RESEARCH ARTICLE

Prefabricated Concrete Elements for the facade Industry with Nano cement composites containing silica fume, nano-silica and TiO_2

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ABSTRACT

Using mineral admixtures in cement composites as a way to improve their mechanical and durability properties is a common practice in concrete technology. Among them silica fume and nano-silica effectively influence the composite's early and long-term properties. Due to the limited particle size distribution of nano and micro silica it is expected that the incorporation of some mineral additives with a size of greater than 500 nm may result in better mechanical and durability performance because of the filler effect. In this study, the effect of different percentages of TiO_2 on mechanical properties of cement composites containing nano-silica and silica fume was investigated. Six designs were tested for compressive strength with respect to zero, 2.5 and 5 percent replacement of cement with TiO_2. The addition of TiO2 has led to an increase in compressive strength. The best results from the sample with 2.5% TiO_2 are obtained. This could be due to the effect of TiO2 particles filling. Comparison of SF3, SF2 and SF1 at 28 days of age showed that SF2 increased the compressive strength. This shows that TiO_2 has a great potential for improving the mechanical properties of composite cement.The results showed that the addition of TiO2 had a positive effect on compressive strength. Increasing TiO_2 nanoparticles content of more than 3 wt% are caused to reduce the compressive strength acording to past studies. But in this study is shown that by adding 3% nanocillis or 20% silicafium to increased TiO_2 nanoparticles content of more than 3% wt, the results of compressive strength are not reduced. The use of 3% combined nano-silica or 20% silicafium will cover this defect of increased TiO_2 nanoparticles content of more than 3% wt.

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INTRODUCTION

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 [1-3]. The effect of nano-silica on the performance of concrete is due to the pozzolanic activity and filler effect [4]. Gesoglu et al. [5] 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% microsilica when packing density was

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concerned. Also incorporation of nano-silica up to 2% improved the mechanical performance of the concrete.

Silica fume is one of the most widely used pozzolans in the concrete industry. The effect of silica fume incorporation on different aspects of cement composites has been investigated by numerus researchers. The addition of silica fume as a partial replacement for cement led to the development of high strength and high performance concrete [6,7]. Dalvand et al. [8] investigated the effect of substituting cement with silica fume on the impact resistance of the concrete. It was reported that the incorporation of silica fume in the amount of 7 and 14% resulted in the improvement of both mechanical properties and impact resistance. Mastali and Dalvand [9] utilized silica fume as a cement replacement in self-compacted concrete. As it was expected the addition of silica fume reduced workability but compressive, flexural and splitting tensile strengths increased significantly as the replacement ratio increased. Pedro et al. [10] partially replaced cement with densified silica fume in HPC. Despite regular silica fume which is an irreplaceable constituent material of HPC, this study showed that using densified silica fume detrimentally affects the properties of high performance concrete.

Incorporation of TiO_2 in cement composites has been studied by some researchers. Li et al. [11] showed that the concrete containing nano TiO_2 has a higher flexural fatigue life compared to that of conventional concrete. Senff et al. [12] 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.

Concrete cleaners and anti-pollution products are produced for use in building facades and road floors. They are widely used in Europe and Japan, such as Jubilee church in Rome, Italy was found in Fig 1.

Hasan and *et al.* (2017) studied the effect of silica fume on mechanical properties of concrete containing recycled asphalt pavement [13]. This paper presents the results of a study that investigated

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

the improvement of the mechanical properties of coarse and fine recycled asphalt pavement (RAP) produced by adding silica fume (SF) with contents of 5%, 10%, and 15% by total weight of the cement. The coarse and fine natural aggregate (NA) were replaced by RAP with a replacement ratio of 20%, 40% and 60% by the total weight of NA. In addition, SF was added to NA concrete mixes as a control for comparison. Twenty eight mixes were produced and tested for compressive, splitting tensile and flexural strength at the age of 28 days. The results show that the mechanical properties decrease with as the content of RAP increases. And the decrease in the compressive strength was more in the fine RAP mixes compared to the coarse RAP mixes, while the decrease in the splitting tensile and flexural strength was more the same in both mixes. Furthermore, using SF enhances the mechanical properties of RAP mixes where the optimum content of SF was found to be 10%, and the mechanical properties enhancement of coarse RAP were better than fine RAP mixes. Accordingly, the RAP has the potential to be used in the concrete pavements or in other low strength construction applications in order to reduce the negative impact of RAP on the environment and human health.

Zhang and *et al.* (2016) studied the effect of silica fume on fresh properties, compressive strength at 28 days and fracture behavior of fly ash concrete composite were studied in this paper [14]. Test results indicated that the fluidity and flow ability of fly ash concrete composites decreased and fly ash concrete composite are more cohesive and appear to be sticky with the addition of silica fume. Addition of silica fume was very effective in improving the compressive strength at 28 days of fly ash concrete composite, and the compressive strength of fly ash concrete composite has a trend of increase with the increase of silica fume content. Results also indicated that all the fracture parameters of effective crack length, fracture toughness, fracture energy, the critical crack opening displacement and the maximum crack opening displacement of fly ash concrete composite decreased with the addition of silica fume. When the content of silica fume increased from 3% to 12%, these fracture parameters decreased gradually with the increase of silica fume content. Furthermore, silica fume had great effect on the relational curves of the three-point bending beam specimen. As the silica fume content increased from 3% to 12%, the areas surrounded by the three relational curves and the axes were becoming smaller and smaller, which indicated that the capability of concrete composite containing fly ash to resist crack propagation was becoming weaker and weaker.

Chen and *et al.* (2018) studied the axial compression behavior of circular recycled concrete-filled steel tubular short columns reinforced by silica fume and steel fiber [15]. This paper presents an experimental work for short circular steel tube columns filled with normal concrete (NAC), recycled aggregate concrete (RAC), and RAC with silica fume and steel fiber. Ten specimens were tested under axial compression to research the effect of silica fume and steel fiber volume percentage on the behavior of recycled aggregate concrete-filled steel tube columns (RACFST). The failure modes, ultimate loads and axial load- strain relationships are presented. The test results indicate that silica fume and steel fiber would not change the failure mode of the RACFST column, but can increase the mechanical performances of the RACFST column because of the filling effect and pozzolanic action of silica fume and the confinement effect of steel fiber. The ultimate load, ductility and energy dissipation capacity of RACFST columns can exceed that of corresponding natural aggregate concrete-filled steel tube (NACFST) column. Design formulas EC4 for the load capacity NACFST and RACFST columns are proposed, and the predictions agree well with the experimental results from this study.

Jalal and *et al.* (2014) studied the corrosion resistant, self-compacting concrete using micro and nano silica admixtures [16]. In this paper, enhancement of corrosion and chloride resistance of high performance self compacting concrete (SCC) through incorporating nano silica into the binder has been investigated. For this purpose, different mixtures were designed with different amounts of silica fume and nano silica admixtures. Different binder contents were also investigated to observe the binder content effect on the concrete properties. Corrosion behavior was evaluated by chloride penetration and resistivity tests. Water absorption and capillary absorption were also measured as other durability-related properties. The results showed that water absorption, capillary absorption and Cl ion percentage decreased rather significantly in the mixtures containing admixtures specially blend of silica fume and nano silica. By the addition of the admixtures, resistivity of the SCC mixtures increased which can lead to reduction of corrosion probability.

Ahmad and *et al.* (2019) studied the performance of self-compacting concrete at room and after elevated temperature incorporating Silica fume[17].

This paper evaluates the workability and hardened properties of self-compacting concrete (SCC) containing silica fume as the partial replacement of cement. SCC mixtures with 0, 2, 4, 6, 8 and 10% silica fume were tested for fresh and hardened properties. Slump flow with T500 time, L-box and V-funnel tests were performed in evaluating the workability properties of SCC mixtures. Compressive strength, splitting tensile strength and modulus of rupture were performed on hardened SCC mixtures. The experiments revealed that replacement of cement by silica fume equal to and more than 4% reduced the slump flow diameter and increased the T500 and V-funnel time linearly. Compressive strength, splitting tensile strength and modulus of rupture increased with increasing the replacement level of cement by silica fume and were found to be maximum for SCC mixture with 10% silica fume. Further, residual hardened properties of SCC mixture yielding maximum strengths (i.e., SCC with 10% silica fume) were determined experimentally after heating the concrete samples up to 200, 400, 600 and $800^0 c$. Reductions in hardened properties up to 200oC were found to be very close to normal vibrated concrete (NVC). For 400 and 600oC reductions in hardened properties of SCC were found to be more than NVC of the same strength. Explosive spalling occurred in concrete specimens before reaching 800^0 [17].

Prusty and *et al.* (2015) studied the nano-engineered concrete using recycled aggregates and nano-silica: Taguchi approach [18]. This paper investigates the influence of various mix design parameters on the characteristics of concrete containing recycled coarse aggregates and Nano-Silica using Taguchi method. The present study adoptsWater-cement ratio, Recycled Coarse Aggregate (%), Maximum cement content and Nano-Silica (%) as factors with each one having three different levels. Using the above mentioned control parameters with levels an Orthogonal Array (OA) matrix experiments of L9 (34) has selected and nine numbers of concrete mixes have been prepared. Compressive Strength, Split Tensile Strength, Flexural Tensile Strength, Modulus of Elasticity and Non-Destructive parameters are selected as responses. Experimental results are analyzed and the optimum level for each response is predicted. Analysis of 28 days CS depicts that NS (%) is the most significant factor among all factors. Analysis of the tensile strength results indicates that the effect of control factorW/C ratio is ranked one and then NS (%) is ranked two which suggests that W/C ratio and NS (%) have more influence as compared to other two factors. However, the factor that affects the modulus of elasticity most is found to be RCA (%). Finally, validation experiments have been carried out with the optimal mixture of concrete with Nano-Silica for the desired engineering properties of recycled aggregate concrete. Moreover, the comparative study of the predicted and experimental results concludes that errors between both experimental and predicted values are within the permissible limits. This present study highlights the application of Taguchi method as an efficient tool in determining the effects of constituent materials in mix proportioning of concrete[18].

Shaikh and *et al.* (2015) studied the Effect of micro-silica on mechanical and durability properties of high volume fly ash recycled aggregate concretes (HVFA-RAC) [19].

This paper presents the effect of different micro-silica (MS) contents of 5, 10 and 15 wt.% as partial replacement of cement on mechanical and durability properties of high volume fly ash - recycled aggregate concretes (HVFA-RAC) containing 50% class F fly ash (FA) and 35% recycled coarse aggregate (RCA) as partial replacement of cement and natural coarse aggregate (NCA), respectively. The measured mechanical and durability properties are compressive strength, indirect tensile strength, elastic modulus, drying shrinkage, and water sorptivity and hloride permeability. The effects of different curing ages of 7, 28, 56 and 91 days on above properties are also considered in this study. The results show that the addition of MS up to 10% improved the early age (7 days) strength properties of HVFA-RAC, however, at later ages (e.g. 28-91 days) the above mechanical properties are improved for all MS contents. The 5% MS exhibited the best performance among all MS contents for all mechanical properties of HVFA-RAC. In the case of measured durability properties, mix results are obtained, where 10% and 5% MS exhibited the lowest sorptivity and drying shrinkage, respectively at all ages. However, in the case of chloride ion permeability a decreasing trend is observed to increase in MS contents and curing ages. Strong correlations of indirect tensile strength and modulus of elasticity with square root of compressive strength are also observed in HVFA-RAC. Nevertheless, it is established in this study that MS, contributes to the sustainability of HVFA-RAC significantly by improving the mechanical and durability properties of concrete containing 50% less cement and 35% less natural coarse aggregates[19].

Shariati Rad and *et al.* (2018) studied the technical and economical assessment of applying silica nanoparticles for construction of concrete structures[20].

The use of nanotechnology materials and applications in the construction industry should be considered for enhancing material properties. However, in this paper, the technical and economical assessment of applying silica nanoparticles for construction of concrete structure is studied. In order to obtain the equivalent material properties of the structure, the Mori-Tanaka model is used considering agglomeration of nanoparticles. The effect of using these nanoparticles on mechanical properties of concrete, such as the modulus of elasticity, compressive strength, as well as its indirect effect on armature percentage is investigated. Finally, the price of silica nanoparticles and its effect on the price increase of concrete structure is investigated. The results show that increasing the volume percent of silica nanoparticles up to 10% improves elastic modulus 111% and reduces amateur percentage up to 72% [20].

Behzadiyan and *et al.* (2019) studied the mechanical properties of concrete composites containing waste PET (polyethylene terephthalate) and nano-silica to produce the lighter, more flexible and high-strength concrete. The mechanical properties and the morphology of the samples were investigated. The mechanical properties such as flexural, tensile and compressive strength of the composites declined with the PET aggregates, but the mechanical properties were significantly improved by incorporating the nano-silica. Optimum composition containing 10 wt.% of PET and 3 wt.% of nano silica was obtained, in which the tensile strength, compressive strength, and flexural strength were increased 27%, 30%, and 9% respectively compared to the neat concrete. The density of the optimum sample was decreased by 4% relative to the neat concrete [21].

Bartos (2009) was a researcher in nanotechnology that reviewed the conditions and resources for the production of nanomaterials, saying that between 2004 and 2030, nanotechnology would undoubtedly have the greatest impact on the construction industry. He suggested new products for building structures, including: 1) the issue of basic quality (the interaction of processes) on a nanoscale, such as cement compounds and nanostructures. 2) The dimensions of traditional building materials should be modified with a nano-structure. 3) How to implement building materials, use of insulation and self-cleaning coatings. 4) Use of multi-purpose and multi-purpose materials and compounds (nanorobots) [22].

Murata and *et al.* (1999) stated that nanomaterials absorb carbon dioxide from the environment and contribute significantly to reducing air pollution by returning oxygen to the air [23].

Zhu and *et al.* (2003) stated that photocatalytic self-cleaning is one of the most important uses of nanotechnology in the construction industry. Natural and industrial contaminants such as NOx, carbon monoxide, VOCs, chlorophenols, and aldehydes from automobiles and industrial effluents are decomposed by photocatalysts and with the active catalyst of titanium dioxide nanoparticles [24].

Chen and Poon (2003) stated that self-cleaning effect in titanium oxide activated by natural daylight, air humidity and oxygen. The activity of photocatalytes based on titanium dioxide can be comprehensively studied in the article [25].

Sikora and *et al.* (2009) in their studies stated that the self-cleaning properties and characteristics of mortar strength development containing waste glass and nanomaterials (nanosilica-nSiO2 and titanium dioxide-TiO2) were examined in terms of waste glass content and the effectiveness of existing commercial nanomaterials. Quartz sand was replaced by brown waste glass at a ratio of 25%, 50% and 100% by weight. Rhodamine B was used to determine the effect of cement containing titanium dioxide, nanosilica, and the presence of waste glass in cement mortar for its potential application in self-cleaning facades. Studies have shown that waste glass can serve as a successful alternative to sand, especially when part of it is mixed with sand. In addition, a positive effect of nanomaterials was observed due to self-cleaning and mechanical properties. A visual observation of the color change of rudamine B on cement mortar surfaces showed that the presence of waste glass did not adversely affect the cleaning properties of commercial cement containing titanium dioxide. The use of waste glass in general can counteract the negative impact of high demand for nanosilica water. Therefore, nanosilica can be successfully incorporated and placed inside cementitious composites without the aid of any additional material. The use of nanosilica improves the cohesion between glass aggregates and cement due to its dough properties and thus the compression of the cement mortar structure. The use of 3% by weight of nanosilica significantly increases the flexural and compressive strength of samples containing waste materials [26].

The research of Sanf and *et al.* (2010) showed that nano-silica corrects the properties of fresh malt. Nano-silica mortar showed higher compressive strength during all test periods. The use of these materials also reduced water absorption in the samples [27].

Sari and *et al.* (1999) used colloidal NS (2% by weight of cement) to produce HPC concrete with a compressive strength of 85 MPa, with the use of two admixtures: a nanometric, amorphous, silica SiO_2 (for its reactivity with the cement paste), combined with a specific polysaccharide (for its suspending ability), both of them used under a liquid form [28].

Heidari and Taheri Sartaneshnizi(1999) useded nano-silica and resin in high-strength self-compacting concrete. In this study, they found that using nanosilica with resin reduced the compressive strength of self-compacting concrete. Lower the amount of nanosilica with resin caused that the compressive strength was greater. Also, the use of 1.5% nanosilica caused the self-compacting concrete to come out of the self-compacting state [29].

Qing and *et al.* (2007) found that nanosilica exhibited higher pozzolanic properties than microsilica, and increased resistance. One of the reasons for the improvement in compressive strength is due to the pozzolanic activity of nano-silica. Nanosilic amorphous particles with a purity of over 99% and a high specific surface area react with hydrogenated calcium hydroxide crystals and produce hydrated silicate silicate gel. This reaction may improve the binding of the aggregate paste [30]. SEM images of this research is shown Fig 2. The white masses in the SEM images are calcium hydroxide crystals. It can be said that the addition

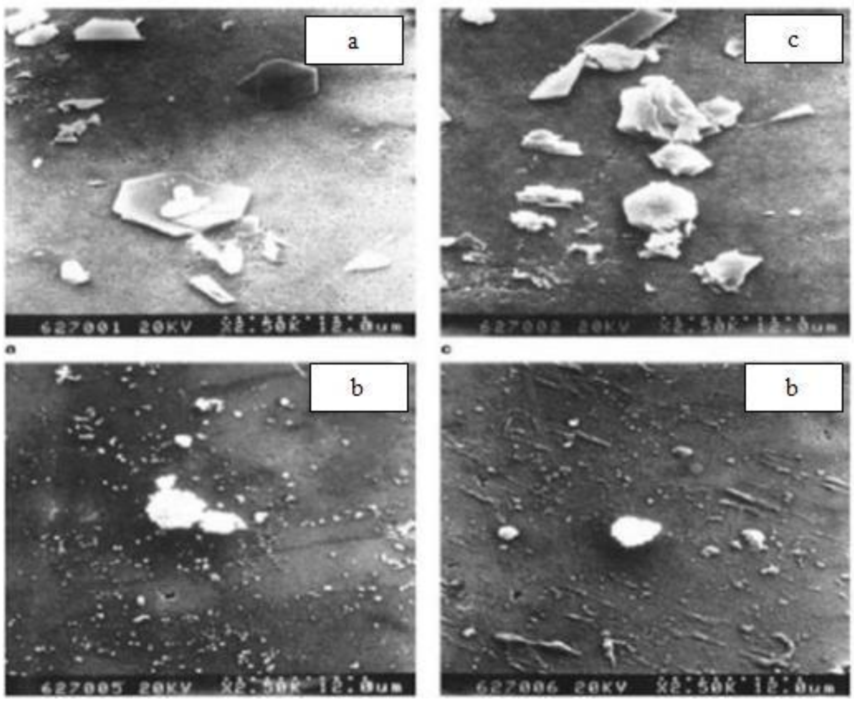

Fig. 2. SEM images of calcium hydroxide crystals in aggregate and 28-day cement paste
a) without the use of nanosilica b) with the use of 3% nanosilica c) with the use of 3% microsilica [30].

of silica and nanosilica to the composition of cement and water in cement paste can reduce the amount and size of calcium hydroxide crystals in the transition zone between dough and aggregate and thus strengthen this area [30].

Li and *et al.* (2006) in concrete, part of the calcium hydroxide produced by cement hydration remains in the form of microstructured pores over time. On the other hand, in nanosilica-containing samples, this calcium hydroxide reacts with nanosilica to produce hydrated calcium silicate gel, which reduces the amount of sediment and washes it out of the concrete [31].

Ramezanianpour and *et al.* (2009) showed that the water permeability of concrete containing nano-silica is significantly reduced compared to ordinary concrete and concrete containing microsilica. In this laboratory study, the mechanical and permeability properties of concretes containing nano-silica and microsilica were investigated through experiments such as compressive strength, water penetration and absorption, accelerated chloride ion penetration and electrical strength of concrete. Research has shown that compressive strength increases with increasing nano-silica content. In addition, nano-silica has a greater effect on reducing the permeability of concrete to water and chloride ions and increasing the electrical resistance of concrete compared to microsilica, especially in the early ages. In this study, the effect of substituting nano-silica and microsilica for 4.5 and 7.5 percent instead of cement on the penetration of water in concrete according to EN12390-8 standard was discussed. The results showed that the water infiltration rate in cubic samples with 15 cm dimensions was the best for the replacement of 7.5% nanosilica at 7 mm compared to 15 mm in the control sample. Also, the use of microsilica is less effective than nanosilica, so that with 7.5% of microsilica, 11 mm of water infiltration was reported. This reduction in penetration depth can be the result of improved transfer zone density due to the intense polarizing activity of nano-silica and the elimination of small cavities in the structure of nanocillis silicate gel [32].

Hossein Ali Beigi and *et al.* (2006) used a combination of nanosilica and microsilica. It was found that the mechanical properties were optimally increased by 1.5% nanosilica and 3% by increasing the microsilica according to Fig 3 and beyond It decreases slowly. This study also shows that the effectiveness of modulus of elasticity with respect to changes in the percentage of nano-silica compared to changes in propylene fibers is significant [33].

Ji and *et al.* (2005) studied the effect of nS addition on concrete water permeability and microstructure. Different concrete mixes were evaluated with nS particles of 10 to 20 nm, fly ash, gravel and. The results show that nS can reduce the water permeability of hardened concrete [34].

Lin and *et al.* (2008) have studied the effect of nS addition on the permeability of eco-concrete. They have shown with a mercury porosimetry test that the relative permeability and pores sizes decrease with nS addition (1 and 2% bwoc) [35]. Li (2004) reported water permeability was decreased in concrete with high fly ash content (50%) and 2% nS concentrations [36]. Kahachi and Abdul Jalil (2017) reviewed the impact of Nano-Concrete in contemporary Architecture [37]. Kooshafar and Madani (2017) studied influential mechanisms and potential applications of Nano-Silicas in cement composites [38]. Raki and *et al.* (2010) studied applications of Nanoscience and Nanotechnology in cement and Concrete. This work at the National Research Council Canada in the area of concrete materials research has shown the potential of improving concrete properties by modifying the structure of cement hydrates, addition of nanoparticles and nanotubes and controlling the delivery of admixtures [39]. Hui Li Zhang and *et al.* (2006) experimentally studied the abrasion resistance of concrete containing nanoparticles (both nano-TiO2 and nano-SiO2) for pavement [31]. The abrasion resistance of concrete containing nano-TiO2 is better than that containing the same amount of nano-SiO2. The effectiveness of nano-TiO2 (NT) in enhancing abrasion resistance increases in the order: 5% NT < 3% NT < 1% NT (with the decrease on NT content) [40].

Nazari and Riahi (2011) studied compressive strength, pore structure, thermal behavior and microstructure characteristics of concrete containing ground granulated blast furnace slag and TiO2 nanoparticles as a binder. TiO2 nanoparticle as a partial replacement of cement up to 3 wt% could accelerate C-S-H gel formation as a result of increased crystalline Ca(OH)2 amount at the early age of hydration and hence increase compressive strength of concrete. The increased TiO2 nanoparticles' content of more than 3 wt% may cause reduced compressive strength because of the decreased crystalline Ca(OH)2 content

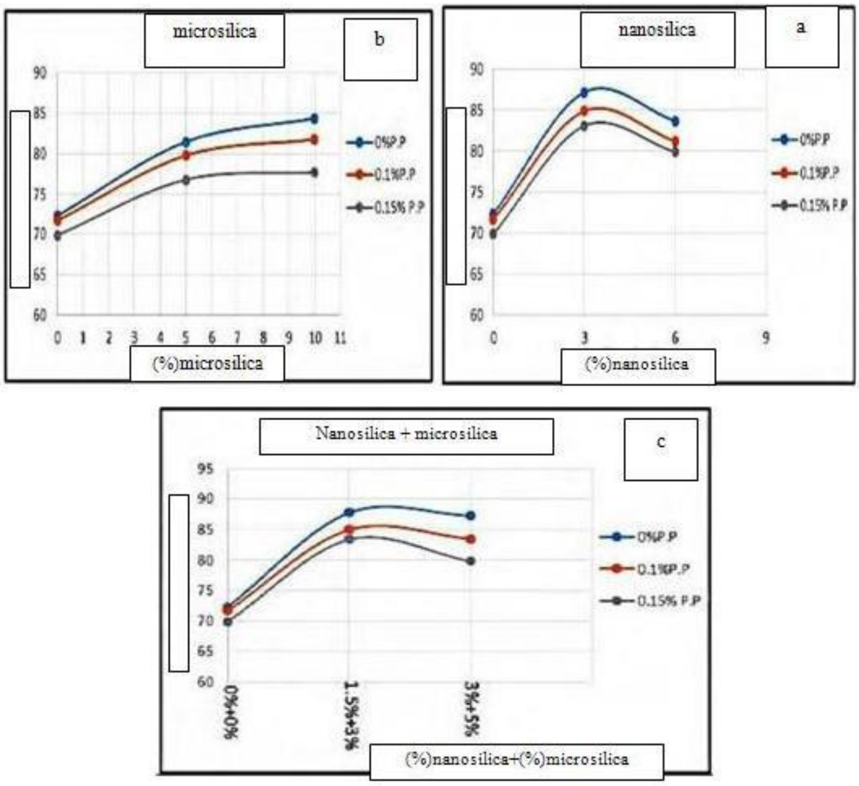

Fig. 3. a) Changes in compressive strength(Mpa) with increasing percentage of nanosilica and propylene fibers. The highest compressive strength(Mpa) was created at 3% nanosilica and zero% propylene. b) Compressive strength(Mpa) changes with increasing microsilica percentage and propylene fibers. The highest compressive strength(Mpa) was created at 10% microsilica and zero% propylene. c) Compressive strength(Mpa) changes with increasing percentage of microsilica and nanosilica and propylene fibers, which created the highest amount of compressive strength(Mpa) in the case of 1.5% nanocillis, 3% microsilica and 0% propylene [33].

required for C-S-H gel formation and unsuitable dispersed nanoparticles in the concrete matrix [41].

Nazari (2011) studied the effect of limewater on flexural strength and water permeability of TiO2 nanoparticles binary blended concrete. TiO2 nanoparticles with partial replacement of cement by 0.5, 1.0, 1.5 and 2.0 weight percent have been added. Test results show a significant reduction in percentage of water absorption. The rate of water absorption and also coefficient of water absorption at all ages with TiO2 nanoparticles are given acording to Tabale1[42].

In order to reduce the color caused by environmental pollution on the surface of prefabricated concrete parts in the architectural facade, it is necessary to do more research on concrete containing nanoparticles such as titanium dioxide, etc.

Research goals

One of the disadvantages of using titanium dioxide is the increased percentage of water absorption according to references [42] by increasing in amount of nano-TiO2 in very hot and humid weather conditions and at the time up to 7 days . The use of 3% combined nano-silica has covered this defect according to references [21], [26] and [33] to [33] that has also been used in this study.

The reference [26] looked at the effect of using recycled glass with fixed nano-silica and cement containing a constant percentage of titanium dioxide in the self-cleaning strength of concrete surface against rudamine B contaminants. In their results, they pointed out that recycled glass does not have a negative impact on self-cleaning properties, but reduces the percentage of water absorption. In other words, this advantage will cause the concrete

Tabale 1. Cofficient of water absorpsion ($m^2/s \times 10^{-10}$) in control and TiO2 nanoparticles blended concerte with curing of the specimens has been carried out in water and saturated limewater [42].

Mix designation	TiO2 nanoparticles (%)	7 days	28 days	90 days
C0-W (control)	0	9.02	2.86	1.35
N1-W	0.5	10.62	3.49	1.21
N2-W	1.0	11.10	3.87	1.27
N3-W	1.5	11.21	4.19	1.28
N4-W	2.0	11.46	4.45	1.32
C0-LW (control)	0	9.06	2.78	1.40
N1-LW	0.5	17.56	11.15	8.30
N2-LW	1.0	17.98	11.45	8.73
N3-LW	1.5	17.32	11.87	9.22
N4-LW	2.0	17.68	12.04	9.34

Table 2. Chemical composition of cement and silica fume

Compound	Cement(%)	Silica Fume(%)
CaO	64.38	1.87
SiO_2	21.08	89.22
Al_2O_3	5.36	1.2
Fe_2O_3	3.64	2.12
MgO	2	1.61
K_2O	0.82	1.056
Na_2O	0.5	0.556
L.O.I(Loss On Ignition)	0.9	2.6

surface to leak, which is one of the benefits of sustainable concrete facade development. They linked the increase in water absorption uptake to nanosilica. But according to [21], [26] and [33] to [33] results of the decrease in water absorption related to nanosilica.

In the our studies, silica instead of coarse-grained glass was used instead of recycled glass. It is used the 3% nanosilica and different percentages of titanium dioxide to investigate affecting of the self-cleaning property. Results will show affecting of increased self-cleaning properties with increased titanium dioxide but the increased TiO2 nanoparticles' content of more than 3 wt% may cause reduced compressive strength acording to [41]. The use of 3% combined nano-silica or 20% silicafium will cover this defect according to references [16] and [26].

The main aim of this study, It was to investigate compressive strength by using increases of titanium dioxide and constant 3% nanocillis or 20% silicafium.

Other aim of this study, It was to investigate percentage of water absorption by using increases of titanium dioxide and constant 3% nanocillis or 20% silicafium.

EXPERIMENTAL

Materials

Cement type I-42.5 in accordance with standard specifications of American Society for Testing and Materials(ASTM)-C150 [43] was used. Silica fume compatible with the standard specifications of ASTM-C1240 [44] was used in mix proportions as a partial replacement for cement. Chemical composition of silica fume and cement are presented in Table 2. 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 [45]. Ultrafine TiO2 with the diameter of about 800 nm and specific gravity of 3.91 gr/ cm^3 was used in mix proportions. Nano-silica with the diameter of about 15 nm was used. The properties of nano-silica are given in Table 3.

Mix designs

Mixing and curing were performed in accordance with the procedure prescribed in ASTM C109 [46]. At first the dry materials were gently mixed until a homogenous dry mixture was gained.

Table 3. Properties of nano-silica

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

Table 4. Mix designs

Mix designation	Cement content(kg/m^3)	Replacement percentage			Water/cement
		Silica fume	Nano-silica	$UFTiO_2$	
SFT0	800	20	0	0	0.38
SFT2.5	800	20	0	2.5	0.38
SFT5	800	20	0	5	0.38
NT0	800	0	3	0	0.38
NT2.5	800	0	3	2.5	0.38
NT5	800	0	3	5	0.38

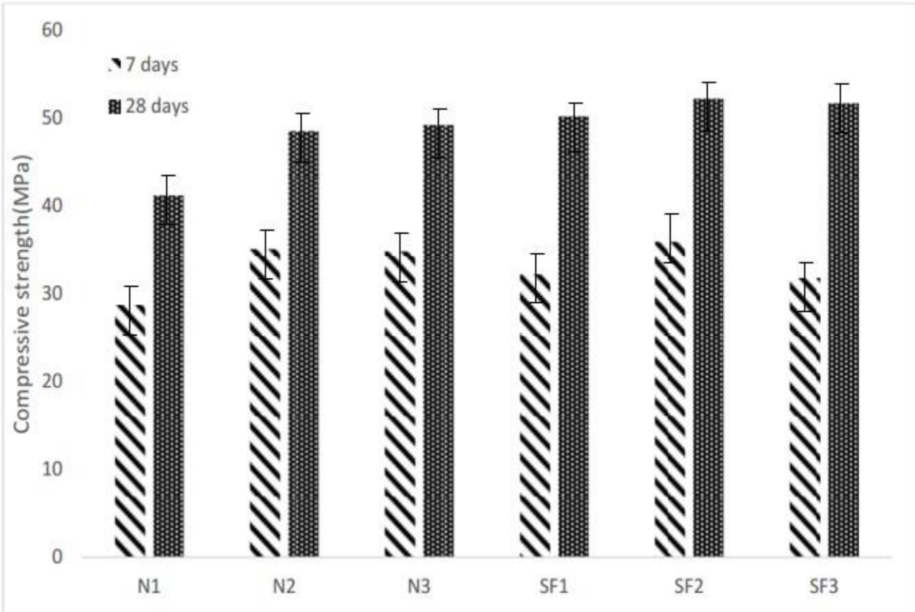

Fig. 4. Compressive strength in 6 samples. N1, N2 , N3, SF1, SF2, SF3. Data are expressed as mean ± SD (n = 5)

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 (silica fume and 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. Table 4 shows the mix proportion designs of this study.

Testing

Compressive strength

The test was performed in complying with ASTM C109 [46]. Cubic specimens with the dimension of 50 mm were fabricated and subjected to compressive loading at the ages of 7 and 28 days.

RESULTS AND DISCUSSION

Fig. 4 and Table 5 shows the results of compressive strength test at the ages of 7 and 28 days. For the specimens containing nano-silica the addition of TiO_2 has led to an increase in compressive strength. At the age of 7 days best results have been obtained from the specimen with 2.5% TiO_2 while at the of

Table 5. Results of compressive strength in 6 samples

Mix designation	Compressive strength	Compressive strength
	Results of 7 days	Results of 28 days
N1	28.7	41.2
N2	35.1	48.5
N3	34.8	49.2
SF1	32.2	50.2
SF2	35.9	52.2
SF3	31.8	51.7

Table 6. Results of final water absorption in 6 samples

Mix designation	*water absorption*
N1	4.9
N2	4.5
N3	4.6
SF1	4
SF2	3.8
SF3	3.6

28 days the specimen with highest TiO_2 content has shown better performance when nano-silica containing specimens are evaluated. This can be due to the filler effect of TiO_2 particles on which the hydration products can grow and consequently a denser microstructure is obtained. Comparing N1 and N2 at the age of 28 days shows that an increase of 17.7% has occurred as the TiO_2 is introduced to the mixtures. This indicates that TiO_2 has a great potential for improving the mechanical strengths of cement composites.

For the specimens with silica fume the addition of TiO_2 did not have a significant effect of compressive strength. Compared to SF1 an increase of only 3.9% has been obtained in the specimen containing 2.5% TiO_2 at the age of 28 days. This negligible increase can be attributed to the similar size distribution of silica fume and ultra-fine TiO_2 used in this research. Further increase in TiO_2 content to 5% has led to a decrease in compressive strength which can be due to the agglomeration of these particles.

The results are displayed as mean ± standard deviation. Statistical differences were determined by Student’s two-tailed *t*-test.

Final water absorption of 6 samples are given at Table 6. In accordance with ASTM C497[47], the maximum final water absorption is 8.5% thus the results of 6 samples are acceptable.

In accordance with the BS EN 1340[48], this subject is related to 6% thus the results of 6 samples are acceptable too.

In according to Table 6, increasing in Titanium dioxide is leaded to in decrease of water absorption in SF1, SF2 and SF3 more than N1, N2 and N3. Because the use of Silica fume is more than Nano-silica in SF1, SF2 and SF3.

CONCLUSIONS

Nanotechnology has shown that it has the ability to improve concrete performance in a comprehensive way. In this paper, a number of applications of nanotechnology in concrete have been investigated. Then, the effect of using titanium dioxide on increasing or decreasing the compressive strength of pre-fabricated concrete parts in the architectural view of concrete structures has been investigated. Six designs were tested for compressive strength with respect to zero, 2.5 and 5 percent replacement of cement with TiO2.

The addition of TiO2 has led to an increase in compressive strength. The best results from the sample with 2.5% TiO2 are obtained. This could be due to the effect of TiO2 particles filling.

Comparison of SF3, SF2 and SF1 at 28 days of age showed that SF2 increased the compressive strength. This shows that TiO2 has a great potential for improving the mechanical properties of composite cement.

Comparison of SF3, SF2 and SF1 at water absorption showed that increasing in Titanium dioxide is leaded to in decrease of water absorption in SF1, SF2 and SF3 more than N1, N2 and N3.

Results show that by increasing of titanium dioxide, the compressive strength is increased. the increased TiO2 nanoparticles content of more than 3 wt% are caused to reduce the compressive strength acording to [42]. But in this study is shown that by adding 3% nanocillis or 20% silicafium to increased TiO2 nanoparticles content of more than 3% wt, the results of compressive strength are not redused. The use of 3% combined nano-silica or 20% silicafium will cover this defect of increased TiO2 nanoparticles content of more than 3% wt.

CONFLICT OF INTEREST

All authors declare that no conflicts of interest exist for the publication of this manuscript.

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