Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Preliminary Study on the Mechanical Behavior of Mortar Containing Waste Polypropylene Fiber and Nano-SiO_2

Ali Sadrmomtazi and Ali Fasihi

Faculty of Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran.
<sadrmomtazi@yahoo.com>, Assistant Professor, Dept. of Civil Engg, Guilan University.
<fasiha66@yahoo.com>, M.S. Student, Dept. of Civil Engg, Guilan University.

ABSTRACT

A great amount of fibrous textile waste is discarded into landfills each year all over the world. One promising reuse of these wastes lies in concrete reinforcement and construction applications. Although synthetic fibers have advantageous characteristics, the weak bond with cement matrix as a result of their smooth surface and chemical inertness remains a large limitation. It seems that nano-SiO_2 due to extremely fine size and high pozzolanic activity has a potential to provide better fiber/matrix bond. The objective of present work is to investigate the effect of integrating nano-SiO_2 with ordinary and RHA mortars containing different contents of waste polypropylene fibers on various properties of the products. Three fiber volume fractions, 0.1%, 0.3% and 0.5% were considered. The measured properties included compressive and flexural strength. Results showed that the presence of nano-SiO_2 in mortar enhanced the polypropylene fiber's effectiveness in the strengthening of mechanical properties.

INTRODUCTION

In less than one century, concrete has become the most widely used construction material in the world and is used in all sorts of civil structures and infrastructures [Aitcin 2000]. Besides its prominent structural importance, concrete can be precious from environmental aspect. For the last decades concrete producers have made wide use of waste or by-product materials in concrete [Wu et al. 1996]. Incorporating these materials in concrete would have two major significances: improving fresh and hardened properties of concrete and minimizing the environmental pollutions due to solid waste disposal. A great amount of fibrous textile waste is discarded into landfills each year all over the world. More than half of this waste is from carpets, which decays at a very slow rate and which is difficult to handle in landfills. One promising reuse of these wastes lies in concrete reinforcement and construction applications. Waste carpet fibers have been used in cement-based composites since the past decades [Wang et al. 1994]. Polypropylene (PP) and other synthetic fibers are added to cement composites as secondary reinforcement to control plastic shrinkage and increase the energy absorption capability of matrix [sun et al. 2001]. PP fibers are hydrophobic therefore they don't influence the water demand of fresh concrete significantly. They have excellent durability in alkaline cement matrix and do not intervene in the hydration of cement. The fibers can be simply added and mixed randomly with concrete without any additional precautions [Tang et al. 2007]. 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 quite clear. Most studies have shown that PP fibers had little contribution to compressive and flexural strength [Toutanji 1999]. It has been found that fiber/matrix bond strongly affects the performance of fiber in improving mechanical properties [Singh et al. 2004]. Studies have shown that there can be little or no chemical adhesion between the fiber and matrix as a result of their chemical inertness [Linfa et al. 1998; Hamou et al. 2005]. 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 formation of a water film at the interface of fiber and matrix called wall effect. Due to the greater mobility of calcium ions in a water environment, portlandite (calcium hydroxide) macro crystals can easily grow and make the transition zone more pores [Hulmer et al. 1999]. This phenomenon has a negative impact on 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.

Recently with the help of advanced nano technology developments, nano-SiO_2 with superlative pozzolanic activity and extremely fine particles size has been introduced. Studies have shown that incorporation of nano-SiO_2 into cement based materials improved their physical and mechanical properties significantly [Li 2004; Jo et al. 2007]. Filling the voids of CSH gel structure and generating homogeneous distribution of hydrated products beside reduction the quantity of big and porous portlandite macro crystals are mainly responsible for mechanical strength improvement caused by nano-SiO_2 [Dotto et al. 2006; Li et al. 2006]. The physical and chemical effects of nano particles may be useful in reduction of wall effect between fiber and matrix. Accordingly present study intended to investigate the usage possibility of nano-SiO_2 in improving the performance of waste polypropylene fibers in cement mortars.

EXPERIMENTAL PROCEDURE

Materials and mix proportions

The cement used in all mortar mixes was ordinary Portland cement which corresponds to ASTM type I. Rice husk ash (RHA) with a silicate (SiO_2) content of 92.1% and an average particle size of 15.83µm was used. The chemical analysis of Portland cement and RHA is shown in Table 1. Nano-SiO_2 in liquid form was used in this study. The basic material properties of nano-SiO_2 are given in Table 2. In order to achieve desire fluidity and better dispersion of nano particles, a polycarboxylate ether based superplastisizer was utilized. The

Table 1. Chemical compositions of cement and rice husk ash

Item	Chemical Compositions (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
Cement	21	4.6	3.2	64.5	2	2.9	1.5
RHA	92.1	0.41	0.21	0.41	0.45	-	-

Table 2. Basic Material Properties of Nano-SiO_2 (in liquid form)

Item	Diameter (nm)	PH value	Composition (mass%)
Target	50	10	SiO_2(30%) + H_2O(70%)

content of superplastisizer was adjusted for each mixture to keep constant the fluidity of mortars. Standard sand confirming to ASTM C778 was used for mortar preparation. Table 3 reveals the physical characteristics of polypropylene fibers. All specimens were fabricated with the water/binder and sand/binder ratios of 0.5 and 2.75 respectively. The weight of cementitious materials was considered equal to the sum of the weight of cement, RHA and nano-SiO_2. In mortars containing RHA, 20% of cement was replaced by RHA that is an acceptable range and is most often used [Sadrmomtazi et al, 2008]. In the initial stage of the present study a total of 10 batches of mortars were prepared to find out the optimum amount of nano-SiO_2 in ordinary and RHA mortars (Table 4).

Table 3. Properties of Polypropylene Fibers

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
Thermal conductivity (W/m/K)	0.12
Length (mm)	6

Table 4. Mix Proportion of the Specimens (initial stage)

Batch No	Sand / binder	Water/Binder	% Content (by weight)		
			O.C.	R.H.A.	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
RHN0	2.75	0.5	80	20	0
RHN1	2.75	0.5	79	20	1
RHN3	2.75	0.5	77	20	3
RHN5	2.75	0.5	75	20	5

According to the initial stage results, in second stage 0.1%, 0.3%, and 0.5% PP fibers (compared with the total mortar volume) were added to the ordinary and RHA cement mortars and the optimum mixtures selected in the initial stage (Table 5).

Test method

The procedures for mixing the fiber-reinforced mortar involved the following. First, the nano-SiO_2 particles were stirred with the 90% of mixing water at high speed and about 1 min. Then, the specified amount of fiber was distributed and mixed for 2 min at medium speed. Next, dry mixed cement and RHA was added to mixture. Then the mixer allowed running for

Table 5. Mix Proportion of the Specimens (second stage)

No	$\frac{S}{B}$	$\frac{W}{B}$	%Content (by weight)			%PP Vol	No	$\frac{S}{B}$	$\frac{W}{B}$	% Content (by weight)			%PP Vol
			OC	RHA	NS					OC	RHA	N	
1	2.75	0.5	100	-	-	0	9	2.75	0.5	100	-	-	0.3
2	2.75	0.5	80	20	-	0	10	2.75	0.5	80	20	-	0.3
3	2.75	0.5	77	20	3	0	11	2.75	0.5	77	20	3	0.3
4	2.75	0.5	93	-	7	0	12	2.75	0.5	93	-	7	0.3
5	2.75	0.5	100	-	-	0.1	13	2.75	0.5	100	-	-	0.5
6	2.75	0.5	80	20	-	0.1	14	2.75	0.5	80	20	-	0.5
7	2.75	0.5	77	20	3	0.1	15	2.75	0.5	77	20	3	0.5
8	2.75	0.5	93	-	7	0.1	16	2.75	0.5	93	-	7	0.5

S: Sand, B: Binder (Cement +RHA +Nano-SiO_2), C: Water

1 min at medium speed. After that, sand was gradually added at 30s while the mixer was running at medium speed. Finally, the superplastisizer and remaining water were added and stirred at high speed for 30s.The mixture was allowed to rest for 90s, Then mixing was continued for 1 min at high speed. Fresh mortar was cast into 50×50×50 mm cubes for compressive test and 50×50×200 steel molds for flexural test. 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.

The compressive strength test was conducted in accordance with ASTM C109 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 strengths were determined at 7, 28, 60 and 90 days of curing.

EXPERIMENTAL INVESTIGATION AND RESULTS

Compressive strength

Figure 2 and Figure 3 display the compressive strength of ordinary and RHA cement mortars with different dosages of nano-SiO_2 at four ages. It is clear that the compressive strength of ordinary cement mortar increases with an increase in the amount of nano-SiO_2. It can be seen that increasing the nano-SiO_2 content from 7% to 9% didn't improved compressive strength significantly. It seems that large amount of nano-SiO_2 even decreases the strength. According to Hui Li [2004] homogeneous hydrated microstructure which is essential for strength of cement matrix can not be formed because nano particles can not be well dispersed. Strength enhancement of nano-SiO_2 can be attributed to reduction in the content of $Ca(OH)_2$ which has not any cementing property and production of hydrated calcium silicate (CSH) that plays a vital role in mechanical characteristics of cement paste [Rao 2003]. Nano-SiO_2 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 [Ji 2005]. It has been also observed that compressive strength of RHA mortars improved with the incorporation of nano-SiO_2. The reason may be due to increase in packing density of binder. Kaufmann et al [2004] announced that packing density of a powder can be improved by adding a fine powder to a coarse one. Integrating nano-SiO_2 particles

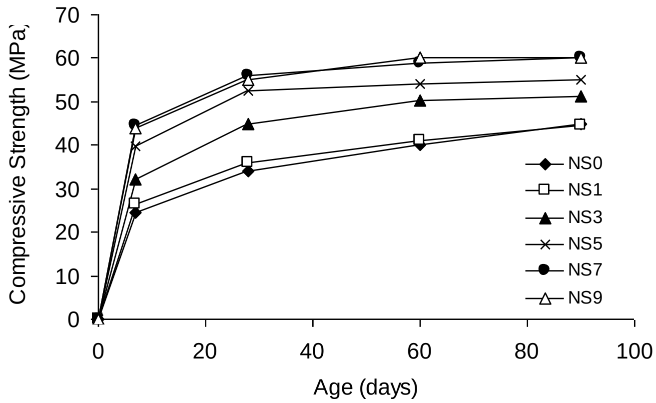

Fig.1. Compressive Strength of Plain Mortars at Different Contents of Nano-SiO_2

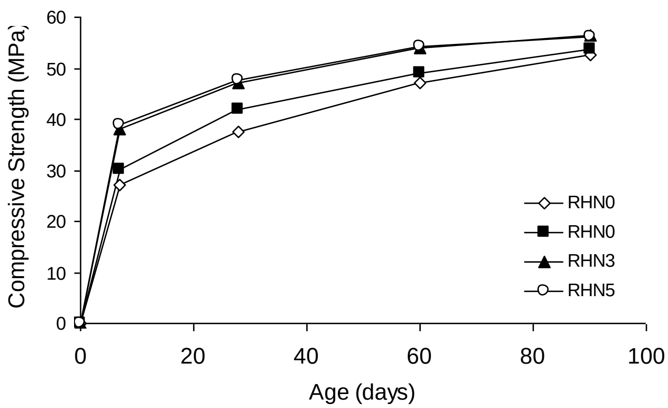

Fig.2. Compressive Strength of RHA Mortars at Different Contents of Nano-SiO_2

with RHA in cement composite mortar improved the packing density and reduced the porosity of cement matrix which plays a vital role in mechanical strength. According to the results above, mixtures NS7 (cement mortar with substitution of cement by 7% nano-SiO_2) and RHN3 (RHA cement mortar containing 3% nano-SiO_2) were selected as the optimum mixtures in order to investigate the effect of PP fiber on their strength.

Figure 3 shows the compressive strength of fiber-reinforced mortars. Results appearing in this Figure indicate that PP fibers inducing 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. 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 [Song et al. 2005]. The strength development at 0.1% pp fiber addition varied depending upon the nature of mixtures. The greatest average enhancement was found for the mixture containing 7% nano-SiO_2 by 4.35%. At 0.3% fiber addition compressive strength of

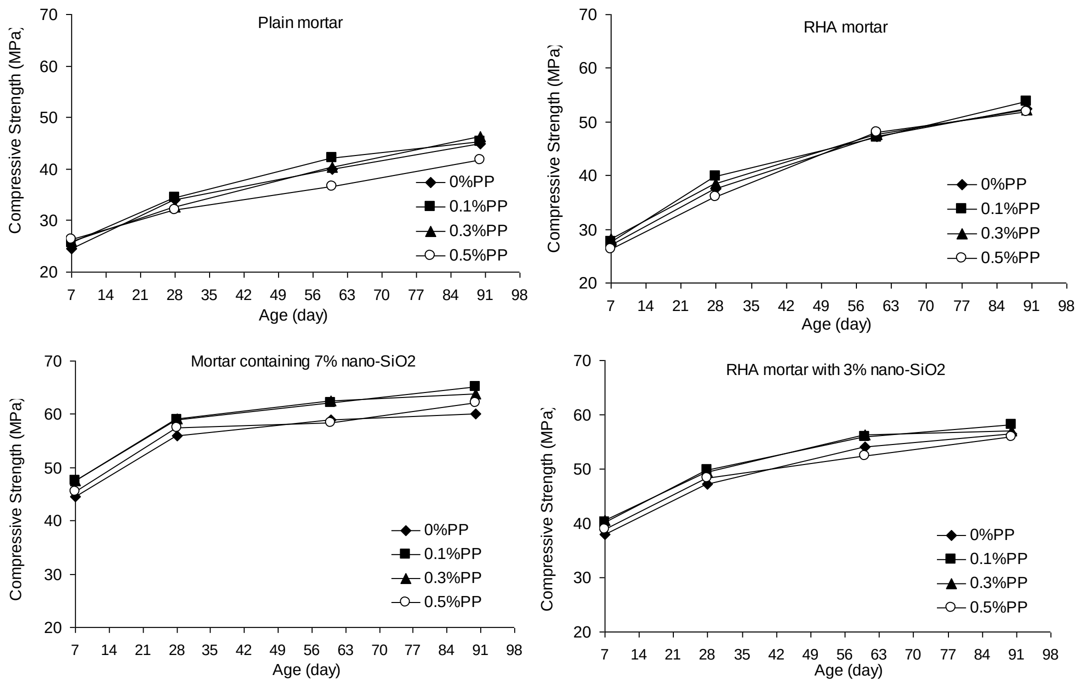

Fig. 3. Compressive Strength of Different Mortars According to the PP Content

the specimens decreased except in mixture containing 7% nano-SiO_2 that still increased. It is obvious that increase in pp dosage beyond 0.3% decreases the compressive strength considerably. 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 reduce the compressive strength of mortar [Li et al. 2004].

Flexural strength

Figure 4 shows the flexural strength of mortar specimens. The flexural strength of unreinforced specimens revealed that nano-SiO_2 was more valuable in developing flexural strength than that of RHA. In comparison with nano-SiO_2 the contribution of RHA in early strength of mortar was low. Incorporating nano- SiO_2 in to RHA mortars compensated for this effect and improved the flexural strength. Results of fiber reinforced specimens showed that the flexural strength of fiber reinforced mortars was slightly higher than those of mortars without fibers. The values of flexural strength of ordinary and RHA 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 nano-SiO_2 a slight increase of flexural strength was observed with increasing of PP content beyond 0.3%. It should be noticed that the presence of nano-SiO_2 in cement matrix improved the effectiveness of fibers in reinforcement of cement mortar. Similar behavior was observed in the case of RHA mortar upon adding nano-SiO_2. The microstructure of cement paste at the interfacial between fiber and matrix is the most important region influences fibers effectiveness. Addition of nano-SiO_2 strengthens this weak region through reduction of the internal porosity especially in transition layer by consumption of porous portlandite crystals which array in the interfacial between fiber and matrix. Therefore fiber/matrix contact area increases and transforming load from matrix to fiber can be increased. Hence effect of pp fibers on flexural strength was more obvious for mortars containing nano-SiO_2.

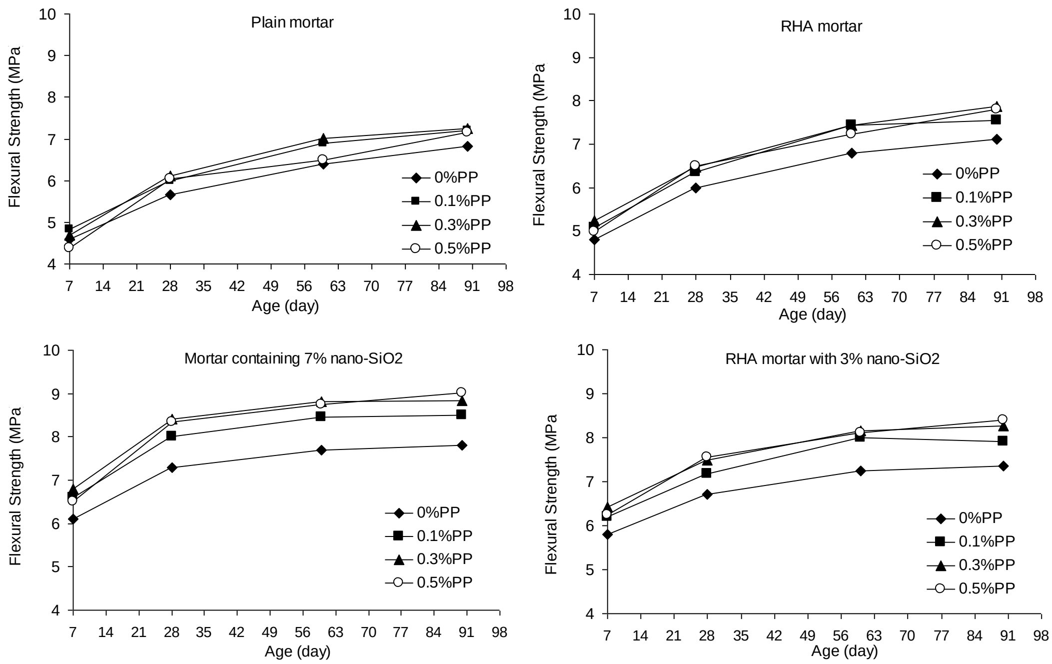

Fig. 4. Flexural Strength of Different Mortars According to the PP Content

CONCLUSION

A preliminary study 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 it can be concluded that application of waste 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 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 internal porosity especially in fiber/matrix transition zone that provides higher contact surface and hence friction between the two.

REFERENCES

Aitcin, P.C. (2000). "Review Cements of yesterday and today Concrete of tomorrow." *Cement and Concrete Research*, 30, 1349-1359.

ASTM C 109. (2000). "Standard test method for compressive strength of hydraulic cement mortars." *Annual book of ASTM standards*, 4.01, 84-89.

Dotto, J., Deabreu, A.G., Dalmolin, D.C.C., Muller, I.L. (2006). "Influence of silica fume addition on concretes physical properties and on corrosion behavior of reinforcement bars." *Cement and Concrete Composites*, 26, 31-39.

Holmer, S.J. Vahan, A. (1999). "Transition zone studies of vegetable fiber-cement paste composites." *Cement and Concrete Composites*, 21, 49-57.

Jo, B., Kim, C., Tae, G., Park, J. (2007). "Characteristics of cement mortar with nano-SiO_2 particles." *Construction and Building Materials*, 21, 1351-1355.

Ji, T. (2005). "Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO_2." *Cement & Concrete Research* 35, 1943-1947.

Kaufmann, J., Winnefeld, F., Hesselbarth, D. (2004). "Effect of the addition of ultra fine cement and short fiber reinforcement on shrinkage rheological and mechanical properties of Portland cement pastes." *Cement & Concrete Research*, 26, 541-549.

Li, G. (2004). "Properties of high-volume fly ash concrete incorporating nano-SiO_2." *Cement & Concrete Research*, 34, 1043-1049.

Li, G., Stubblefield, M.A., Garrick, G., Eggers, J., Abadie, C., Huang, B. (2004). "Development of waste tire modified concrete." *Cement & Concrete Research*, 34, 2283-2289.

Li**,** H., Xiao, H., Yuan, J., Ou**,** J. (2004). "Microstructure of cement mortar with nano-particles." *Composite: part B*, 35, 185-189.

Li, H., Zhang, M.H., Ou, J. (2006). "Abrasion resistance of concrete containing nano-particles for pavement." *Wear*, 260, 1262–1266.

Linfa, Y., Pendleton, R.L., Jenkins, C.H.M. (1998) "Interface morphologies in polyolefin fiber reinforced concrete composites." *Composite Part A* , 29, 643-650.

Rao, G.A. (2003). "Investigations on the performance of silica fume-incorporated cement pastes and mortars." *Cement & Concrete Research*, 33, 1765-1770.

Sadrmomtazi, A., Haghi, A.K. (2008). "Mechanical properties of cement based and composite containing rice husk ash." *International journal of applied mechanic and engineering*, 13(3).

Singh, S., Shukla, A., Brown, R. (2004). "Pullout behavior of polypropylene fibers from cementitious matrix." *Cement & Concrete Research*, 34, 1919-1925.

Song, P.S., Hwang, S., Sheu, B.C. (2005). "Strength properties of nylon-and polypropylene-fiber-reinforced concretes." *Cement & Concrete Research*, 35, 1546-1550.

Sun, W., Chen, H., Luo, X. and Qian, H. (2001). "The effect of hybrid fibers and expansive agent on the shrinkage and permeability of high-performance concrete." *Cement & Concrete Research*, 31, 595-601

Tang, C., Shi, B., Gao, W., Chen, F., Cai, Y. (2007). "Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil." *Geotextiles and Geomembranes*, 25, 194-202.

Tasnit-Hamou, A., Vanhove, Y., Petrov, N. (2005). "Microstructural analysis of the bond mechanism between polyolefin fibers and cement pastes." Cement *& Concrete Research*, 35, 364-370.

Toutanji, H. (1999). "Properties of polypropylene fiber reinforced silica fume expansive-cement concrete." *Construction and Building Materials*, 13, 171-177.

Wang, Y., Yureick, A., Cho, B., and Scott, D. (1994). "Properties of Fiber Reinforced Concrete Using Recycled Fibers from Carpet Industrial Waste." *Journal of Materials Science*, 29(16), 4191-4199

Wu, H.C., Lim, Y.M., Li, V.C. (1996). "Application of recycled tyre cord in concrete for shrinkage crack control." *Journal of Materials Science Letters*, 15(20), 1828-1831.