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EFFECT OF POLYPROPYLENE FIBERS ON MECHANICAL AND PHYSICAL PROPERTIES OF MORTARS CONTAINING NANO-SIO_2

A. Sadrmomtazi[1], A. Fasihi[2], A.K. Haghi[3]
[1]Assistant Professor, Dept. of Civil Engg, Faculty of Engg, University of Guilan, Rasht, Iran
[2]M.S. Student, Dept. of Civil Engg, Faculty of Engg, University of Guilan, Rasht, Iran
[3]Professor, Dept of Textile Engg, Faculty of Engg, University of Guilan, Rasht, Iran

ABSTRACT
It has been demonstrated that the fiber-matrix bond strongly affects the ability of fibers to stabilize crack propagation in the matrix. As the bond between fiber and matrix is mainly mechanical, it seems that incorporating nano-SiO_2 (NS) into fiber reinforced cement composites provides better bond with matrix through pore refinement and better distribution of the hydrated products. Hence in this paper an effort was made to study the effect of polypropylene (PP) fibers on mechanical properties and shrinkage of mortar incorporating NS. Three fiber volume fractions, 0.1%, 0.3% and 0.5% were considered. Compressive and flexural strength, water absorption and shrinkage of mortars were reported. Results showed that NS improved mechanical and water absorption characteristics of mortars significantly. It has been observed that the addition of NS fairly enhanced the fibers effectiveness in improving the mechanical strength of mortars.

Keywords: mortar, nano-SiO_2, compressive strength, flexural strength, shrinkage

1. INTRODUCTION
Nano-particles possess unique physical and chemical properties that can improve the function and properties of many types of materials. Among the nano-particles, nano silica have been used to improve the properties of cement based materials and some efforts on excellent mechanical properties and microstructure of cement composite with NS have been also reported. Studies have shown that application of NS into the production of mortar and concrete can lead to improvement in compressive strength, flexural behavior and abrasion resistance [1-4]. Therefore NS can be applied in production of high performance concrete (HPC) which has been gradually replacing normal strength concrete. As the rate of pozzolanic reaction is proportional to the amount of surface available for reaction and owing to the high specific surface of nano particles, they possess high pozzolanic activity that consume calcium hydroxide (CH) which arrays in the interfacial transition zone between hardened cement paste and aggregates and produce hydrated calcium silicate (CSH) which enhances the strength of cement paste [5]. In addition, due to nano scale size of particles, NS can fill the ultra fine pores in cement matrix. This physical effect of the finer grains leads to reduction in porosity of transition zone in

the fresh concrete. This mechanism strengthens the bond between the matrix and the aggregates and improves the cement microstructure and properties. Furthermore, it has been found that when the small particles of NS uniformly disperse in the paste due to their high activity, they generate a large number of nucleation sites for the precipitation of the hydration products which accelerates cement hydration [6].

Polypropylene fibers have been widely used for the reinforcement of cementitious materials to improve the toughness and energy absorption capability of matrix [7]. They were found to be extremely effective in reducing free plastic shrinkage, in retarding first crack appearance and in controlling crack development [8]. Although effectiveness of PP fibers in shrinkage cracking, impact resistance and ductility of cement matrices has been proved by many researchers, effect of PP fibers on compressive and flexural strength is not quit clear [9]. Studies have shown that there can be little or no chemical adhesion between the fiber and matrix as a result of their chemical inertness [10]. It seems that smooth surface of PP fibers intensifies this effect. Moreover, it has been suggested that the presence of PP fibers in cement paste results in the formation of a water film at the interface of fiber and matrix called wall effect. Due to greater mobility of calcium ions in a water environment, portlandite (calcium hydroxide) macro crystals can easily grow and make the transition zone more pores [11]. This phenomenon has a negative impact on the bond between fiber and matrix. It is clear that in order to utilize the maximum strength of the fiber and improve the composite properties, it is essential to enhance the interfacial bond of pp fibers. It seems that the physical and chemical effects of nano particles can be useful in reduction of wall effect between fiber and matrix. Accordingly, present study focuses on the effect of NS on mechanical and physical properties of fiber reinforced cement composite mortar.

2. EXPERIMENTAL PROCEDURE

Materials and mix proportions: The cement used in all mortar mixes was ordinary Portland cement which corresponds to ASTM type 1. The chemical analysis of Portland cement is shown in Table 1. NS in liquid form with the average particles size of 50 nm was used in this study. In order to achieve desire fluidity and better dispersion of nano particles, a polycarboxylate ether based superplastisizer was utilized. The content of superplastisizer was adjusted for each mixture to keep constant the fluidity of mortars. Ottawa sand conforming to ASTM-C778 [12] was used for mortar preparation. Table 2 reveals the physical properties of PP fibers. All specimens were fabricated with the water/binder and sand/binder ratios of 0.5 and 2.75 respectively. The weight of binder was considered equal to the sum of the weight of cement and NS.

In the initial stage of the present study a total of 6 batches of mortars were prepared to find the optimum amount of NS in ordinary cement mortar (Table 3). According to the initial stage results, in the second stage 0.1%, 0.3%, and 0.5% PP fiber (Compared with the total mortar volume) were added to the ordinary and the optimum mixtures selected in the initial stage with the purpose of evaluating the influence of the PP fibers on the strength and shrinkage properties (Table 4). In all the tests, specimens without fiber were considered reference materials.

Table 6: Chemical compositions of cement

Items	Chemical compositions (%)
SiO_2	21.5
AL_2O_3	3.68
Fe_2O_3	2.76
CaO	61.5
MgO	4.8
SO_3	-
L.O.I	1.35

Table 2: Properties of polypropylene fiber

Property	Polypropylene
Unit weight (gr/cm^3)	0.9-0.91
Reaction with water	Hydrophobic
Tensile strength (MPa)	300-400
Elongation at break (%)	100-600
Melting point	175
Thermal conductivity (W/m/K)	0.12
Length (mm)	6

Test method: In order to achieve desire properties, it is essential to disperse NS and PP fibers uniformly. Accordingly, mixing was carried out in a rotary mixer as follows:

1. The NS particles were stirred with 90% of mixing water at high speed and for about 1 min.
2. The specified amount of fiber was added and mixed for 2 min at medium speed.
3. The cement was added and the mixer was allowed to run for 1 min at medium speed.
4. The sand was gradually added at 30s while the mixer was running at medium speed.
5. The superplastisizer and remaining water were added and stirred at high speed for 30s.
6. The mixture was allowed to rest for 90s. Then mixing was continued for 2 min at high speed.

Fresh mortar was cast into 50×50×50 mm cubes for compressive and water absorption tests and 50×50×200 steel molds for flexural and shrinkage tests. The specimens were tamped using a hard mallet to decrease the amount of the air bulbs. After the feeding operation, each of the specimens was allowed to stand for 24 h. Then the specimens were demolded and kept in water at 23±3 $^{\circ}C$ until they were tested.

Compressive strength test was conducted in accordance with ASTM-C109 [13] using a hydraulic testing machine under load control at 1350N/s. The three-point (i.e. center-point) loading flexural test was carried out with the span of 180mm and at a loading rate of 44N/s. The flexural and compressive strength were determined at 7, 28, 60 and 90 days of curing. Shrinkage test samples were cured in the laboratory environment at 27±3 °C. Changes in the length of the mortar samples were measured using a length comparator with the precision of 0.002mm. The first measurement was taken after 24h of mixing, while the rest of the measurements were taken at the ages of 3, 7, 14, 21, 28, 35 and 42 days. The water absorption test was carried out at 28 days as follows: Saturated surface dry specimens were kept in an oven at 110°C for 72 h. After measuring the initial weight, specimens were immersed in water for 72h. Then the final weight was measured and the final absorption was reported to assess the mortar permeability.

Table 3: Mix proportion of the specimens (initial stage)

Batch No	Sand/Binder	Water/Binder	% Content (by weight)	
			O.P.C.	N.S.
NS0	2.75	0.5	100	0
NS1	2.75	0.5	99	1
NS3	2.75	0.5	97	3
NS5	2.75	0.5	95	5
NS7	2.75	0.5	93	7
NS9	2.75	0.5	91	9

Table 4: Mix proportion of the specimens (second stage)

No	S^a/B^b	W^c/B^b	%Content(by weight)		%PP (Vol)	No	S^a/B^b	W^c/B^b	% Content (by weight)		%PP (Vol)
			O.P.C	N.S					O.P.C	N.S	
1	2.75	0.5	100	-	0	5	2.75	0.5	100	-	0.3
2	2.75	0.5	93	7	0	6	2.75	0.5	93	7	0.3
3	2.75	0.5	100	-	0.1	7	2.75	0.5	100	-	0.5
4	2.75	0.5	93	7	0.1	8	2.75	0.5	93	7	0.5

a: Sand b: Binder (Cement +Nano-SiO_2) c: Water

3. EXPERIMENTAL INVESTIGATION AND RESULTS

Compressive strength: The compressive strength of cement mortars with different dosages of NS at four ages are given in figure 1. It is clear that the compressive strength of ordinary cement mortar increases with an increase in the amount of NS. It can be seen that increasing the NS content from 7% to 9% didn't improve the compressive strength significantly. It seems that a large amount of NS even decreases the strength. According to Hui Li [14] homogeneous hydrated microstructure which is essential for the strength of cement matrix can not be formed because nano particles can not be well dispersed. Strength enhancement of NS can be attributed to reduction in the content of $Ca(OH)_2$ which does not have any cementing property and production of hydrated calcium silicate (CSH) that plays a vital role in mechanical characteristics of cement paste [15,16]. NS particles also generate a large number of nucleation sites for the cement hydration products making the paste microstructure more homogenous and improve its strength and permeability [17]. In the view of the results above, cement mortar with substitution of cement by 7% NS was selected as the optimum mixture. Figure 2 shows the compressive strength of fiber reinforced mortars. Results appearing in this Figure indicate that PP fibers induce a slight modification in the compressive strength. The compressive strength of mortar increased gradually at first with the increase of fiber content but then decreased with the further increasing of fiber content. Almost all the specimens containing 0.1% pp fiber by volume exhibited an increase in compressive strength compared to the target specimens. A possible reason for this may be that PP fibers act as crack arresters.

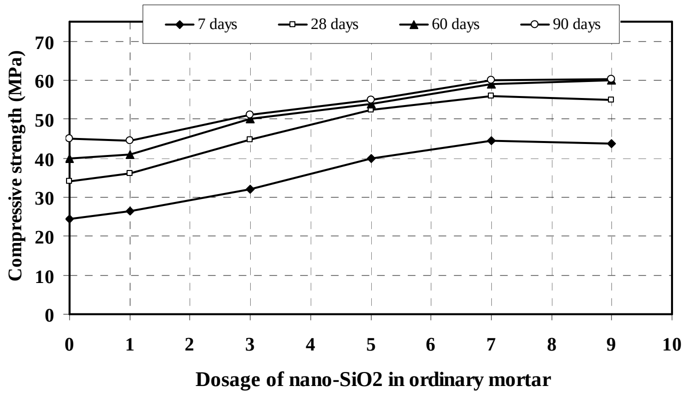


Figure 1. Compressive strength of ordinary mortars at different contents of nano-SiO_2

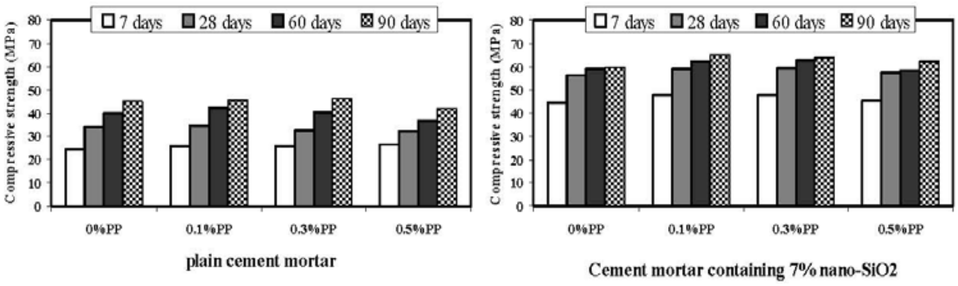


Figure 2. Compressive strength of different mortar mixtures according to the PP content

The uniformly distributed PP fibers reinforce the mortar against disintegration by resisting further opening of initial cracks and disallowing the microcracks from growing into macro cracks [18].

The strength development at 0.1% pp fiber addition varied depending upon the nature of mixtures. The mortar containing 7% NS showed greater average enhancement by 6.49% compared to plain cement mortar by 3.1%. At 0.3% fiber addition, the compressive strength of plain cement mortar decreased contrary to mortar containing 7% NS that still increased. It is obvious that increase in pp dosage beyond 0.3% decreases the compressive strength. This is understandable because large contents of pp fibers are more difficult to disperse uniformly. Therefore fibers form clusters and create more micro-defects in cement matrix which inevitably reduces the compressive strength of mortar.

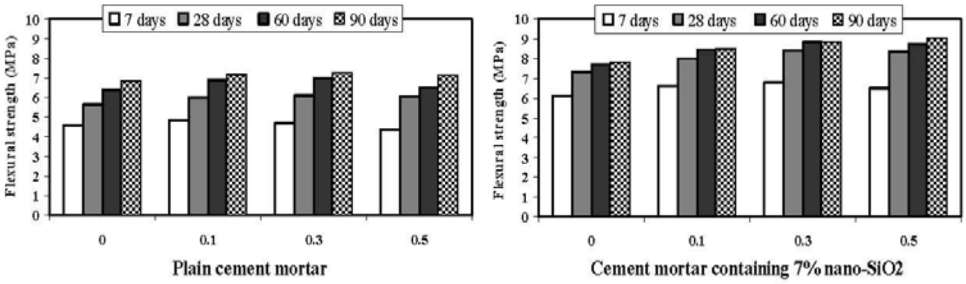
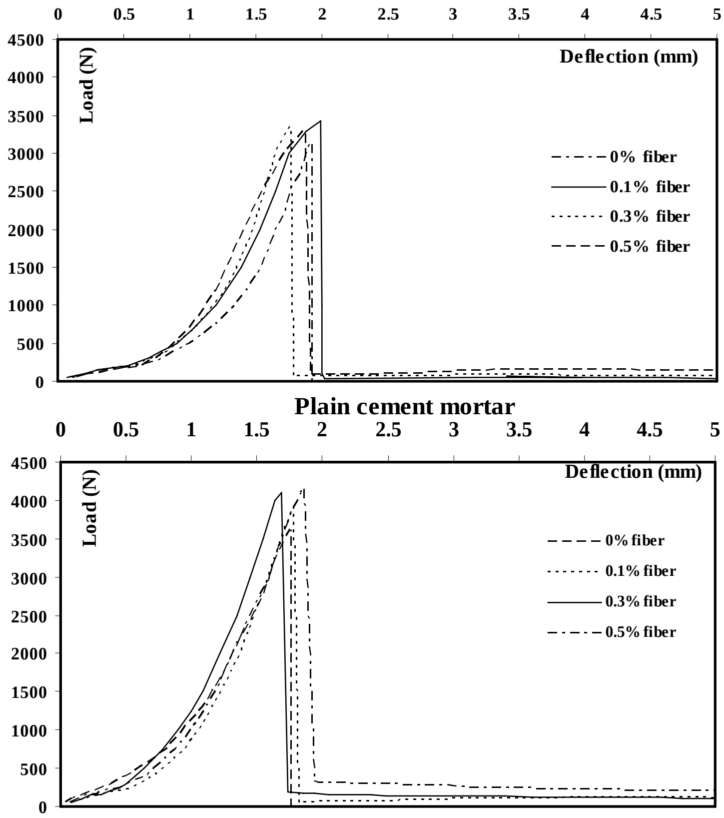


Figure 3. Flexural strength of different mortar mixtures according to the PP content

Flexural strength: The flexural strength of mortar specimens are presented in Figure 3. Comparing the flexural strength of nonfibrous specimens revealed that NS effectively increased the flexural strength of mortar. Results of fiber reinforced specimens showed that the flexural strength in fiber reinforced mortars was slightly higher than that of mortars without fibers. The values of flexural strength of cement composites increased with increasing the fiber content until it reached an optimal amount of 0.3% and then dropped to some lower value at 0.5%, however for mortar containing NS a slight increase of flexural strength was observed beyond 0.3%. It should be noticed that presence of NS in cement matrix improved the effectiveness of fibers in reinforcement of cement mortar. The microstructure of cement paste at the interfacial between fiber and matrix is the most important region influences of the fibers effectiveness. The addition of NS strengthens this weak region through reduction of the internal porosity especially in the transition layer by consumption of porous portlandite crystals which array in the interfacial between fiber and matrix. Therefore, fiber/matrix contact area increases and higher friction can be formed between the two. Typical flexural load deflection response of different mixtures containing 0%, 0.1%, 0.3% and 0.5% PP fibers at 90 days are represented in Figure 4. The test was controlled automatically by computer with a constant cross head movement of 1mm/min. It was found from the figures that for the unreinforced mortar, the materials demonstrated brittle behavior. The samples fully fractured with increase of mid span deflection after peak load while fiber reinforced mortar exhibited some what ductile behavior. A study of the load-deflection graphs showed that mortar containing NS was obviously more brittle than that of plain mortar, however integrating PP fibers somewhat compensated for this shortage. A small effect was noted upon fiber volume fraction of 0.1% and a relatively bigger increase was observed while increasing fiber content to 0.5%. When cracks occur and propagate, fibers are able to bridge across the surface of the cracks and prevent the crack face separation in the tension half of the reinforced beam. The fibers sustain the load until they pullout from the matrix. This mechanism provides an additional energy-absorbing which leads to a stable fracture process and higher fracture energy. The presence of NS enhanced the efficiency of transforming load from matrix to fiber by increasing the friction coefficient between fiber and composite matrix. Hence effect of pp fibers on post-peak resistance was more obvious for mortars containing NS.

Water absorption: The water absorption of specimens is shown in Table 5. A study of the water absorption values of the unreinforced specimens revealed that incorporating NS into cement mortar improved the water absorption properties of the products. The reason for this observation is that the fine particles of pozzolan block the channels connecting capillary pores in cement paste and generate more homogenous distribution of CSH gel resulting in less pore structure and permeable voids [19].



Cement mortar containing 7% nano-SiO2

Figure 4. Flexural behavior (load-deflection) of different mixtures

Adding PP fibers changed the water absorption properties. The water absorption values of the mixtures decreased at 0.1% fiber content. It was observed that increasing the fiber percentage increased the water absorption of cement mortars. The reason behind this observation could be the poor dispersion of PP fibers in mortar that consequently increases the pore volume of cement matrix, for plain cement mortar water absorption started to rise up at 0.3% fiber content, while in mortars containing NS at 0.5%. This means that presence of NS in cement matrix provided better fiber dispersion. The reason may be due to an increase in the cohesiveness of the cementitious matrix by NS which is beneficial for better dispersion of PP fibers [20].

Table5: Water absorption of different mixes.

Batch No	Absorption (%)	Batch No	Absorption (%)
1	6.120	5	6.45
2	4.230	6	4.187
3	6.040	7	7.091
4	4.204	8	4.211

Shrinkage behavior: The shrinkage behavior of mortars is presented in figures 5and 6. From the results it can be concluded that presence of NS in mortar increased the drying shrinkage apparently. It may be due to self desiccation caused by pore size refinement of NS [21]. Moreover, from the data presented by the previous researchers it is seen that NS particles act as an activator to accelerate cement hydration [22]. Therefore, the autogenous shrinkage related to chemical shrinkage can be increased.

Results of fiber reinforced specimens demonstrated that small amounts of fiber could contribute positively to moderate the length change caused by drying shrinkage. All the mortars reinforced with 0.1% pp fiber, provided better improvement for shrinkage. Obviously, using higher content of PP fibers (beyond 0.3%) did not work for moderating shrinkage strain. At 0.5% PP content, drying shrinkage of all specimens increased even more than reference mortars. More investigations are needed to explain this effect.

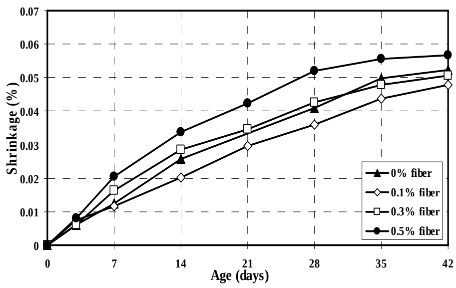


Figure 5. Effect of PP fibers on shrinkage of plain cement mortar

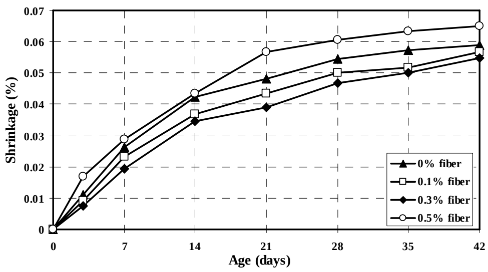


Figure 6. Effect of PP fibers on shrinkage of cement mortar containing 7% nano-SiO_2

4. CONCLUSIONS

A comprehensive experimental investigation was carried out to evaluate the influence of nano-SiO_2 on properties of fiber reinforced cement composite mortars. Based on the test and analysis results the following preliminary conclusions are obtained.

- Utilizing polypropylene fibers in cement matrix caused a slight enhancement in compressive and flexural strength. The contribution of further increase of the fiber content to mechanical strength was not positive. A possible reason for this observation could be the poor dispersion of PP fibers in mortar that increases pore volume and creates more micro defects in cement matrix.
- The fiber reinforced mortar demonstrated higher post-peak flexural strength compared with reference mortars. This effect was more obvious at larger contents of fibers. The effectiveness of the fiber reinforcement on mechanical strength somewhat improved with the incorporation of nano-SiO_2 particles. This can be due to reduction of the internal porosity especially in fiber/matrix transition zone that provides higher contact surface and hence friction between the two.
- Water absorption of ordinary mortar decreased by incorporating nano-SiO_2. Adding small amount of pp fibers resulted in an improvement in water absorption characteristics, however higher amounts of fiber especially in ordinary cement mortar did not have any positive effect.
- Presence of nano-SiO_2 in cement matrix increased the dying shrinkage of mortars. The inclusion of fiber reinforcement within composite cement mortar could moderate this effect. However, utilizing high contents of fiber (beyond 0.3%) didn't have any positive impact on shrinkage strain.

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