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Fibers Addition to Nano Engineered Sand Dunes Mortars Subjected To Severe Loading and Environmental Conditions

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Abstract— although dune sands in concrete could be very scarce, there is only a limited number of researches in that field. Generally mixes made with dune sand only resulted in lower strengths. One of the major advantages of reinforcing cement-based materials with randomly distributed fibers is the improved resistance to dynamic loads. This property is critical when designing structures subjected to impact and impulsively applied loads or performing fiber reinforced cement composite under cyclic and impact load to study that under severe conditions; such as elevated temperatures and acidic attack. This study aims at analyzing the evolution of different types of fibers (steel, glass, polypropylene and carbon nano-tubes) into the cement- sand dunes matrix, under different severe conditions and with the incorporation of nano to micro sized silica addition. Five mixes were prepared and tested for; compressive strength at elevated temperatures (room temperature, 200, 400, and 600 ^{o}C), flexural strength, acid attack, and cyclic and impact loadings. The results showed that the optimum use of fibers in cement mortars varied from condition to the other. Steel and glass fibers showed a distinguished effect in the improvement of compressive and flexural strengths and the resistance to fire and cyclic loading. Steel fibers and CNT had the best effect to resist acid attack. Polypropylene had the best resistance to spalling occurrance. Steel and polypropylene fibers had the best resistance to impact loading.

Index Terms—Steel, glass, polypropylene and carbon nano-tube fibers, nano silica, resistance to fire, cyclic loading, acid attack, compressive strength.

1 INTRODUCTION

Every year, harms caused by corrosion because of the presence of concrete structures in acidic or other deteriorating situations achieve a lot of destruction to these structures; in addition to incurring huge economic losses. To dispense with these harms, retrofitting and remaking are being done on an a large scale, which thusly prompt the generation of a huge measure of cement requiring the utilization of extra amounts of concrete, at last further adding to the environmental pollution induced by cement production. Although concrete structures are typically composed and worked for a lifetime of no less than 50 years, at times, because of the of destructive arrangements, for example, sulfuric corrosive, these structures encounter nearby or worldwide harm simply following a couple of years. As the corrosion rate expands the redesign and, at times, entire substitution of harmed structures, which is an expensive practice and involves numerous community issues, end up inescapable.

Using nano-silica as well as fly ash and silica fume in micro scale in cement mortar improve its properties and becomes well-compacted concrete but more brittle [1-9], then the use of materials with high tensile properties to improve this imperfection is highly required. Fibers are considered a very well material to improve the tensile properties of cement mortars.

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There are many types of fibers were used in cement mortar such as steel, glass, polypropylene and recently, carbon nanotubes. Although the effects of the different types of fibers on the properties of cement mortars were previously studied, however, no study on the effect of using different types of fibers in nano engineered sand dunes mortars subjected to severe conditions. The results of Jong-Pil Won et al [10] at high temperature showed that the use of polypropylene fibers improved the splitting tensile strength of concrete but decreased the compressive and flexural strengths by 31–32% and 28–31%, respectively. Using steel and polypropylene fibers at 1 and 2% by weight in concrete mixes improved the compressive strength of concrete and enhanced its resistance to fires. Polypropylene fibers had a great effect than steel fibers to resist fires [11-18]. Hu Feng et al [19] used steel fibers to change the behavior mode of failure from brittle to ductile. Moreover, recent investigation took place regarding the effect of carbon nano tubes in enhancing the tensile, and flexural behaviour of cement composites, but few literature could be found in studying the CNT's effect on the fire resistance or their resistance when being subjected to other aggressive environments [20].

There is a limited amount of previous works conducted on the use of dune sands in concrete. Guettalla et al [21] have compared strength properties of mortar mixes made with conventional sands and dune sand. Mixes made with dune sand only resulted in lower strengths. Kay at al [22] made a comparison among concrete mixtures made with beach sand, wadi sand, dune sand, screened dune sand, and combinations of dune sand or screened dune sand with crushed rock fines. Their results indicated that dune sand may provide a readily available alternative material for use as fine aggregate in concrete.

The aim of the proposed research is to study the effect of using the different types of fibers on the properties of cement mortars subjected to severe conditions (elevated temperatures, acidic attack, and impact and cyclic loadings). The mortars will incorporate nano and micro scale particles with the use of dune sand as a replacement of fine aggregate.

2 Experimental procedure

Ordinary Portland cement (OPC) with grade CEM I 52.5 N was used. It complies with Egyptian standard specification (ESS: 4756-1/2009). Its chemical composition is shown in Table (1). Commercial nano-silica (NS) with an average particle size of 20 to 80 nm was used. Its chemical composition, particle size distribution (PSD) and properties are shown in Table (1) and Figs. (1-3). As observed the nano-silica was at a peak centered at 2(Θ) = 23 °, which revealed the amorphous nature of its particles. Amorphous and agglomerated micro-silica with size ranging from 48 to 625 nm was used. Its chemical composition, particle and properties are shown in Table (1) and Figs. (1-3). As observed the silica fume was at a peak centered at 2(Θ) = 21°, which revealed the amorphous nature of its particles.

Fly ash, the fine particulate waste material produced by the pulverized coal-based thermal power station, was an environmental pollutant. Its chemical composition, particle, and properties are shown in Table (1) and Figs. (1-3). A sand dune was used in the experimental program. Figure (4) shows the sieve analysis test for the sand dunes used. Portable water was used. The super plasticizer used was SikaViscoCrete-425 P. Four different types of fibers were used, normally; steel fibers (Sika Fiber-CHO 65/35 NB) with 35 mm length and 0.54 mm diameter, glass fiber with 6 mm length and 13 microns diameter, polypropylene fibers with 18 micron diameter and 18 mm length and carbon nano-tube fibers with an aspect ratio (L/D 1000:1). Table (2) shows the quantities of materials used in the five mixtures; control mix without fibers and four mixes with fourdifferent types of fibers.

TABLE 1
Chemical composition of cement, nano silica, silica fume and fly ash(%).

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I	P_2O_5
Cement	20.13	5.32	3.61	61.63	2.39	2.87	0.37	0.13	1.96	-
Nano silica	99.17	0.13	0.06	0.14	0.11	-	0.4	-	-	0.01
Silica fume	94.7	0.26	0.25	1.13	-	0.6	0.36	2.45	-	-
Fly ash	49.9	19.2	10.1	8.21	2.84	0.71	1.01	0.72	5.21	-

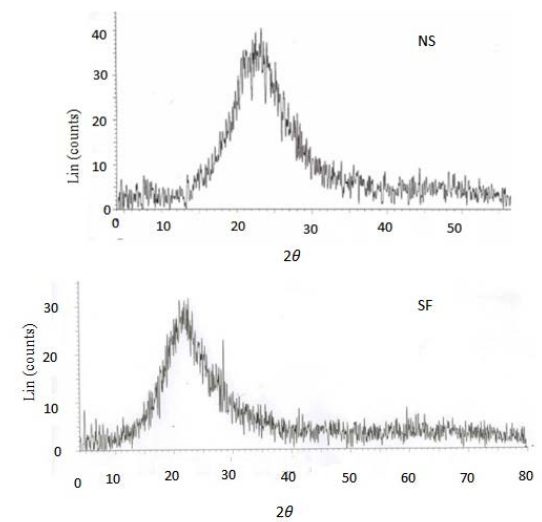

Fig. (2): XRD analysis of NS and SF.

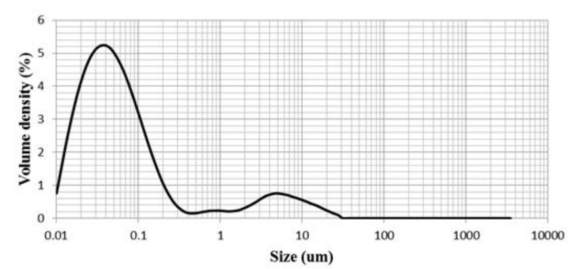

Fig. (3): Particle size distribution of nano silica.

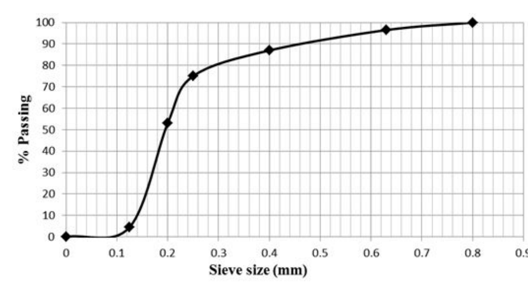

Fig. (4): Sieve analysis of fine aggregate.

The

compressive strength was measured using cubes 10 x 10 x 10 cm dimensions subjected to heating at 200, 400 and 600 ^{0}C for one hour, and compared with those tested at room temperature. The flexural strength was measured using prisms 5 x 5 x 20 cm dimensions. The acid attack test was carried out by immersing 10 x 10 x 10 cm cubes statically in sulfuric acid solution with a concentration of 5% in a tank for 60 days. The impact load test was carried out using a steel ball of 400 gm weight, falling free from a distance of 45 cm on 10 x 10 x 6 cm cubes and 5 x 5 x 20 cm prisms.

TABLE 2
QUANTITIES OF MATERIALS USED IN ALL MIXTURES (KG/M^3).

N.S	S.F	F.A	Cement	water	sp	sand	steel fiber	glass fiber	polypropylene fiber	CNT fiber
16.0	64.0	128.0	592.0	200.0	12.0	1600	79.0	26.8	10.6	0.4

3 Results and Discussion

3.1 Mechanical Properties

Figure (5) presents the compressive strength of different mixes at different temperatures. Comparing the results at room temperature shows that addition of steel and glass fibers increased the compressive strength by about 30 and 20%, respectively, while addition of polypropylene and CNT fibers had not any significant effect on the compressive strength. At 200 ^{0}C, the compressive strengths of control and polypropylene mixes were increased by 7 and 2%, while decreased for steel, glass and CNT fibers mixes by 9, 6 and 21%, respectively, as compared to the same mixes at room temperature. At 400^{0}C the compressive strengths of control, polypropylene, glass and CNT fibers mixes were increased by 6, 12, 10, and 4%, respectively, while there was no effect in the mix with steel fiber when compared with the corresponding mix at room temperature. On the other hand the compressive strength for glass fiber at 600 ^{0}C was increased by 29% and it was decreased for control, steel, polypropylene and CNT fibers mixes by 10, 13, 27 and 16%, respectively, when compared with the corresponding mix at room temperature., Figure (6) presents the effect of high temperature on the cubes of different types of mixes. As can be seen, the control mix showed an explosive fracture with wide and deep cracks, explosion of the specimens started at 400 ^{0}C and the cubes were subjected to spalling at temperature of 600 ^{0}C. Cubes made from mixes with steel, glass and CNT fibers showed less explosive breaks and the spalling was started at 600 ^{0}C temperature, while cubes made from mix with polypropylene fiber didn't explode at all temperature grades.

The above mentioned results for mortars subjected to high temperatures, proved that the addition of steel fibers increases the mortar porosity at a lesser extent than in the case of the addition of polypropylene fibers. Thus reducing pressure in the pores in the deeper mortar areas, and contributing to the confinement of dehydrated paste and controlling cracking [2]. The addition of polypropylene fibers in the mortar, when the melting point is reached (170 ^{o}C), created a series of channels in the mortar mass that allows water vapor to evacuate, releasing pore pressure, gradually reducing the temperature and decreasing the cracks in the cooling phase [2]. The addition of glass fibers in the mortar prevented spalling occurred because the high melting point, which reached to 600 ^{0}C. The addition of CNT had no obvious effect because its amount was little and its dimensions were small, it could not arrest the cracks that occurred due to vapour pressures through out the temperature increase.

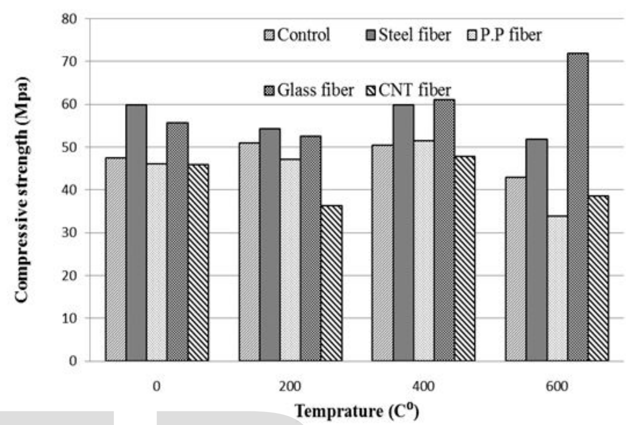

Fig. (5): Results of compressive strengths of different mixes at the different degree of temperature.

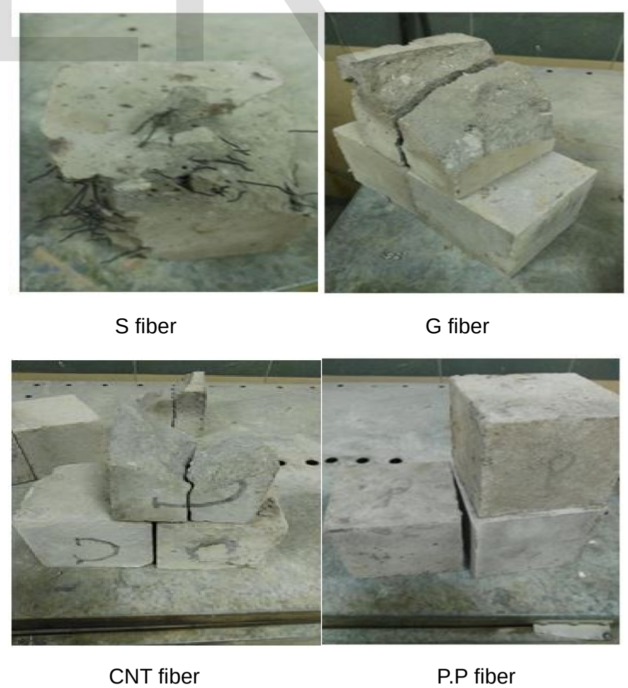

Fig. (6): Effect of high temperature at (600 ^{0}C) on different types of mixes.

Using fibers improved the flexural strength at 28 days age for all types of fibers with all studied ratios, see Fig. (7). The flexural strength was increased as compared to the control mix for steel, polypropylene, glass and CNT fibers by 49, 1, 45 and 11%, respectively. As well-known the fibers major effect is in arresting the crack propagation and enhancing the crack bridging.

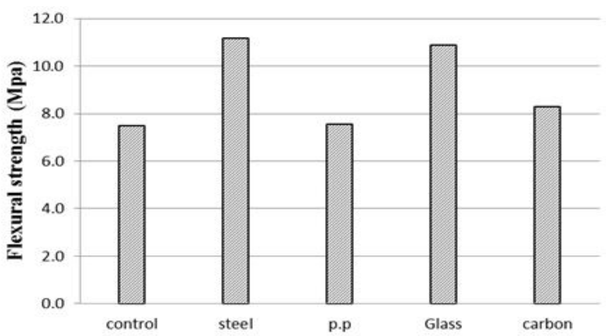

Fig. (7): Flexural strength of all mixes at 28 days age.

3.2 Aggressive Conditions Results

Figure (8) shows cube specimens contained nano silica, silica fume and fly ash particles, which had high pozzolanic reactivity and high PH values that resist the acidic attack. Moreover, the presence of well graded amorphous silica particles helped in reducing the pore contents and distribution within the cement matrix; resulting in decreasing the possibility of the acid penetration to the core of samples. There were no losses in the compressive strength after the test, but in some cases the compressive strength was increased. This could be due to aging, where the test needed about 60 days after 28 days for immersion of the cubes that resulted in a gain of strength for all mixes as compared to the 28 days. The gain in compressive strength for control mix, steel, polypropylene, glass and CNT fiber mixes was 3, 20, 33, -8 and 10%, respectively, as shown in Fig (9). The glass fiber was the worst, while the polypropylene was the best of utilized fiber types.

Before compression test After compression test

Fig. (8): Effect of the acid attack on the cube specimens.

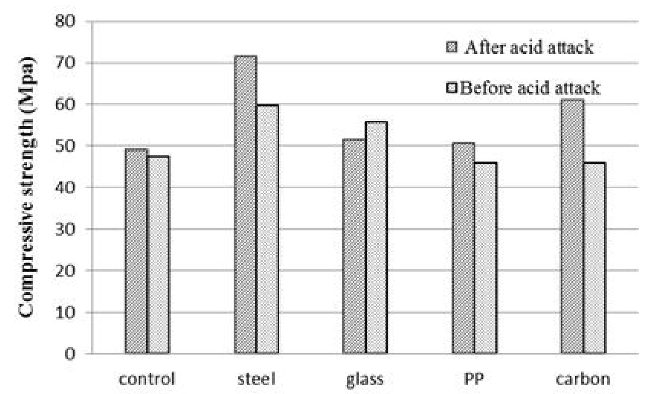

Fig. (9): Comparison of compressive strength before and after exposure to acid attack.

3.3 Resistance to Cyclic and Impact Loading

Cyclic loading test showed that the addition of fibers to the mix considerably improved the resistance of specimens to cyclic loading, as shown in Fig. (10). The results revealed that the control and CNT mixes failed after 62 and 72 cycles, respectively, at flexural strength of 5.4 Mpa, while steel, polypropylene and glass survived about 100 cycles without any crack and failed at an increased flexural strength of 11.7, 8.1 and 11 Mpa, respectively.

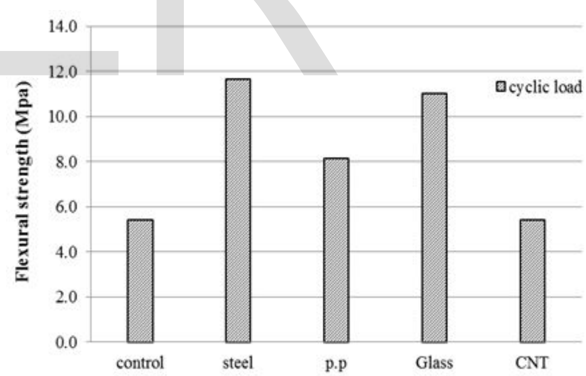

Fig. (10): Flexural strength of specimens subjected to cyclic loading.

Cube specimen incorporated steel, polypropylene and glass fibers showed good resistance to impact loading as compared to control mix with gain ratios of 382, 218 and 318%, respectively, see Fig. (11). Also in case of prisms specimens, the results revealed that the steel and polypropylene fibers had a very well gain in resisting the impact load as compared to all other mixes, as shown in Fig. (12). Figure (13) shows failure of specimens subjected to impact loading.

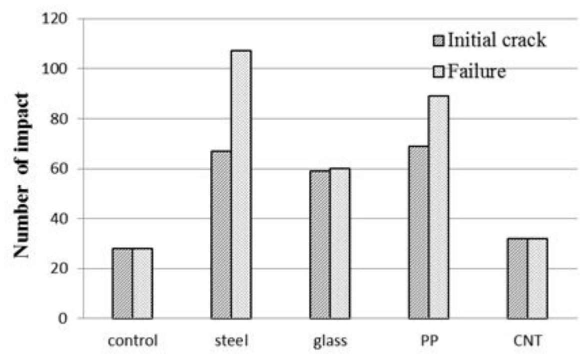

Fig. (11): Results of impact load test on cube specimens.

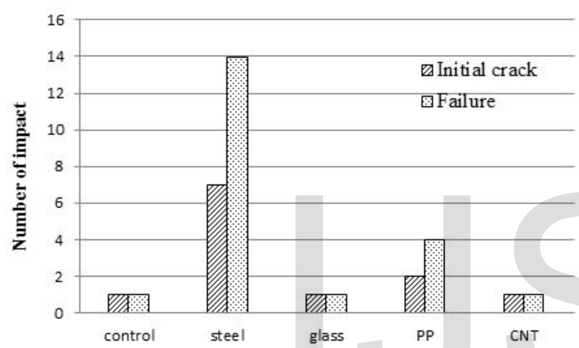

Fig. (12): Results of impact load test on prism specimens.

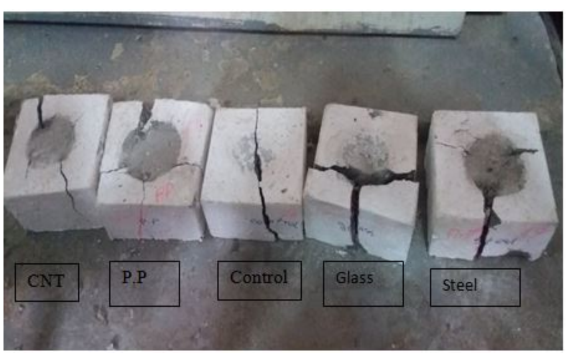

Fig. (13): Failure of specimen subjected to impact loading.

4. Conclusions

From discussing the previous results, the following can be concluded:

1- Adding steel and glass fibers to nano-engineered sand dunes mortars improved its compressive strength at room temperature with about 30 and 20% respectively, compared with the control mix.

2- Glass fibers gave the best attitude to gain compressive strength at high temperatures, where it gained about 29% in the compressive strength at 600 ^{0}C temperature compared to that at room temperature. All other mixes showed gain in compressive strength only up to 400 ^{0}C followed by loss in range (10:27) % in the compressive strength with increasing the temperature.

3- Use of well-graded silica particles in the mix constituents gave very will-compacted specimens with very less voids; as a result the specimens were exploded when subjected to 400 ^{0}C temperature. Adding fibers to this type of mix delayed the exploding to take place at 600 ^{0}C temperature, except the mix with polypropylene fiber that didn't explode at 600 ^{0}C temperature.

4- Adding steel and glass fibers to nano-engineered sand dunes mortars improved its flexural strength at room temperature with about 49 and 45% respectively, compared with the control mix.

5- All mixes showed better resistance to acid attack, except mix with glass fiber where its compressive strength was decreased by about 8%.

6- Steel, polypropylene and glass fibers showed better resistance to cyclic loading. Their flexural strengths were increased over that of the control mix by about 54, 34 and 51%, respectively.

7- Steel, glass and polypropylene fiber had good resistance to dropped impact load as compared to control with gain ratios of 382, 218 and 318%, respectively. Also, thehad good resistance to impact flexural loads.

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