

# Investigation of some durability properties of concrete pavements containing nanoparticles

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## ABSTRACT

Mechanical and durability properties of concrete structures, including concrete pavements, has been a focus of attention. In this regard, the potential of nanomaterials needs to be discussed more. Water permeability, abrasion, and compressive strength are assessed in this study. So far, the incorporation of diverse types of nanomaterials with different methods has caused enhancement of some mechanical and durability properties of concrete. In the present study, five types of nanoparticles as NanoSiO<sub>2</sub>, NanoTiO<sub>2</sub>, NanoAl<sub>2</sub>O<sub>3</sub>, NanoFe<sub>2</sub>O<sub>3</sub>, and NanoFe<sub>3</sub>O<sub>4</sub> in different amounts are uniformly dispersed and added to the concrete. To reduce the cost and to decrease the required nanomaterials, specimens are made in two layers. The surface layer of specimens is made from self-compacting concrete containing nanoparticles with 1 cm depth, which is placed over the bottom layer from conventional concrete with different depths depending on the tests. The test results indicate that the properties of concrete pavements containing nanoparticles are improved comparing to the control specimen. For instance, in specimens containing NanoTiO<sub>2</sub> as much as 3% by the weight of cement, the water permeability improved by 84.6%. Furthermore, the abrasion resistance of specimens containing NanoSiO<sub>2</sub> at an amount of 1% enhanced by 88.1%, and the addition of 3% of NanoSiO<sub>2</sub> raised compressive strength by 88%.

## KEYWORDS

Concrete pavements, Abrasion, Permeability, Compressive strength, Nanoparticles

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## 1. Introduction

The durability of concrete pavements is an important issue. They are exposed to external detrimental factors such as abrasion and freezing of permeated water. Some nanomaterials are incorporated in concrete to enhance its mechanical strengths and improve its water permeability. Incorporation of oxide of some metals in the form of nanoparticles such as Nano Silica, Nano Titania, Nano Alumina, Nano Hematite, and Nano Magnetite has led to positive effects on mechanical and duration properties of concrete [1-7].

Uniform dispersion of nanomaterials in a composite plays a pivotal role in its effectiveness in improving the expected properties of the composite. Otherwise, the formed agglomerates hinder the anticipated enhancements through the formation of weak zones. Different methods of dispersing nanomaterials in cementitious matrices are discussed in the literature [8, 9].

In the present study, water permeability, abrasion resistance, and compressive strength of concrete pavements containing five different nanoparticles have been investigated. The tested specimens are made of two layers to reduce the cost of nanomaterials and the amount used. The top layer consists of self-compacting concrete incorporating nanoparticles with a depth of one centimeter, which is cast over a layer of normal concrete placed underneath. The proposed method in this paper could be applied both in the construction of new concrete pavements and in the retrofit of existing ones. Comparing mechanical and duration properties of specimens containing different amounts of nanoparticles in an identical experimental condition provides useful information on optimum amounts and improvement rates, which could be a supplement to the previous literature.

## 2. Methodology

The nanoparticles used in this study are five types of metal oxides with the specifications, as shown in Table 1. The maximum aggregate size in self-compacting and normal concrete is 2.38 mm and 19 mm, respectively. The fineness modulus of the sand used in the mentioned concrete types is 3 and 3.4, respectively. Type II Portland cement and a polycarboxylic superplasticizer with a pH of 6.5, as well as potable water, are used in concrete mixes.

Mix proportions, according to Table 2, are selected after investigating some mixes. All specimens were demolded after 24 hours and then cured in water at a temperature of 24°C until the age of 28 days.

**Table 1. Specifications of incorporated nanomaterials**

Nano Particles	Diameter (nm)	Specific surface area (m <sup>2</sup> /gr)	Used amounts (wt.% of cement)
NanoSiO <sub>2</sub>	20-30	180-600	1,3,5
NanoTiO <sub>2</sub>	20	10-45	1,2,3
NanoAl <sub>2</sub> O <sub>3</sub>	50	>19	1.5,2,3
NanoFe <sub>2</sub> O <sub>3</sub>	20-40	20-60	1,3,4
NanoFe <sub>3</sub> O <sub>4</sub>	20-30	40-60	1,3,4

Cubic specimens of self-compacted concrete with 5 cm dimensions were tested according to the ASTM C109 standard to evaluate their compressive strength. Water permeability tests conducted on two-layered cubic specimens, cast as mentioned in the previous section, with 15 cm dimensions in accordance with BS EN 12390-8 standard. For evaluating abrasion resistance, two-layered 3x15x15 cm specimens were used in a way that agrees with the ASTM C944 standard.

Each test conducted on a group consisting of three specimens and the average of three measured values reported as a result. Furthermore, for each of the three tests mentioned above, a group of control specimens is prepared without any nanoparticles to measure the improvement rates. Overall, 144 specimens prepared and tested in this study, taking into account five types of nanoparticles at three different amounts.

**Table 2. Mix proportions of self-compacting and normal concrete**

Mix	self-compacting concrete	normal concrete
Cement	564.6	345
Water	179	189
Micro Silica	77	--
Limestone powder	185	--
Superplasticizer	13	--
Sand	1304	1064
Coarse aggregate	--	867
Specific weight	2320	2517

All values are in (kg/m<sup>3</sup>).

Self-compacting concrete on the top layer of specimens contains five types of nanoparticles at three different amounts, which are considered as weight percentages of cement, as shown in Table 1.

Superplasticizer as a surfactant in combination with mechanical stirring is used to reach a uniform dispersion of nanoparticles in the water, which is added to the concrete subsequently.

### 3. Results and Discussion

Results of the water permeability, abrasion resistance, and compressive strength tests are shown in Table 3. The increase of compressive strength in specimens containing NanoTiO<sub>2</sub> and NanoFe<sub>2</sub>O<sub>3</sub> accompanied by improvement in abrasion resistance and permeability, and maximum values are measured in those with higher nanoparticle content. This trend is observed in the specimens containing NanoAl<sub>2</sub>O<sub>3</sub> and NanoSiO<sub>2</sub> to some extent, despite the fact that the best results are almost associated with the medium content of nanoparticles. Incorporation of NanoFe<sub>3</sub>O<sub>4</sub> raised the porosity due to foam formation, which consequently diminished the compressive strength.

**Table 3. Results of the compressive strength, permeability and abrasion resistance tests (improvement percentages)**

Nano Particles	Amount (wt. %)	Permeability	Abrasion resistance	compressive strength
NanoSiO <sub>2</sub>	1	39.8	88.1	65.4
	3	73.8	81.1	88.1
	5	73.8	80.4	68.6
NanoTiO <sub>2</sub>	1	34.6	58.9	4.2
	2	71.3	62.8	56.8
	3	84.6	67.2	85.8
NanoAl <sub>2</sub> O <sub>3</sub>	1.5	2	59.9	8.8
	2	69.2	86.6	77
	3	23.1	84	85.8
NanoFe <sub>2</sub> O <sub>3</sub>	1	13.8	-20.7	3.3
	3	18.5	84	54.1
	4	29.2	87.1	59.5
NanoFe <sub>3</sub> O <sub>4</sub>	1	-13.3	-347	-51.4
	3	56.9	29.5	-65.9
	4	23.1	29.5	-60.3

In the case of uniform dispersion of nanoparticles in the concrete, if suitable amount and distance are provided, nanoparticles can be placed in cement hydration products as a core, and limit the growth of Ca(OH)<sub>2</sub> crystals and make a homogeneous and dense cement matrix, which leads to higher mechanical properties. On the other hand, an increased amount of nanoparticles by impeding enough growth of Ca(OH)<sub>2</sub> crystals lessens their ratio against Calcium-silicate-hydrate, which results in a porous matrix. It should be noted that rising the content of nanoparticles declines the workability of concrete. Moreover, dispersion of higher amounts of nanoparticles is difficult, which increases the probability of agglomeration and diminishing of mechanical properties.

### 4. Conclusions

The effect of five different nanoparticles in some mechanical and durability properties of concrete pavements is investigated in this study.

According to the results, the compressive strength, permeability, and abrasion resistance can be enhanced by the incorporation of nanoparticles as they can improve the structure of concrete both by pozzolanic activity and filling the pores.

### 5. References

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