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Investigation on Mechanical Properties of Cementitious Composites Cured in Colloidal Nanosilica SiO_2 Solution

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ABSTRACT

Nano technology is one of the most widely searched techniques in the world nowadays. Several studies reported with nanoparticles are based on the nano-silica (nano-SiO_2) addition to the fresh mix to improve the performance of concrete. Nano-SiO_2 is highly reactive with calcium hydroxide and is able to act not only as a filler, blocking the concrete pores, but also as an activator to promote pozzolanic reaction. In this paper, the effect of different concentration of nano silica solution on concrete compressive strength have been studied (when using it in curing instead of water). Samples were made by adding fly ash (FA/PC= 1.2 and 2.2) and some were immersed in water and others in a solution of water and Nano SiO_2 with different concentrations (0.5, 1, 2 and 3) %. Then the samples have submitted to compression test after 3, 7 and 28 days to notice the impact of using Nano silica solution in curing stage. Fly ash has been used in this experiment for several reasons. 1. Development of the mechanical properties of the cement-bonded composites. 2. Reduces the percentage of cement use and therefore environment will keep clean because the cement reaction produces CO_2 which cause pollution to the environment.
Keywords: *Nanosilica, Engineered cementitious composites (ECC), fly ash, supplementary cementing materials SCM, Pozzolan materials.*

1. Introduction

Several studies reported with nanoparticles are based on the nano-silica (nano-SiO_2) addition to the fresh mix to improve the performance of concrete. Nano-SiO_2 is highly reactive with calcium hydroxide and is able to act not only as a filler, blocking the concrete pores, but also as an activator to promote pozzolanic reaction. In this sense, nano-SiO_2 is expected to be an active sealing with self-healing properties based on the high reactivity of these nanoparticles with the calcium hydroxide of solid phases of concrete, blocking the transport of aggressive ions or refurbishing damaged or cracked concrete. (Elshikh & Tahwia, 2016). Nano silica is the first nano product that replaced the micro silica. Advancement made by the study of concrete at nano scale have proved nano silica much better than silica used in conventional concrete. Because it will provide the concrete with better properties like: high compressive strengths, high workability with reduced water/cement ratio, fills up all the micro pores and micro spaces and also cement saving up to 35-45% (Şahmaran et al, 2013). The use of supplementary cementing materials SCM (active mineral admixtures) such as silica fume, blast furnace slag, fly ash in the concrete mix is influential way of reducing Portland cement clinker and the same time reducing CO_2 and improving the engineering properties of concrete when they are used as additive or partial replacement of cement among these mineral admixtures, Fly ash is finely divided residue that is by product from combustion of powdered coal in power plant. Fly ash has been used in concrete protection for over 50 years in the world. Recently, a new high performance cementitious composite, or HPFRCC, has been developed by (Li, 1993) called Engineering Cementitious Composites (ECC). This class of composites, designed from micromechanical concepts, has been tailored to exhibit pseudo-strain hardening up to a strain capacity between 4% and 5%, far beyond that of ordinary concrete. This high level of strain capacity allows the material to undergo large deformations while maintaining load capacity. Previous studies conducted by (Weimann and Li, 2003) have shown that even as ECC undergoes large strains, the crack widths remain constant at approximately 60µm, depending on the exact composition of the material. (Lepech and Li, 2005). The material ingredients of engineered cementitious composite are similar to that of fiber reinforced concrete, including cement, sand, water, fiber, and a few chemical additives. The mixing procedure of engineered cementitious composites is similar to that employed for the normal concrete. Concrete with adequately high compressive strength has been in use for structural purposes (Şahmaran & Li, 2009). However, the majority of these materials continue to be brittle. It has been observed that sometimes the brittleness is increased as the compressive strength rises. This creates potential restrictions on the use of high strength concrete in structures. When there is a contact between concrete and steel, a high stress concentration is produced that may cause a fracture of the concrete. In this study, the curing stage have been done by using different concentration of nano silica solution (0.5, 1, 2 and 3) %. To learn the effect of nano silica solution on concrete compressive strength. Samples were made by two ECC mixtures, one of them is mixture made with fly ash (FA/PC= 1.2) and the second mixture made with fly ash (FA/PC= 2.2). Some of the samples were immersed in water and others in a suspension containing water with Nano SiO_2 with different concentrations. Then submit the samples to compression test after 3, 7 and 28 days to notice the impact of using Nano silica solution in curing stage. In all tests, the average of three different values were taken.

1. MATERIAL AND EXPERIMENTAL METHOD

The mix design for ECC Concrete is based on Micromechanics design (Micromechanics is the analysis of composite or heterogeneous materials on the level of the individual constituents that form these materials). It captures the mechanical interactions. ECC can be produced by utilizing ordinary Portland cement. Compared with conventional concrete, ECC contains considerably higher cement content that is typically two to three times higher than normal concrete. Cement is the major component which binds all the ingredients and contributes to the strength. Fly ash is also used for the preparation of ECC mix, according to ASTM C618 (2003), fly ash is divided into F and C classes. F-class, fly ash obtained from bituminous coal and having a total SiO2 + Al2O3 + Fe2O3 percentage of more than 70%. For casting, a proper and good practice of mixing can lead to better performance and quality of the ECC because the performance of the ECC is influenced by the mixing. The material used in ECC mixtures in this experiment were Portland cement (PC), class F fly ash, quartz sand, high range water reducing admixture (super plasticizer) and tap water.

1.1 Materials Used

In this experiment, two ECC mixtures have been prepared, with FA/PC of 1.2 and 2.2 by weight.

2.1.1 Portland Cement (PC)

Cement used is Ordinary Portland cement. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. Standard CEM I 42.5R Portland cement (PC) was used in the studies (Fig.2.1). The specific weight of Portland cement is 3.06 and the Blaine grade is 325 m^2/kg. Physical and chemical properties of the Portland cement used during the work are shown in Table 1.

Fig. 2.1. CEM I 42,5R Portland cement

2.1.2 F-Class Fly Ash

One of the most important material used in this experiment is fly ash which recently (FA) is considered as a necessary component of ECC. Fly ash is one of the naturally-occurring products from the coal combustion process (Fig.2.2). When coal is burned in today's modern electric generating plants, combustion temperatures reach approximately 2800°F. The non-combustible minerals that naturally occur from burning coal form bottom ash and fly ash. Fly ash reacts as a pozzolan with the lime in cement as it hydrates, creating more of the durable binder that holds concrete together. In this research, F-class, fly ash obtained from bituminous coal and having a total SiO_2 + $Al2O_3$ + Fe_2O_3 percentage of more than 70%. Since the percentage of CaO in this type of ash is below 10%, they can also be named as low calcareous fly ash. In the same time, F-class fly ashes have pozzolanic properties.

Fig. 2.2. Fly ash type F

F fly ash and cement physical and chemical properties are shown in Table 1, and the results of 3,7and 28 days of pozzolanic activity test are presented in Table 2.

TABLE 1

Chemical and physical properties of F fly ash and cement used in mixtures

Chemical Composition (%)	FA (F)	PC
SiO_2	58.75	20.8
Al2O3	25.24	5.42
Fe2O3	5.76	2.98
S+A+F	89.75	29.2
CaO	1.46	61.53
MgO	2.22	2.39
SO3	0.08	2.4
K2O	4.05	0.75
Na2O	0.60	0.21
Physical Properties		
specific weight (g/cm3)	2	3.06
Fineness (m^2/kg)	290	325

TABLE 2
Pozzolanic activity results of F fly ash used in mixtures

Sample	28 Days (%)	TSN 450 28 Days (%)
(class F)	73	>75

Within the scope of the project, no grinding and sieving process was applied on the ashes requested from the thermal power plants, and the mixing was included as collected from the power plants.

2.1.3 Quartz Sand

According to the micromechanical-based design of the ECC, the matrix fracture toughness must be low in order for the composite material to exhibit strain hardening and ductile behavior by forming multiple micro-cracks. Restrictions are made on the grain size and amount of sand that must be used in ECC blend designs because of the increase in the sand grain size and the usage amount in the blends and the matrix fracture toughness values significantly increase. For this reason, the ECC has been successfully produced so far by selecting a specific sand and sand-binder ratio of about 0.36, with an average grain size of about 110 μm and a maximum grain size of 400 μm. Many studies show that the use of industrial by-products such as fly ash in high volumes is effective in reducing matrix fracture toughness and provides freedom in changing sand size and utilization rates. For this reason, angular fine-quartz sand with an average grain size of about 200 μm and a maximum grain size of 400 μm was chosen for use in ECC production. The water absorption capacity of micro-quartz sand is 0.3% and the specific weight is 2.60 gr/cm^3.

2.1.4 High Range Water Reducing Addtive (Super Plasticizer)

The superplasticizing additive used in the experiment is a liquid additive containing about 40% solids and a specific weight of about 1.1 kg/dm^3. The amount of superplasticizer additive is adjusted depending on the performance of the mixture during mixing and the consistency of the mixture to be obtained.

2.1.5 Water

Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalis or other organic Impurities.

2.1.6 Nano Silica

Ready Nano silica solution have been used from (Biyotez factory/Turkey)with 30% concentration. Then the concentration of the solution have been reduced by adding water to get the values (0.5, 1, 2 and 3) %.

2. EXPERIMENTAL METHOD

In this experiment, two ECC mixtures, with (FA/PC = 1.2 and 2.2) by weight have been prepared. Portland cement, quartz sand, tap water and super plasticizer have been used in both mixtures and the samples made from both mixtures were 50×50×50mm cubes specimens (45 specimens form each mixture), the samples remain for 24 hours in the mold. One day after, the samples have been removed from the mold to immerse them into basins containing Nano silica solutions (0, 0.5, 1, 2, 3) % (9 samples in each basin) to submit them for curing for 3, 7 and 28 days.

Firstly, experiment started by dry mixing of solid materials (Portland cement, fly ash and sand) with low speed (100 cycles/min) for 1 minutes (Fig.3.1). Then tap water has been added to the pervious mixture and continue mixing for two minutes with speed (100 cycles/min). (Fig.3.2).

Fig 3.1. Dry mixing

Fig 3.2. Adding water

After these steps super plasticizer added to the mixture and mixing continued for 3 minutes with speed (150 cycle/min). Details of the two ECC mixtures, with FA/PC of 1.2 and 2.2 by weight, used in this investigation are given in Table 3.3. Mixtures of ECC-F (1.2) and ECC-F (2.2) prepared by using the ratios given in Table 3.

TABLE 3
Proportions of materials used in ECC blends

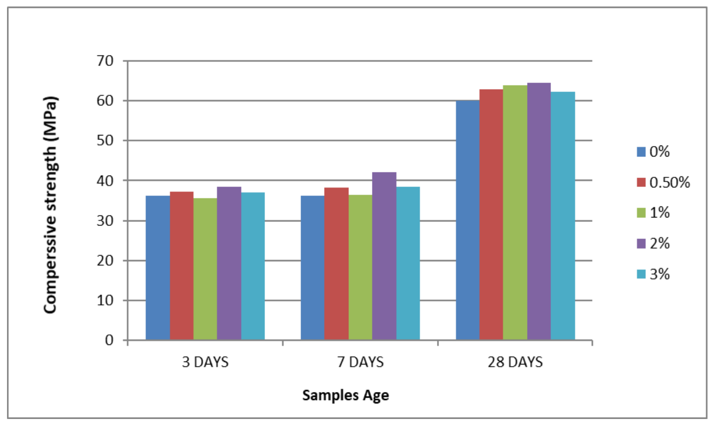
Mixing Ratios	ECC-F (1.2)	ECC- F (2.2)
Cement(PC)	1	1
(FA-F)/PC	1.2	2.2
Water/(FA+PC)	0.27	0.27
Sand/(FA+PC)	0.36	0.36
SP (kg/m^3)	4	3.8

For each mixture 50×50×50mm cubes specimens were prepared (45 specimens form each mixture), so the total number of specimens are 90 cube. In curing stage, Nano silica with different concentrations (0.5%, 1%, 2% and 3%) have been used. In concrete, the Nano silica works on two levels. The first one is the chemical effect: the pozzolanic reaction of silica with calcium hydroxide forms more CSH-gel at final stages. The second function is physical one, Nano-silica can fill the remaining voids in partially hydrated cement paste, increasing its final density.

So as a preparation for curing stage, all the samples (cubes) dried for one day and removed from molds to immerse them into the water and Nano silica solutions. In this experiment, five basins were prepared, four basins filled with Nano silica solution (water with 0.5, 1, 2 and 3% Nano silica concentration) and one basin filled with water only. So as final step, nine specimens distributed and immersed in each basin. (Fig. 3.3). Then samples have been examined for compressive strength after 3, 7, and 28 days to determine the effect of the concentration of Nano-silica on it.

Fig. 3.3. Samples cured in water and in water containing Nano silica at different ratios.

3. RESULTS



In the figures 4.1 and 4.2, the compressive strengths of 3, 7 and 28 days of samples with 2 different mixtures and their averages are given.

Fig. 4.1. Compressive strength values of ECC-F (1.2) samples for 3, 7 and 28 days.

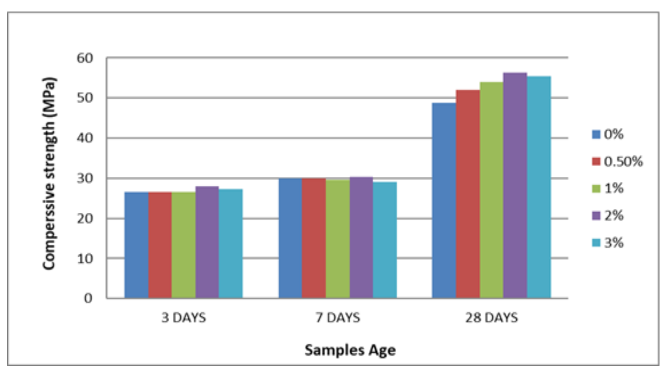


Fig. 4.2. The 3, 7 and 28 days compressive strength values of ECC-F (2.2) samples

Figures 4.3 – 4.7 show comparison plots of compressive strength values of 3, 7 and 28 days of cured samples in solutions containing Nano silica at different ratios and in water. As can be seen from the graphs, the use of fly ash in different proportions, regardless of curing conditions, affects the compressive strength values in a similar way. In all curing conditions, the compressive strengths of ECC-F (1.2) samples were higher than the compressive strengths of the other samples made with ECC-F (2.2).

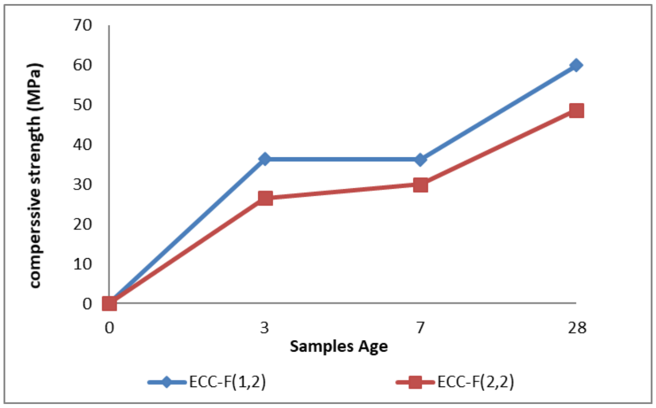


Fig 4.3. Comparison of compressive strength values of samples cured in water

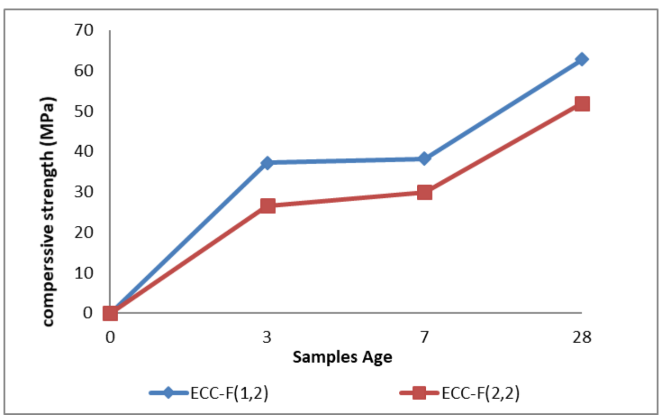


Fig 4.4. Comparison of compressive strength values of samples cured in 0.5% nanosilica

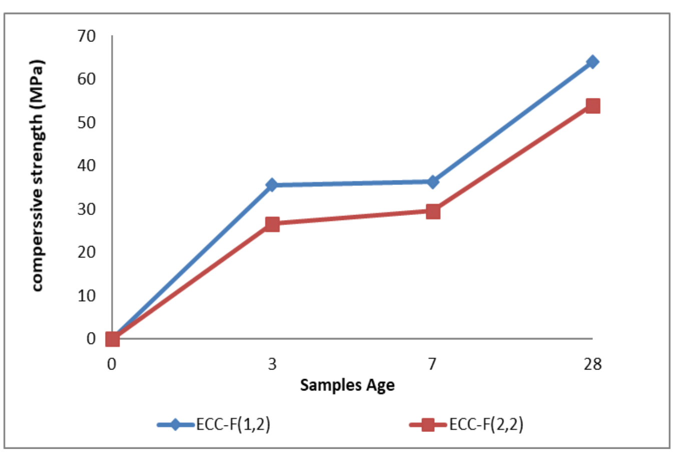


Fig 4.5. Comparison of compressive strength values of samples cured in 1% nanosilica

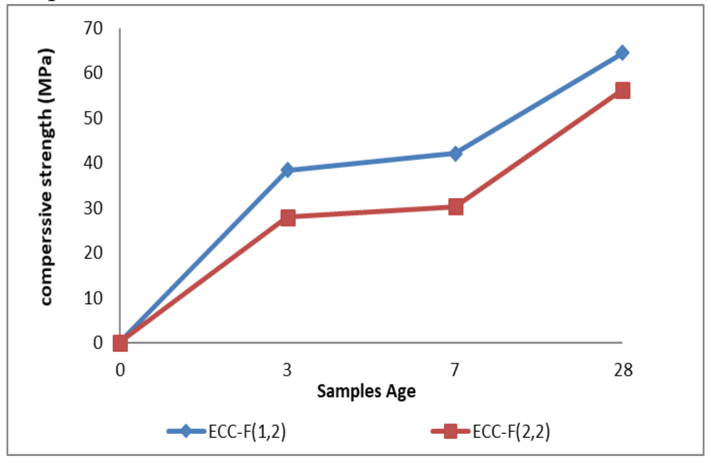


Fig 4.6. Comparison of compressive strength values of samples cured in 2% nanosilica solution

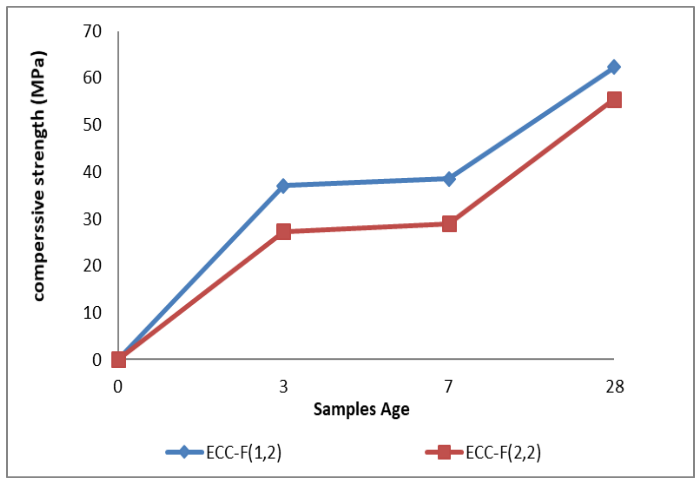


Fig 4.7. Comparison of compressive strength values of samples cured in 3% nanosilica solution

The results show that the highest compressive strength values are obtained from samples cured in a solution with a 2% nano-silica concentration and the use of fly ash in different proportions, regardless of curing conditions, affects the compressive strength values in a similar way. In all curing conditions, the compressive strengths of ECC-F (1.2) samples were higher than the compressive strengths of the other samples made with ECC-F (2.2).

4. CONCLUSION

In this study, ECCs produced in two different locations (FA / PC = 1.2 and 2.2) using F class fly ash were mixed with water and cured with different nano silica concentrations (0.5%, 1%, 2% 3%) in water and were tested in the ages of 3, 7 and 28 days, and their compressive strength values were determined.

In the same time for curing conditions nano silica with different concentrations have been mixed with water for many chemical and physical effects.

Normally the addition of pozzolan materials such as fly ash to mixtures, will work as a partial substitute for cement. The superior performance of this type of concrete is attributed to the fly ash mixtures due to the combination of fly ash and calcium hydroxide emitted as a result of the hydrogenation of cement process. The two components Al_2O_3, SiO_2 in fly ash react with free lime or limestone found in concrete to form CSH and CAH gel. This gel provides the cement materials as well as fills the pores in the concrete and makes it possible to reduce the amount of cement used in the mixture.

As a conclusion and the benefit from this study, it has been found out that Nano silica solution can be used as alternative for water in curing stage because samples cured with solutions containing Nano silica in different concentrations shows highest compressive strength values than samples cured with water only. In this research, it has been noticed from the previous results that there is no significant differences between the compressive strength values in samples cured in water and in solutions containing Nano silica in different proportions, the highest values were obtained from samples cured in 2% solution but it could be higher values of compressive strength if the tests' results have taken at the later ages like after 60 or 180 days.

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