Effect of Nano-Silica and Micro Steel Fiber on Compressive Strength Development of Fly Ash Geopolymer Paste Cured Under Ambient Temperature

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Abstract. This paper presents the development of compressive strength of fly ash geopolymer paste under the effectiveness of nano-silica and micro steel fiber. Twelve geopolymer paste mixes under two series, the first series with replacement (0% to 1.4%) by increment (0.2%) of binder by nano-silica and using the optimum concentration of nano-silica in second series with addition (0.5% to 2%) by increment (0.5%) of micro steel fiber. The mixes were using fly ash as binder with Sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH) solutions as the alkali activators. (Na₂SiO₃ to NaOH) ratio was (2.0) with molarity of sodium hydroxide (10 M), and the specimens cured under room temperature (35±2)°C. Results show that the compressive strength of fly ash geopolymer paste can be improved as high as 76.5MPa at 28 days by add 0.8% nano silica and 1% micro steel fiber which were the optimum proportion that caused noteworthy improvement of compressive strength.

Keywords: nano silica, micro steel fiber, geopolymer paste and compressive strength

1. Introduction

Production of Portland cement is known to expend considerable energy and product large amounts of carbon dioxide which contributes in global warming [1, 2]. To produce ton of Portland cement produces ton of carbon dioxide in the atmosphere, so increasing environmental worry with the using of concrete in construction have led to search for materials more sustainable and environmentally friendly [3]. Fly ash (FA) is one of the most common industrial products may be used as bonding materials. It has been used as alternative of cement and enhance the physical, chemical and mechanical properties of concrete, CO₂ emissions may be reduce by 80% when using geopolymer with compared with the use of ordinary Portland cement [4]. Geopolymers are a three-dimensional structure materials, synthesized by alkaline activation consist of an aluminosilicate. Geopolymerization process depend on the reaction of silica and alumina with alkali solutions. The constituents may be any industrial or agricultural by-products having silica and alumina. These aluminosilicate reactive materials are rapidly dissolved in alkaline solution resulting in formation of free SiO₄ and AlO₄ tetrahedral units [5]. In case of using geopolymer, high temperature in early curing stage is essential to provide enough strength increases to access high mechanical properties [6]. However, there are several practical issues with the application of heat curing in large scale structures; so nano-silica (NS) is one of the common mineral admixtures to accelerate, where use of nano-silica is gaining wider attention due to its significant effect on the microstructural and mechanical properties of Portland cement based binders [7]. The aim of this paper is to show the optimum quantity of nano-silica and its effect on...
compressive strength of fly ash geopolymer paste, then improve the compressive strength by addition different dosages of micro steel fiber for fly ash geopolymer paste.

2. Experimental Context

2.1 Material

Fly ash class F (FA) was using in this study and nano-silica (NS) were obtained from a commercial provider in Turkey. The average particle diameter of nano-silica was 15-20 nm. The chemical composition of the fly-ash and nano-silica shown in Table 1. Micro steel fiber with length 6mm and aspect ratio 30, yield strength equal to 1500N/mm, young modulus 200GPa and density 7850kg/m3. The alkaline activator was compound of sodium silicate solutions (UAE origin) and sodium hydroxide (Kuwait origin). The molarity of sodium hydroxide solution 10M was prepared by mixing with pure water, and the chemical composition of sodium silicate solution was Na2O 13.1-13.7%, SiO 32-33%, specific gravity 1.534-1.551 and viscosity 600-1200. The using material shown in Figure 1.

Table 1: Chemical composition of fly ash and Nano-silica

| Chemical analysis | Fly ash (wt. %) | Nano silica (wt. %) |
|-------------------|-----------------|---------------------|
| SiO2              | 57.2            | >99.8               |
| Al2O3             | 24.4            | -                   |
| CaO               | 4.24            | -                   |
| Fe2O3             | 6.1             | -                   |
| MgO               | 2.4             | -                   |
| SO3               | 0.29            | -                   |
| K2O               | 2.37            | -                   |
| Na2O              | 0.38            | -                   |
| LOI               | 1.58            | <1.5                |
| Specific gravity  | 2.25            | 2.2                 |
| Surface volume ratio (m²/g) | -         | 170-230             |

Figure 1. Used materials.
2.2 Geopolymer Mixes

Twelve geopolymer paste mixes were prepared in two series, the mix proportions are given in Table 2. The main binder has been fly ash with replacement (%0 to 1.4% increment 0.2%) by nano-silica in first series, in second series using the optimum concentration of nano silica with addition (0.5% to 2% increment 0.5%) of micro steel fiber. The alkaline liquid was prepared before 24 hour of mixing with ratio of sodium silicate to sodium hydroxide 2.0 at each mix. The samples were named according to the proportion of nano silica (NS) and micro steel fiber (SF) used in the mix.

Table 2. Mix proportions of fly ash geopolymer pastes.

| Mix           | Binder (wt%) | Solution (kg/m³) | SF (wt%) of volume |
|---------------|--------------|-------------------|-------------------|
|               | FA | NS | NaOH (10M) | Na₂SiO₃ |                |
| FA-NS0.0-SF0.0a | 100 | 0 | 0.42 | 236 | 474 | 0 |
| FA-NS0.2-SF0.0 | 99.8 | 0.2 | 0.42 | 236 | 474 | 0 |
| FA-NS0.4-SF0.0 | 99.6 | 0.4 | 0.42 | 236 | 474 | 0 |
| FA-NS0.6-SF0.0 | 99.4 | 0.6 | 0.42 | 236 | 474 | 0 |
| FA-NS0.8-SF0.0 | 99.2 | 0.8 | 0.42 | 236 | 474 | 0 |
| FA-NS1.0-SF0.0 | 99 | 1.0 | 0.42 | 236 | 474 | 0 |
| FA-NS1.2-SF0.0 | 98.8 | 1.2 | 0.42 | 236 | 474 | 0 |
| FA-NS1.4-SF0.0 | 98.6 | 1.4 | 0.42 | 236 | 474 | 0 |
| FA-NS0.8-SF0.5 | 99.2 | 0.8 | 0.42 | 236 | 474 | 0.5 |
| FA-NS0.8-SF1.0 | 99.2 | 0.8 | 0.42 | 236 | 474 | 1.0 |
| FA-NS0.8-SF1.5 | 99.2 | 0.8 | 0.42 | 236 | 474 | 1.5 |
| FA-NS0.8-SF2.0 | 99.2 | 0.8 | 0.42 | 236 | 474 | 2 |

*FA-NS0-SF0 represents the mix having: fly ash, 0% nano-silica (NS) and 0% steel fiber (SF) in the fly ash geopolymer paste.

2.3 Mixing Procedure and Curing

The alkaline solution was production before 24 hour of working [8], NaOH flakes were dissolved in pure water to obtain the desired molarity and mixing sodium hydroxide solutions with sodium silicate at the required proportion. Firstly, mixing nano-silica particles with the alkaline solution by using electric-mixer because nano-silica may not disbanded well through moistening and caused agglomerations in the mixture. So, a disband of nanoparticles is very important to obviate agglomeration which may be have negative effect on the reaction. The distributed of nano-silica in the alkaline liquid before and after mixing, shown in Figure 2.

For prepare each mix of the first series, putting weighted fly ash in the mixer and addition of the solution with nano silica and mixing it for five minutes, and for prepare each mix of the other series putting weighted fly ash with required dosage of micro steel fiber in the mixer and mixing it for two minutes then following by addition of the solution with nano silica and mixing it for five minutes [9, 10]. The pastes were cast in 50×50×50 mm³ cubes accordance with the ASTM C109 standard [11]. Then using a table vibrator for compacting the specimens for 30 second in two layers and demolded after 48 hour of casting. The specimens were putting in isolated bags during curing period and cured in room temperature (35 ± 2)°C. Compressive strength was tested at the age 7, 14 and 28 days. The stages of the work shows in Figure 3.
3. Results and discussion

3.1. Compressive strength development under effectiveness of nano-silica

Effect of the different concentrations of nano-silica on the compressive strength shows in Figure 4. In 28-days the compressive strength of the reference (with zero nano-silica) was 34.5MPa which increased to 71.8MPa by the additive nano-silica. Figure 4, shows that the mixes containing 0.8% nano-silica have higher compressive strengths than the other mixes, its higher than the reference mix by (41%, 63% and 108%) at (7, 14 and 28) days respectively. And in general, all the mixes which contain nano-silica were higher than that of the reference mix, its higher than the reference mix by (15%, 8% and 33%) at (7, 14 and 28) days respectively for mixes containing 0.2% nano-silica, (24%, 21% and 58%) at (7, 14 and 28) days respectively for mixes containing 0.4% nano-silica, (28%, 43% and 83%) at (7, 14 and 28) days respectively for mixes containing 0.6% nano-silica, the mixes containing 0.8% nano-silica have higher compressive strengths but
when addition more contain of nano-silica cause drop in result but it’s remaining higher than that of the reference mix, whereas, at mixes containing 1% nano-silica compressive strength was higher than the reference mix by (41%, 63% and 101%) at (7, 14 and 28) days respectively, (35%, 54% and 97%) at (7, 14 and 28) days respectively for mixes containing 1.2% nano-silica and (24%, 43% and 86%) at (7, 14 and 28) days respectively for mixes containing 1.4% nano-silica. This means that the geopolymer matrix becomes stronger by replace proportion of binder by nano-silica. It was also observed similar behavior by other researchers [12]. In fact, the nano-silica was controlling on geopolymerization process, it’s made as acceleration factor; because of its high surface area then its reacts faster, but increasing the nano-silica on the desired limit causes declined in the strength. This is mean the replacement of binder by 0.8% of nano-silica was suitable for reaction and any addition was more than 0.8% did not partake in the reaction and formed as weakness areas.

3.2. Compressive strength development under effectiveness of micro steel fiber

The results presented a slight develop in compressive strength when adding different dosages of micro-steel fiber. The highest increase was show in dosage 1% of micro steel fiber, its higher than the reference mix by (4%, 7.5% and 6.5%) at (7, 14 and 28) days respectively, after which there was causes declined in the strength. At other dosages the develop in compressive strength was very simple not exceed 3%. In fact, the micro steel fiber has a minor effect on compressive strength development, but it may be improve other properties of the geopolymer paste such as bonding, flexural and tensile strength. The effect of micro steel fiber on the compressive strength shown in Figure 5.

Figure 4. Compressive strength development under effectiveness of nano-silica.

Figure 5. Compressive strength development under effectiveness of micro steel fiber.
4. Conclusions

The compressive strength development of fly ash geopolymer pastes under effectiveness of different concentrations of nano-silica and different dosages of micro steel fiber was studied under the ambient curing. The following conclusions can be found:

- Compressive strength of fly-ash geopolymer paste was increase with the addition of nano-silica when cured under ambient temperature. The proportion of replace 0.8% of binder by nano silica was the optimum which showed best increase in compressive strength, then when increase the proportion of nano-silica caused decline in compressive strength. Compressive strength at the optimum proportion of nano-silica was higher than the reference by 41%, 63% and 108% at 7, 14 and 28 days respectively.

- Micro steel fiber was showed a simple increase in compressive strength and the optimum proportion of micro steel fiber was 1% additive but it’s may be more developed other properties of geopolymer paste. Compressive strength at the optimum proportion of micro steel fiber was higher than the reference mix by 4%, 7.5% and 6.5% at 7, 14 and 28 days respectively.

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