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Application of Nanoscience in Self-cleaning Properties of Concrete Facade for Development of Sustainable Environment

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Abstract: Using mineral admixtures in cement composites as a way to improve their mechanical and sustainable environmental properties is a common practice in concrete technology. Among them Nano-silica effectively influences the composite's early and long-term properties. In this study, the effect of different percentages of TiO_2 (0, 2.5 and 5 %) on self-cleaning properties and water absorption of cement composites containing Nano-silica were investigated. According to the use of different cementitious material (Nano-silica) and TiO2 in mix proportions, to obtain mixtures with a desirable workability, superplasticizer was added in different volume percentages. Better size distribution and pore refinement lead to a denser cement matrix with low porosity which in turn considerably the lower water absorption of the cement composites. The maximum final water absorption according to ASTM C497 is 9% for method A and 8.5% for method B. Comparisons of water absorption tests as a result of adding of TiO_2 and Nano-silica in concrete show that the maximum final water absorption is 4.9% in N1 design mixture and the minimum final water absorption is 4.3% in N2 design mixture. The incorporation of TiO_2 has positively affected the results for Nano-silica containing specimens. A decrease of 6.5% and 11.1% between N1 and N3 respectively shows the positive effect of TiO_2 on decrease of water absorption. The results show that TiO2 along with Nano-silica has great potential for improving the environmental and self-cleaning properties of concrete facades of buildings in cities exposed to high levels of cleanliness.

Keywords: Prefabricated facade, Sustainable Environment, Self-Cleaning, Titanium Dioxide, Nano-silica, Water absorption.

1. Introduction

Background

Self-cleaning photo catalytic is one of the most important uses of nanotechnology in the building industry. Natural and industrial pollutants such as NOx, carbon monoxide, VOCs, hlorophenols, and aldehydes from cars and industrial wastewaters are decomposed by photocatalyst and using a highly active catalytic converter of titanium dioxide nanoparticles (Murata and Obara (1999)). For activating the self-daylight, air humidity and oxygen are required. A comprehensive study of how photocatalytic activity based on titanium dioxide can be studied can be found in Chen and Poon (2009). Currently, self-cleaning and anti-polluting concrete products are produced by various companies for use in the facade of buildings and pavements, and have been used extensively in Europe and Japan, for example, the name of the Jubilee Church in Rome, Italy. Researchers have also shown that the use of titanium dioxide nanoparticles, in addition to its self-cleaning properties, increases the hydration speed and reduces the stamping time (Jayapalan and Kurtis 2009) and also increases the flexural strength and compression strength of concrete (Li et al. 2006, 2007). One of the disadvantages of this method is to reduce its decomposition efficiency over time (Lackhoff et al. 2003).

Micro-silicon is one of the materials that has been seriously considered by building engineers in recent decades to use it in concrete. Due to the specific characteristics of pozzolan micro silica, its use to improve mechanical properties and increase the durability of concrete in advanced countries is increasing. Its use in concrete has many benefits including: reducing the cracks of the cement hydration, better durability against damage of sulphates and water acidic and finding the resistance of high-end using a variety of Super Lubricants concrete. Another benefit of using micro silica is to reduce the mobility of chlorine ions and thus reduce the chlorine penetration depth in concrete, especially in coastal areas of southern Iran. The indications for their use can be found in the concrete of the dock by the sea, piles, columns and prefabricated components, the foundation for all concrete structures exposed to chemical attack, particularly chloride and sulfate are named (Du et al. 2014).

Nanotechnology is a science that deals with the materials at their Nano scale and manipulates their molecular structure. Similar to other industries, concrete industry is also influenced by the appearance of Nano materials. Nano silica seems to be the most popular Nano material in concrete technology due to its remarkable effects on the properties of cement composites. Recent literatures have reviewed the effect of Nano-silica on physical, mechanical and durability properties of concrete (Sanchez and Sobolev 2010; Taheri-Behrooz et al. 2015; Du et al. 2014). The effect of Nano-silica on the performance of concrete is due to the pozzolanic activity and filler effect (Aly et al. 2012). Gesoglu et al. (2016) compared the role of silica fume and Nano-silica in high performance concrete. It was found that 1% of NS has a similar effect of 10% micro-silica when packing density was concerned. Also incorporation of Nano-silica up to 2% improved the mechanical performance of the concrete. In recent years, studies have focused on silica nanoparticles, with the aim of increasing the specificity of concrete by using this material. The addition of nano-silica to concrete increases compressive strength, tensile and flexural strength, reduces drainage time and reduces the water permeability of concrete, as well as higher resistance to chemical attack.

Nano silica experiments have shown that these particles are not problematic to the environment but provide better results than micro silica (Du et al. 2014). Research has shown that adding Nano-silica more than micro-silica can increase concrete resistance (Qing et al. 2005). Nano-silica mixed with concrete in the long run will protect the health of workers, concrete and the environment. Nano silica can also reduce cement consumption, improve concrete quality and increase its efficiency (Shannag 2000; Yazici 2007). Adding 10% of Nano-silica increased the compressive strength of concrete by 26%, while the same amount of micro silicon increased the compressive strength of concrete by 15% (Shannag 2000). Even adding a small amount of 0.25% of Nano-silica causes a 10% increase in compressive strength and a 25% increase in flexural strength (Dalvand et al. 2014). Incorporation of TiO_2 in cement composites has been studied by some researchers. Li et al. (2007) showed that the concrete containing Nano TiO_2 has a higher flexural fatigue life compared to that of conventional concrete. Senff et al. (2012) added different volume fractions of Nano-silica and Nano TiO_2 to mortar mixtures and evaluated the properties of hardened state. It was reported that when the content of Nano-silica and TiO_2 is low the mechanical strengths are not affected significantly, but as the volume percentages increase to 3% and 12% for Nano-silica and TiO_2 respectively the strengths increase as well. Crupi et al. (2018) studied a nanocomposite coating with self-cleaning effect for stone material of Italy to find the optimum amount of TiO_2. They evaluated the contact angle measurements and capillary water absorption by using Neutron radiography and UV synchrotron radiation. In this study we evaluated the effects of nanomaterials (Nano-silica and TiO_2) on mixing in concrete for prefabricated façade concrete. Mohammadi Aloucheh et al. (2018) studied the effect of nanobiosensors in determination of environmental risks. They found that nanobiosensors could identify heavy metals and environmental contaminants.

Figure 1- Jubilee Church, Rome, Italy. In the facade of this structure, concrete is used to combine titanium dioxide nanoparticles

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The essential feature of the network is the existence of horizontal spider web links between its components that distinguish it from other bureaucratic structures (Gilchrist 2009). Networks facilitate social interactions and reduce transaction costs (Isett et al. 2011; Fischer, 1990).

Natural and industrial pollutants such as NOx, carbon monoxide, VOCs, chlorophenols and aldehydes from automobiles and industrial effluents are decomposed by photocatalysis using a highly active titanium dioxide nanoparticle catalyst. In this study the specimens containing Nano-silica the addition of TiO_2 is investigated in changes of water absorption. Better size distribution and pore refinement lead to a denser cement matrix with low porosity which in turn considerably lower the water absorption of the cement composites. The incorporation of TiO_2 has positively affected the results for Nano-silica containing specimens.

Considering that the purpose of this paper is to investigate in optimum adding TiO_2 in water absorption properties of concrete facade for sustainable development. In this paper, Research questions are:

– What are the characteristics of optimum adding TiO_2 in water absorption properties of concrete facade?

2. Methodology

Cement type I-42.5 in accordance with standard specifications of American Society for Testing and Materials(ASTM)-C150 (2007) was used. Chemical composition of cement is presented in Table 1. For fine aggregates, silica sand which passed sieve number 30 (smaller than 600 microns) was used. No coarse aggregate was used. Polycarboxylate based superplasticizer as a water-reducing agent and retarder was used which is compatible with the standard specifications of ASTM-C494 (2008). Ultrafine TiO2 with the diameter of about 800 nm and specific gravity of 3.91 gr/cm3 was used in mix proportions. Nano-silica with the diameter of about 15 nm was used. The properties of Nano-silica are given in Table2.

Table 1- Chemical composition of cement and silica fume

Compound	Cement (%)
CaO	64.38
SiO_2	21.08
Al_2O_3	5.36
Fe_2O_3	3.64
MgO	2
K_2O	0.82
Na_2O	0.5
L.O.I(Loss On Ignition)	0.9

Table 2- Properties of Nano-silica

Diameter (nm)	Surface area (m^2/gr)	Density (gr/cm^3)	LOI (%)
15±2	190±25	≤0.15	≤1

Mixing and curing were performed in accordance with the procedure prescribed in ASTM C109 (2008). At first the dry materials were gently mixed until a homogenous dry mixture was gained. The blend of water and superplasticizer was added slowly and mixing continued for 5 minutes in high speed until a homogenous mortar was obtained. In all mix designs water to cementitious material ratio was kept constant to prevent the loss of mechanical strength. But, according to the use of different cementitious material (Nano-silica) and TiO2 in mix proportions, to obtain mixtures with a desirable workability, superplasticizer was added in different volume percentages. The specimens were demolded after 24 hours and were immersed in a water tank until the date of testing. Table3 shows the mix proportion designs of this study.

Water absorption test was carried out according to ASTM C642-06 (2008) on the specimens at the age of 28 days.

Although in the short and long-term water absorption test, the BS 1881 can be used to achieve final water absorption through continuous testing to reach constant weight, and even boil it in water to obtain more final water absorption. But such predictions have not been made in this order. In ASTM C642, the amount of final water absorption is obtained and density and porosity can be obtained, even boiling of the sample in water is predicted. There is no sensitivity to the shape and size of the specimen in this standard, but at least the mass and volume are specified because it addresses the issue of final water absorption. This test is mainly used for prefabricated pieces ASTM C642-13 (2008). In EN-1340 (2003), the final water absorption of prefabricated components, such as concrete tables, has been observed for at least the volume or mass of the specimen. In standards such as ASTM C497, the amount of water absorption of concrete pipes is obtained by two methods A and B according to the method of drying and boiling time of the sample in water ASTM C497-19 (2019).

For example, in some standard standards for prefabricated components in ASTM C76 such as water and sewage RC pipes, the maximum final water absorption according to ASTM C497-19. (2019) is 9% for method A and 8.5% for method B, and in this regard It is possible to provide a benchmark for the durability of concrete, especially if the concrete piece is flooded and water is always in the vicinity. Such specifications have been used in the standard water and wastewater pipelines of Iran No. 8906 ISIRI, No. 8906 (2007).

In BS EN 1340, in cases where there are no ice conditions and no water-solubility in ice-free salts. The maximum final water absorption of 6% is provided for prefabricated concrete tables BS EN-1340. (2003).

It seems that for concrete durability, the maximum final water absorption of concrete should be reduced to 6% and for the boiled state it should be limited to 5.5%.

Table 3- Mix designs

		Replacement percentage		
Mix designation	**Cement content (kg/m^3)**	**Nano-silica**	**UFTiO2**	**Water/cement**
N1	800	3	0	0.38
N2	800	3	2.5	0.38
N3	800	3	5	0.38

3. Results

The research results are presented in Figures 2 to 5 and Table 4 as follows.

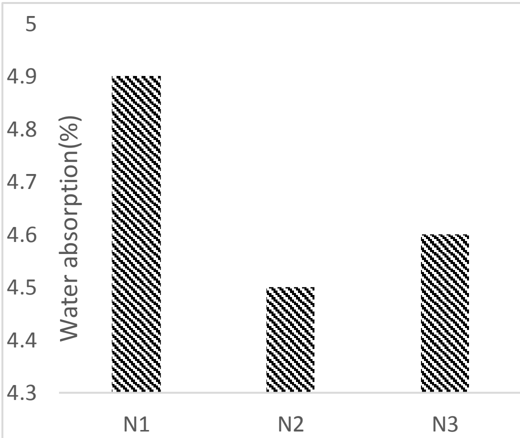

Figure 2- Comparsion of water absorption test as a result of adding of TiO_2 and Nano-silica in concrete

Table 4: Results of final water absorption in 3 samples. In accordance with ASTM C497, the maximum final water absorption is 8.5% thus the results of 3 samples are acceptable.

Mix designation	*water absorption*
N1	4.9
N2	4.5
N3	4.6

In accordance with ASTM C497, the maximum final water absorption is 8.5% thus the results of 3 samples are acceptable.
In accordance with the BS EN 1340, this subject is related to 6% thus the results of 3 samples are acceptable too.

In accordance with Table 4, increasing Titanium dioxide led to decrease of water absorption in N2 compared with N3.

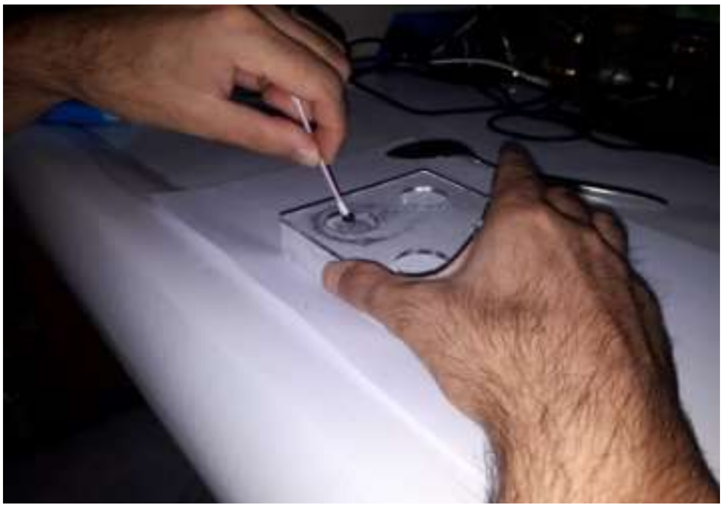

Figure 3 -Surface of concrete sample impregnated. Rhodamine B (pink) was spread on the concrete surface.

Figure 4 - Experiment on the concrete surface color of the sample with 2.5% titanium dioxide at the beginning of the experiment.

Figure 5 - Experiment on the concrete surface color of the sample with 2.5% titanium dioxide after 24 hours. Comparison of Figure 4 and 5 shows that self - cleaning properties were significantly affected by Nano TiO2.

4. Discussion

The results of water absorption test are given in Figure 2. Better size distribution and pore refinement lead to a denser cement matrix with low porosity which in turn considerably lower the water absorption of the cement composites. The incorporation of TiO_2 has positively affected the results for nano-silica containing specimens. In this study, the effect of different percentages of TiO_2 (0, 2.5 and 5 %) on mechanical properties of cement composites containing nano-silica was investigated. A decrease of 6.5% and 11.1% between N1 and N3 respectively shows the positive effect of TiO_2 on water absorption. Senff et al. (2012) evaluated using of nano-SiO2 and nano-TiO2 in cement. Mix designs with 0-3wt% nano-SiO2, 0-12wt% nano-TiO2 and 0.5 w/c were done. Experimental measurements were done. In mix designs with more than nano-SiO2 and nano-TiO2 obtained significant changes compared with the others without nanomaterials. Properties were not remarkably added by nanomaterials in the range investigated in this research.

We compared with Senff et al. (2012)'s studies that adding TiO_2 with constant percentage of nano-silica (3%) has a great potential for improving the water absorption. This subject was not studied in their studies. We compared with Crupi et al. (2018) 's studies that adding TiO_2 with constant percentage of nano-silica(3%) has a great potential for improving the self- cleaning and water absorption in prefabricated concrete facade. This subject was not studied in their study. Experiment on the concrete surface color of the sample with 2.5% titanium dioxide at the beginning of the experiment with Rhodamine B was done (Figure 3 and 4).

After 24 hours, comparison of Figure 4 and 5 shows that self - cleaning properties were significantly affected by Nano TiO2.

Figure 4 and 5 showed that self - cleaning properties were significantly affected by Nano-TiO2. By using of Nano-TiO2, the pink paint impregnated on the concrete surface decreased.

5. Conclusion

Fig.(2) shows the results of water absorption test at the 3 states. For the specimens containing Nano-silica the **addition** of TiO_2 has led to an increase in water absorption. Comparing N1, N2 and N3 show that an increase of water absorption has occurred by decreasing of the TiO_2. Comparisons of water absorption tests as a result of adding of TiO_2 and nano-silica in concrete show that the maximum final water absorption is 4.9% in N1 design mixture and the minimum final water absorption is 4.3% in N2 design mixture. Comparison of Figure 4 and 5 shows that self - cleaning properties were significantly affected by Nano TiO2. Experiment on the concrete surface color of the sample with 2.5% titanium dioxide after 24 hours indicates that TiO_2 has a great potential for improving the self- cleaning of cement composites.

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7. Additional information and declarations

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Author Contributions

Sayedeh Fatemeh Khoshkalam Soleimandarabi: proposed the plan, conceived the experiments, analyzed the data, prepared figures, and tables, authored or revised drafts of the paper, and approved the final draft.

Raheleh Rostami: conceived and designed the experiments, analyzed the data, contributed reagents /materials/analysis tools, prepared figures, and tables.

Mehdi Nezhadnaderi: Conceived and designed the experiments, analyzed the data, contributed reagents /materials/analysis tools, prepared figures, and tables. Authored or revised the drafts of the paper. Approved the final draft.

Data Availability: All the data are shown in the tables of this article .

Ethics Statement

The study was conducted by Nour Branch Islamic Azad University for the thesis of Architecture engineering .

Supplemental Information

There is no supplementary information on this paper. Any questions and request for more information should be addressed on correspondence author.

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