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High performance cement composites with nano-SiO_2 and nano-Al_2O_3 powders

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Abstract – In this study, the effects nano-SiO_2 and nano-Al_2O_3 on cement mortars were experimentally studied. The percentage of nano-powders were used as 1%, 3% and 5% into the material. Different types of analysis were used to nano-powder's impact on the cement mortars. Compressive strength tests were applied to the samples of different ages. Mechanical tests were examined at early and late ages. Tests were carried out 3 and 7 days of early ages and also 28 and 90 days of late ages. Scanning electron microscope (SEM) analysis were carried out to investigate the microstructure of the samples. Compressive strengths results indicated that the nano-powder additive cement mortar mixtures were higher than the control specimens. Compressive strengths results of the nano-powder additive cement mortars were higher than the control specimens. Moreover, can be seen in the microstructure, nano-powders reduced the pore structure significantly in the specimens. The objective of this study is obtaining a material which has less pore ratio, higher strength and performance.

Keywords – *Cement composites, nano powders, compressive strength, microstructure analysis, performance*

I. Introduction

In recent years, researchers investigated on cement-based composite materials. Different waste materials are used as an additive in cement-based composite materials like various fibers, mineral additives, volcanic tuff, fly ash, silica fume etc. Such composites have minimal pore which is important in terms of their performance [1]. But various additives can't fill in the micro level pores. Thus, they have adverse effects on the properties of materials [2]. In order to reduce the these effects, nanoparticles can be added into cement mortar.

Recent studies in nano-technology have revealed that nano-dimensional structures, such as, nano-particles, nano-powders, tubes and nano-coatings have a very large surface to volume ratio [3]. So they are a tool for optimal use of composite materials in manufacturing applications. In recent studies, nano-sized powders are investigated for using as an additive in cement mortars. Hui Li [4] investigated cement mortars with different nano powders (nano-SiO_2, nano-Fe_2O_3) to increase their mechanical strength. Mechanical tests showed high strength result. Jo et.al. [5] studied the separately influence of nano-SiO_2 and silica fume for using additive in cement mortar. Mechanical strength of nano-SiO_2 and pozzolanic effect of silica fume were compared. The mechanical properties of the mortar were better improved by the additions of nano-SiO_2.

Nanoparticles were used as cement replacing the materials for producing ecologic concrete [6]. The addition of nano-sized particles improves the performance of cement. Meng et al. [7] in another work reports that early age strength increased due to nano-TiO_2 slag powder and superplasticizer in cement mortar mixtures. Moreover good dispersion of slag powder and superplasticizer effect made an increase of strength. Zhang et al. [8] replaced % 2 portland cement by nano-SiO_2 powders in order to make cement mortar mixtures. 3 and 7 days early age strengths were studied. Nano-SiO_2 showed quite good distribution of cement mortar which was observed in the microstructure. Thus nano-particles which significantly reduce pore ratio.

Physical properties of nano-powders			**Physical Properties of Portland Cement**	
Nano powder	**Particle size (nm)**	**Specific surface area (m^2/gr)**	**Properties**	**Content (%)**
Nano SiO_2	10-20	250	CaO	63.54
Nano Al_2O_3	<50	50-245	Fe_2O_3	3.07
			Al_2O_3	4.91
			SiO_2	18.79
			Loss of ignition	2.68
			Specific surface area cm^2/gr	3550

This study focuses on the mechanical properties and microstructure changes observation of the cement mortars with the addition of nano-SiO_2 and nano-Al_2O_3 powders in different percentages. Scanning electron microscope (SEM) analysis were carried out to investigate the structural changes of the samples. Mechanical tests were examined at early and late ages. The objective of this study is obtaining a material which has less pore ratio, higher strength and performance.

II. MATERIALS AND METHOD

A. Materials

The ordinary portland cement (OPC) used in this study was CEM I 42.5 as classified by the European standards and also Turkish standards [9]. The physical and chemical composition of the OPC are shown in Table 1. During experimental studies, the fine sand was used as an aggregate when composing the cement mortar. 1350 gr sand in packages that comply with the standard reference sand was used [9].

Table 1. Chemical and physical properties of portland cement (wt%) and Physical properties of nano powders

The nano-SiO_2 and nano-Al_2O_3 were obtained from Sigma Aldrich Company. The properties of nano-powders are shown in Table 1. Visco Crete-PC15 superplasticizer was used in the experiments. The superplasticizer, a polycarboxylate is manufactured by Sika in Turkey. [10].

B. Mix proportions

R series mixtures were prepared as control specimens. Sample mixtures were consisted of 1350 g sand, 450 g cement and 225 ml of water. Water/cement ratio was taken as 0.5 and binder/sand weight ratio (B/S) is 1:3 [9]. As a result of the literature search, the percentages of 1%, 3%, 5% nano-SiO2 and nano-Al2O3 were added to mortar instead of cement. Specimens were prepared for compressive strength test. Mortar specimens of size 4x4x4 cm3 cubic prisms were manufactured. Nine cubic specimens were made from each mixture.

C. Method

The cement prism specimens obtained after 24 hours of curing at 20 ±10C and 95 % water saturated air. For each mixture, nine cubic specimens of 4x4x4 cm3 were made for compressive strength test. Before the test, they were cured for early ages strength 2, 7 days and late ages strength 28, 90 days. After the strength tests, the specimens were analyzed by XRD (X-ray diffraction) and SEM observations.

III. DISCUSSION

Mechanical properties were performed for all the mortar mixtures at different ages. When the percentage of 1% nano-S (nano-SiO_2) and nano-A (nano-Al_2O_3) powders were replaced by cement. Compressive strength tests gave the highest results which are shown in Figure 1-a and 1-b. Nano-S added samples showed high durability compared to the reference. The strengths of samples S1, S3 and S5 were increased at the ages of 2, 7 and 28 days likewise, late ages strength of 90 days. These results are in agreement with the previous studies [11-12].

On the other hand, compared with sample R (control specimens), the strengths of samples A3 and A5 were decreased at the ages of 28 and 90 days. Excluding of 1% contribution, addition of 3% and 5% nano-A does not improve the compressive strength of cement paste at early age (Fig 1-b). This result is consistent with previous finding [13].

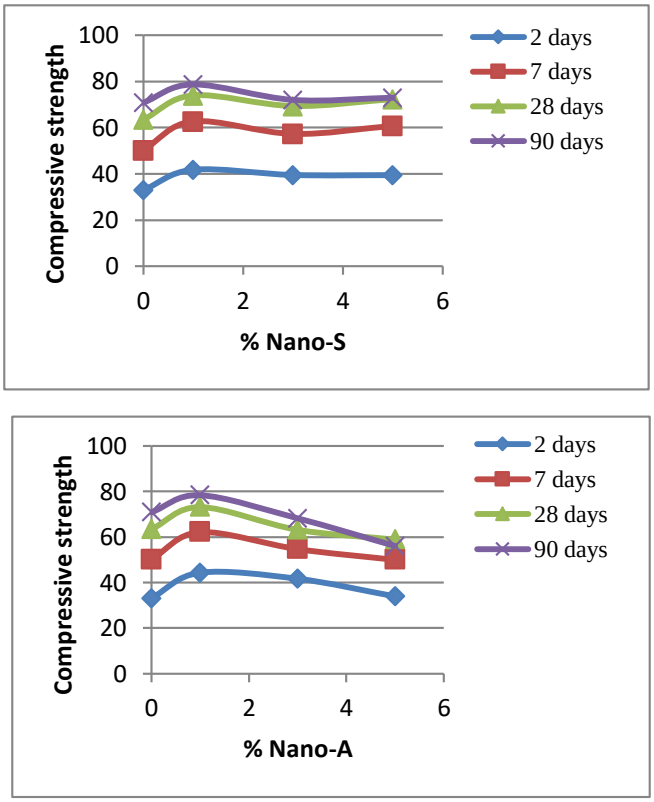

Figure 1.a-b Nano-SiO_2 and Nano-Al_2O_3 powders additives samples of 2, 7, 28 and 90 days compressive strength results were compared to the reference sample

XRD analysis was taken from 5 to 75 deg. for the cement based materials. XRD diagram of the percentages of 1%, 3%, 5% nano-S and nano-A specimens are shown in Fig 2. As a result, Q (Quartz), portlandite (CH), C-S-H, $CaCO_3$ peaks were observed in the specimens.

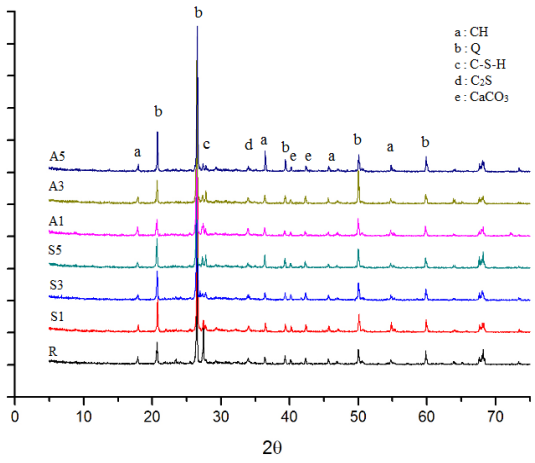

Figure 2. Results of XRD analysis of the specimens with the addition of nano powders in different percentages

VI. CONCLUSION

In this study, effects of nano- Al_2O_3 and nano-SiO_2 on microstructure and mechanical properties of cement mortar were studied. Nano powders were added 1%, 3% and 5% in cement mortar. Compared to the control samples nanopowders added samples showed less pore structure. Because of nanoparticles filled in the pores, they increased the cement mortar strength. The compressive strength results of cement mortar increased for 28 days by 16.4% (1% nano-A added) and 15.4% (1% nano-S added) and for 90 days by %11 (1% nano-S added) and %10.6 (1% nano-A added). Mechanical strength results of different ratio of nano-A and nano-S added specimens are higher with respect to control specimen. However, they are within the limits of both European and Turkish standards [9].

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