

## Influence of Al<sub>2</sub>O<sub>3</sub> nanoparticles on the compressive strength and workability of blended concrete

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**Abstract:** The compressive strength and workability of concrete by partial replacement of cement with nano-phase Al<sub>2</sub>O<sub>3</sub> particles. Al<sub>2</sub>O<sub>3</sub> nanoparticles with the average diameter of 15 nm were used with four different contents of 0.5%, 0.1%, 1.5% and 2.0% by weight. The results showed that the use of nano-Al<sub>2</sub>O<sub>3</sub> particles up to maximum replacement level of 2.0% produces concrete with improved strength. However, the ultimate strength of concrete was gained at 1.0 wt% of cement replacement. The workability of fresh concrete was decreased by increasing the content of Al<sub>2</sub>O<sub>3</sub> nanoparticles. It is concluded that partial replacement of cement with nanophase Al<sub>2</sub>O<sub>3</sub> particles improves the compressive strength of concrete but decreases its workability. [Journal of American Science 2010;6(5):6-9]. (ISSN: 1545-1003).

**Key words:** Al<sub>2</sub>O<sub>3</sub> nanoparticles; concrete; compressive strength; workability.

### 1. Introduction

Portland cement-based binders are the primary active components of concretes used in most modern construction. The other components are water and both fine and coarse aggregate. Binders are made from Portland 'clinker' ground together with a little calcium sulfate, and frequently also contain fine mineral powders such as limestone, pozzolan (typically volcanic ash), fly ash (usually from coal-burning power plants) and granulated blast furnace slag. Such powders are referred to as supplementary cementitious materials (SCMs) since they are used to replace some of the more expensive clinker. Chemical admixtures such as superplasticisers and air-entraining agents can be added in small amounts to modify the properties of a concrete for specific applications.

Another type of admixtures recently used are nanoparticles. However, there are few reports on incorporation of nanoparticles in cement-based concrete. Hui et al. (2003) [1] investigated the properties of cement mortars blended with nanoparticles to explore their super mechanical and smart (temperature and strain sensing) potentials. Also useful applications of nano-SiO<sub>2</sub> are addressed by the Fuji Chimera Research Institute (2002). However, until now, research performed over the years has been mainly aimed at achieving high mechanical performance with cement replacement materials in micro level. Recently, the effect of nano-SiO<sub>2</sub> particles by adding to blended concrete has been

reviewed by Nazari et al. (2010) [2]. Several researchers have demonstrated that the finer the SiO<sub>2</sub> particle sizes in micron level, the higher the compressive strength. But there is a lack of knowledge on effects of ultra fine and nano-size particles on concrete's properties. Lu and Young [3] achieved high strengths on compressed samples and Richard and Cheyrezy [4] developed Reactive Power Concretes (RPCs) with high compressive strength and appropriate fracture energy. The development of an ultrahigh strength concrete was made possible by the application of DSP (Densified System containing homogeneously arranged ultra-fine Particles) with super plasticizer and silica fume content [5].

In this work, the influences of nano-Al<sub>2</sub>O<sub>3</sub> on workability and compressive strength of binary blended concrete has been investigated. The reason for using Al<sub>2</sub>O<sub>3</sub> as a partial replacement by cement is the C-A-H (lime-alumina-calcium sulfate) gel formation in concrete. The major constituent of a pozzolan is the alumina that can be amorphous or glassy. This component reacts with calcium hydroxide produced from the hydration of calcium aluminates. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. Therefore, it is possible to add nano-Al<sub>2</sub>O<sub>3</sub> of a high purity (99.9%) and a high Blaine fineness value (60 m<sup>2</sup>/g) in order to improve the characteristics of cement mortars [5]. In this study an attempt has been made to prove that using new materials, it is possible to obtain HPC or HSC with slight increase in cost.

HPC and HSC are very useful in constructions and multistory buildings because they can decrease the cross-

sectional area of the structural fundamentals.

## 2. Materials and Methods

### 2.1. Materials and mixtures

#### 2.1.1. Cement

Ordinary Portland Cement (OPC) obtained from Holcim Cement Manufacturing Company of Malaysia conforming to ASTM C150 standard was used as received. The chemical and physical properties of the cement are shown in Table 1.

Table 1. Chemical and physical properties of Portland cement (Wt. %) Chemical properties

Material	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO
Cement	21.89	5.3	3.34	53.27	6.45
Material	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	Loss on ignition	
Cement	3.67	0.18	0.98	3.21	

Specific gravity: 1.7 g/cm<sup>3</sup>

#### 2.1.2. Nano- Al<sub>2</sub>O<sub>3</sub> particles

Nano- Al<sub>2</sub>O<sub>3</sub> with average particle size of 15 nm was used as received. The properties of nano- Al<sub>2</sub>O<sub>3</sub> particles are shown in Table 2.

Table 2. The properties of nano-Al<sub>2</sub>O<sub>3</sub>

Diameter (nm)	Surface Volume ratio (m <sup>2</sup> /g)	Density (g/cm <sup>3</sup> )	Purity (%)
15 ± 3	165 ± 12	< 0.1	>99.9

#### 2.1.3. Aggregates

Locally available natural sand with particles smaller than 0.5mm and fineness modulus of 2.25 and specific gravity of 2.58g/cm<sup>3</sup> was used as fine aggregate. Crushed basalt stored in the laboratory with maximum size of 15mm and specific gravity of 2.96 g/cm<sup>3</sup> was used as coarse aggregate.

#### 2.1.4. Mixture proportioning

A total of two series of mixtures were prepared in the laboratory trials. Series C0 mixtures were prepared as control specimens. The control mixtures were made of natural aggregates, cement and water. Series N were prepared with different contents of nano- Al<sub>2</sub>O<sub>3</sub> particles with average particle size of 15 nm. The mixtures were prepared with the cement replacement of 0.5%, 1.0%, 1.5% and 2.0% by weight. The water to binder ratio for all mixtures was set at 0.40 [9]. The aggregates for the mixtures consisted of a combination of crushed basalt and of fine sand, with the sand percentage of 30% by weight. The binder content of all mixtures was 550 kg/m<sup>3</sup>. The proportions of the mixtures are presented in Table 3.

### 2.2. Preparation of test specimens

Series N mixtures were prepared by mixing the course aggregates, fine aggregates and powder materials (cement and nano- Al<sub>2</sub>O<sub>3</sub> particles) in a laboratory concrete drum mixer. The powder material in the series C0 mixtures was only cement. They were mixed in dry condition for two minutes, and for another three minutes after adding the water. Slumps of the fresh concrete were determined immediately to evaluate the workability following the mixing procedure. Cubes of 100 mm edge were cast and compacted in two layers on a vibrating table, where each layer was vibrated for 10 s [10]. The moulds were covered with polyethylene sheets and moistened for 24 h. Then the specimens were demoulded and cured in water at a temperature of 20° C prior to test days. The compressive strengths tests of the concrete samples were determined at 7, 28 and 90 days. The reported results are the average of three trials.

Table 3. Mixture proportion of nano-Al<sub>2</sub>O<sub>3</sub> particles blended concretes

Sample designation	nano- Al <sub>2</sub> O <sub>3</sub> particles	Quantities (kg/m <sup>3</sup> )	
		Cement	nano- Al <sub>2</sub> O <sub>3</sub> particles
C0 (control)	0	550	0
N1	0.5	547.25	2.75
N2	1.0	544.50	5.50
N3	1.5	541.75	8.25
N4	2.0	539.00	11.00

Water to binder [cement + nano-Al<sub>2</sub>O<sub>3</sub>] ratio of 0.40, sand 492 kg/m<sup>3</sup>, and aggregate 1148 kg/m<sup>3</sup>

### 2.3. Compressive strength of nano-Al<sub>2</sub>O<sub>3</sub> particles blended concrete

Compressive strength of nano-Al<sub>2</sub>O<sub>3</sub> particles blended cement concrete cubes was determined as per ASTM C 39 after 7, 28 and 90 days of moisture curing.

### 2.4. Workability

Standard slump tests conforming to ASTM C143 were used to determine the workability of the concrete.

## 3. Experimental results and discussion

The compressive strength results obtained from the experimental investigations are shown in tables and the comparison between the results of workability test is presented in form of bar chart. All the values are the average of the three trails in each case in the testing program of this study. The results are discussed as follows.

### 3.1. Compressive strength

The compressive strength results of series C0 and N mixtures are shown in Table 4. Comparison of the results from the 7, 28 and 90 days samples shows that the

compressive strength increases with nano-Al<sub>2</sub>O<sub>3</sub> particles up to 1.0% replacement (N2) and then it decreases, although the results of 2.0% replacement (N4) is still higher than those of the plain cement concrete (C0). It was shown that the use of 2.0% nano-Al<sub>2</sub>O<sub>3</sub> particles decreases the compressive strength to a value which is near to the control concrete. This may be due to the fact that the quantity of nano-Al<sub>2</sub>O<sub>3</sub> particles (pozzolan) present in the mix is higher than the amount required to combine with the liberated lime during the process of hydration thus leading to excess silica leaching out and causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength [11]. Also, it may be due to the defects generated in dispersion of nanoparticles that causes weak zones.

Table 4. Compressive strength of nano-Al<sub>2</sub>O<sub>3</sub> particle blended cement mortars

Sample designation	nano- Al <sub>2</sub> O <sub>3</sub> particle (%)	Compressive strength (MPa)		
		7 days	28 days	90 days
C0 (control)	0	27.3	36.8	42.3
N1	0.5	30.4	41.1	44.1
N2	1.0	31.7	42.3	46.1
N3	1.5	31.9	42.8	45.3
N4	2.0	27.5	37.7	42.6

Water to binder [cement + nano-Al<sub>2</sub>O<sub>3</sub>] ratio of 0.40

The high enhancement of compressive strength in the N series blended concrete are due to the rapid consuming of Ca(OH)<sub>2</sub> which was formed during hydration of Portland cement specially at early ages related to the high reactivity of nano-Al<sub>2</sub>O<sub>3</sub> particles. As a consequence, the hydration of cement is accelerated and larger volumes of reaction products are formed. Also nano-Al<sub>2</sub>O<sub>3</sub> particles recover the particle packing density of the blended cement, directing to a reduced volume of larger pores in the cement paste.

### 3.2. Workability

A high-quality concrete is one which has acceptable workability (around 6.5 cm slump height) in the fresh condition and develops sufficient strength. Basically, the bigger the measured height of slump, the better the workability will be, indicating that the concrete flows easily but at the same time is free from segregation [12, 13]. Maximum strength of concrete is related to the workability and can only be obtained if the concrete has adequate degree of workability because of self compacting ability. Self-compacting repair mortars, as new technology products, are especially preferred for the

rehabilitation and repair of reinforced concrete structures [14]. The water/powder (cement, fly ash, limestone filler, silica fume, nano-particles, etc.) ratio of mortar and the type of chemical admixtures should be determined, in order to place the fresh mortar without any external compaction and at the same time without causing any segregation [15]. In other words, the rheology of paste phase of self-repairing mortar should have suitable properties from flowability and segregation point of view [16–19].

The workability of C0 and N series concrete are presented in Figure 1. The figure shows the influence of nano- Al<sub>2</sub>O<sub>3</sub> particles content on the workability of mixtures at constant water to binder ratio of 0.40. The results show that unlike the C0 series, all investigated nano-Al<sub>2</sub>O<sub>3</sub> particles blended mixtures had low slump values and non-acceptable workability. This may be due to the increasing in the surface area of powder after adding nanoparticles that needs more water to wetting the cement particles.

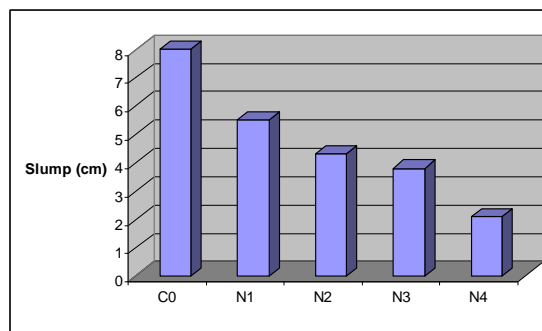


Figure 1. Particle size effects of nano-Al<sub>2</sub>O<sub>3</sub> on workability of concrete. N1, N2, N3 and N4 are the series N blended concrete with 0.5, 1.0, 1.5 and 2.0 percent of nano-Al<sub>2</sub>O<sub>3</sub> particles, respectively.

With the improvement of novel plasticizers, to obtain high filling rates is possible even for compound molding systems. The fresh characteristics of concrete, strength and durability of mortars can be improved by the addition of inert or pozzolanic [20]. The selection of the amount and the type of cementitious or inert powders depends on the physical and physico-chemical properties of these powders which are affecting the performance of fresh paste such as particle shape, surface texture, surface porosity and rate of superplasticizer adsorption, surface energy (zeta potential), finest fraction content, Blaine fineness and particle size distribution.

There is no universally accepted agreement on the effect of these factors due to the complex influence of the combination of these factors [21].

Usually, increasing the fine particles content in cements changes the rheological properties of pastes and

consequently influences the workability of mortars and fresh concrete mixtures. The observed changes can be advantageous or not as a result of many factors influencing the rheology of cement pastes [22]. It is usually expected that, if the volume concentration of a solid is held constant, for a specific workability, the replacement of cement with a fine powder will increase the water demand due to the increase in surface area. This is more observed for nanoparticles blended concrete. However, in some cases, the above-mentioned conclusion is not appropriate. Lange et al. [23] obtained same results with fly ash blended concrete. But In this study, the addition of nano-Al<sub>2</sub>O<sub>3</sub> particles decreased the fluidity and increased the water demand for normal consistency

### Conclusions

The results show that the nano-Al<sub>2</sub>O<sub>3</sub> particles blended concrete had significantly higher compressive strength compare to that of the concrete without nano-Al<sub>2</sub>O<sub>3</sub> particles. It is found that the cement could be advantageously replaced with nano-Al<sub>2</sub>O<sub>3</sub> particles up to maximum limit of 2.0% with average particle sizes of 15 nm. Although, the optimal level of nano-Al<sub>2</sub>O<sub>3</sub> particles content was achieved with 1.0% replacement. Partial replacement of cement by nano-Al<sub>2</sub>O<sub>3</sub> particles decreased workability of fresh concrete; therefore use of super plasticizer is substantial.

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