.5% SiO$_2$). The first picture of $M_0$ showed fabricated ettringete matrix while the second picture of $M_4$ appeared dense with uniform distribution of conducted gel with very few pores. Figure (9) & (10) showed all the mentioned facts with all related phases.

![SEM Micrograph of $M_0$.](image1.png)

![EDS images of $M_0$.](image2.png)

**Figure (9).** Microstructure analysis Tests of control concrete mix
Figure (10). Microstructure analysis Tests of nano concrete mix (1% Al₂O₃ + 0.5% SiO₂)

4. Thickness Design of Nano Concrete Layer
The thickness of concrete layer utilized in rigid highway pavement was designed in accordance to AASHTO Guide [25]. All mixes were prepared to withstand the same conditions. Table (4) showed the comparison between control mix (0% nano combination addition) and mixes contain different percentages of nano combination admixtures depending on layer thickness. The mixes incorporated nano combination admixture provided lower thickness than the control mixes due to their high values of Modulus of elasticity and Flexural strength.

Table (4): Calculated Thickness Values of Concrete Layer For Control And Nano Combination Mixes

| Mix Type | W₁₈ x 10⁶ (pci) | K (pci) | MR (psi) | E x 10⁶ (psi) | H (inch) |
|----------|-----------------|---------|----------|---------------|----------|
| M₀       | 60              | 200     | 718      | 4.67          | 13.93    |
| M₁       | 60              | 200     | 741      | 5.84          | 5.97     | 13.81    | 12.61    |
| M₂       | 60              | 200     | 966      | 6.94          | 7.08     | 12.12    | 11.52    |
| M₃       | 60              | 200     | 827      | 6.09          | 6.34     | 13.07    | 11.92    |
| M₄       | 60              | 200     | 1176     | 7.88          | 8.09     | 11.00    | 10.52    |
| M₅       | 60              | 200     | 1031     | 7.47          | 7.59     | 11.75    | 11.29    |
| M₆       | 60              | 200     | 869      | 6.58          | 6.83     | 12.77    | 11.81    |

5. Conclusion:
According to the results of the mechanical properties, the following points can be concluded:

1. The combination of various types and size of (nano additives) reduced the total volume of voids between aggregates within nano concrete mixes.
2. From microstructure analysis by SEM, the nano alumina and nano silica particles filling the pores also reduced the content of Ca(OH)₂ within the hydration products. These nano particles participated in the pozzalanic reaction resulting also in additional C-S-H gel.
3. The workability of concrete decreased with the addition of nano particles combination for all nano concrete mixes in spite of combination percentages.
4. Well dispersed nano particles combination especially of optimum combination dosage, acted as centers of crystallization of cement hydrates, therefore accelerating the hydration, improving the hardened properties and saving in construction cost by reducing the produced thickness of concrete pavement. That the reduction in thickness of set the relatively high cost of nano admixtures.
5. Optimum combination dosage of nano particles (nano alumina 1% + 0.5% nano silica) which related with increment rate reached to 41%, 79%, and 73% for compressive strength, flexural
strength and modulus of elasticity respectively at (28 curing days) depending on the more effective method (dry mixing method). Whereas, for wet mixing method, the increment rate of same properties reached to 31%, 64%, and 69% respectively. Therefore, the decrement rate reach to 25% for thickness of nano concrete pavement from dry mixing method and reached to 21% from wet mixing method.

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