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An Investigation of the Strength Properties of Fly Ash and Metakaolin-Based Geopolymer Mortars Containing Multi-Wall Carbon Nanotube, Nano Silica, and Nano Zinc

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Abstract

In this study, the mechanical properties of geopolymer mortar composites containing different nanomaterials were investigated. Fly ash (FA) and metakaolin (MK) were used as binders in geopolymer mortar samples. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions (12 M) were used as alkali activators. Multi-walled carbon nanotubes (MW-CNT), nano-SiO_2 (NS), and nano-ZnO (NZ) were used in the study. Geopolymer mortar samples without nanomaterials were determined as control samples, and geopolymer mortar samples containing 0.5% by weight of MW-CNT, NS, and NZ were prepared. All prepared samples were cured at 20±2 °C in laboratory conditions for 7-day and 28 day. The curing geopolymer mortar samples were subjected to compressive strength and flexural strength tests. As a result of this study, the mechanical strength of all geopolymer mortar samples containing nanomaterials increased compared to the control samples. The highest compressive strength and flexural strength were obtained from geopolymer mortar samples containing MW-CNT. These samples were followed by geopolymer mortar samples containing NS and NZ, respectively.

1. Introduction

Concrete is the most frequently used building material in the world, especially in the construction industry. Cement, which is the main component and binder of concrete, causes 7% of CO_2 emissions in the world [1], [2]. In addition, since cement production can be carried out at high temperatures such as 1400-1500 °C, it also necessitates a significant energy requirement. The increase in energy prices also increases the cost of cement production. The amount, dosage, and technical properties of cement directly affect the cost, performance, and workability of concrete. In this case, fly ash, blast furnace slag, silica fume, rice husk ash, etc. are used in research to reduce the amount of cement used, and the cost of concrete, and make concrete more sustainable. The reuse of industrial waste materials that can increase mechanical properties and strength has been revealed [3], [4]. Due to economic and environmental reasons, the search for alternative binders to cement has gained serious importance recently. In this case, an alternative composite material to cement called geopolymer has come to the fore and has gained a place in the construction technology sector by finding widespread use day by day. Geopolymers are alumina silicate-type binder materials formed by activating natural and waste pozzolans with various alkali activators. It has been repeatedly stated in various sources that geopolymer production causes 80% fewer CO_2 emissions compared to cement production [5]-[7] and provides 60% energy savings [8], [9].

Geopolymer mortar or concrete is defined as a mortar or concrete that uses one or more of the material components considered waste during

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production and does not harm the environment. According to literature research, although geopolymer mortar, or concrete, is known as an environmentally friendly type of concrete, it also means cementless concrete. Geopolymers are three-dimensional Si-O-Al- framed inorganic materials made of alkali-soluble aluminum silicate [10]. The use of industrial wastes with pozzolanic properties and limited storage areas in the production of geopolymer mortar or concrete causes it to be known as environmentally friendly concrete. Geopolymer has become an alternative binder to cement in some applications because of its sustainability qualities, such as low energy consumption and low CO_2 emissions. In fact, after lime and cement, geopolymer has started to be considered the third-generation binder. The use of industrial wastes instead of cement reduces cement consumption and provides positive contributions to the physical and mechanical properties of mortar or concrete. It also has superior performance and longevity [11]. Geopolymer mortars, ground blast furnace slag, fly ash (FA), baked clays and shales, silica fume, heat-treated materials such as metakaolin (MK), natural pozzolans such as volcanic ash, trasses, and diatomite soils, industrial wastes, and volcanic glassy rock can be produced by activating materials such as pumice, also known as pumice, and ground perlite, a volcanic rock, with alkaline activators.

Nanotechnology is the expression of matter at the nanometer level (1-100 nm.) in order to produce materials with new properties and functions, and it is one of the emerging fields to develop new materials with superior properties and high performance [12]. The properties of building materials can be further improved using nanomaterials. Nano-sized materials improve the mechanical strength properties of geopolymer mortars due to their superior physical, chemical, and rheological properties, which are completely different from the same products with larger dimensions [13]. The addition of nanomaterials to geopolymer mortars has an effect similar to that of micro-based materials such as metakaolin (MK) and silica fume and improves the mechanical strength properties [14]. If a homogeneous distribution is provided, composite materials with high mechanical and durability properties can be produced, depending on the material type and ratio used. Nanomaterials with small particle sizes have very high chemical activities because they have very large, specific surface areas. High microstructure density is achieved thanks to this high reactivity feature and the mechanisms of filling the pores with the filler effect of the materials. The addition of nanomaterials increases both the early and advanced-age compressive strengths of mortars and improves the aggregate and cement paste interface. For this reason, it has been observed that nanomaterials lead to improvements in the mechanical properties of geopolymer mortars and concretes [15]-[17]. Nanomaterials have been added to geopolymer mortars to improve their mechanical properties. Many properties vary according to the different nanomaterials used. Theoretically, all materials in the aluminosilicate class can be activated by alkalis and show binding properties. However, the physical, chemical and rheological properties of nanomaterials directly affect the behavior of the geopolymer binder. In this respect, knowing the properties of the nanomaterial to be used is very important in terms of determining the performance of the geopolymer binder [18]. The nanomaterial most commonly added to geopolymer mortars is nano-SiO_2, which has high activity. Nano-SiO_2 (NS) improves the mechanical properties of geopolymer mortars by reacting with alkali activators in solution and forming gels to improve the pore structure [19] and prevent the calcification of geopolymer mortars [20]. The improvement of the mechanical properties of NS in geopolymer mortars is also due to its high pozzolanic activity and filler effect [21]. In the literature, there are many studies that have produced geopolymer mortar and concrete containing NS added to the composite by dry and wet mixing methods in different volumetric ratios [22], [23].

Geopolymer composites containing 1% NS by volume, especially affecting the initial stages of binder formation and thus mechanical performance, yielded high mechanical strength results [17], [24]-[28]. In some studies, geopolymer composites containing 2% by volume NS yielded high compressive strength results [15], [16], [29]-[34]. Fly ash shows pozzolanic properties because they are very fine-grained materials with a siliceous and aluminous amorphous structure. Metakaolin (MK), on the other hand, is widely used in the production of geopolymer mortar and concrete due to its high content of amorphous silica and its special production. MK reacts with $Ca(OH)_2$ and water and provides C-S-H gel formation, giving the geopolymer high strength. In the literature, studies comparing the mechanical strength of metakaolin (MK) and fly ash (FA) based geopolymer mortars containing different nanomaterials are limited.

In this study, geopolymer mortar samples were produced by using equal amounts of MK and FA, containing different nanomaterials in the same volumetric mixing ratios and activating with alkalis. For this purpose, geopolymer mortars were produced by adding multi-walled carbon nanotubes (MW-CNT), nano silicon dioxide (nano-SiO2), and nano zinc oxide (nano-ZnO) to the composite at 0.5% volumetric ratios, and both among themselves and with control samples that did not contain nanomaterials mechanical strengths were compared. After curing the produced mortar samples at 20±2 °C in laboratory conditions for 7 and 28 days, their mechanical properties were investigated.

2. Materials and Method

2.1. Materials

The fly ash (FA) used in this study is classified as class F fly ash according to ASTM C 618 [35]. In this study, F-class fly ash produced by burning imported hard coal at the Sugözü thermal power plant in the Yumurtalık district of Adana was used. FA and MK were used as pozzolanic materials in the study. FA and MK specifications are given in Table 1.

Table 1. FA and MK characteristics

Chemical components	%	
	FA	**MK**
SiO_2	58.25	56.10
Al_2O_3	22.95	40.25
Fe_2O_3	7.25	0.85
CaO	2.58	0.19
MgO	2.42	0.16
Na_2O	0.92	0.24
K_2O	0.99	0.55
LOI (loss on ignition)	0.91	1.11
Blaine (cm^2/g)	3000	-
Specific gravity (g/cm^3)	2.31	2.52

As an aggregate, natural river sand was obtained from the Murat River in the Palu district of Elazig province. The alkali activator, which is often preferred for the activation of geopolymer raw materials, is sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution, which is called glass water due to its easy availability and viscosity. In this study, solid NaOH was used to prepare an activator solution. The NaOH concentration was chosen as 12 M, and the solution was kept under laboratory conditions for 24 hours. Then, sodium hydroxide solution and sodium silicate were added to the geopolymer mortar mixture. Some physical and chemical properties of alkali activators are shown in Table 2.

Table 2. Chemical properties of Na_2SiO_3 and NaOH solution

Chemical properties	Na_2SiO_3	NaOH
Molecular weight (g/mol)	122.08	40
Density (g/cm^3)	1.39	2.13
H_2O (%)	64.8	–
SiO_2 (%)	28.7	–
Na_2O (%)	8.9	–
pH	-	13.5
Color	White	White

Metakaolin increases the water requirement of the mortar due to the clay structure it contains. For this reason, plasticizer additives were used in the study, and their ratio was chosen as 1% of the binder amount. The nanomaterials used in the study are multi-walled industrial grade carbon nanotube (MW-CNT), nano silicon dioxide (nano-SiO2), and nano oxide (nano-ZnO). These nanomaterials are expressed as M-CNT, NS, and NZ, respectively, and some of their technical properties are given in Table 3.

2.2. Preparation of Geopolymer Mortar Samples

While preparing the geopolymer mortar mixtures, the geopolymer mortar samples that do not contain nanomaterials were determined as control samples in the study and indicated with K.

Geopolymer mortar samples containing 0.5% nanomaterial were expressed as M-CNT, NS, and NZ, respectively. Geopolymer mortar samples were subjected to flexural strength and compressive strength tests after they were kept at 20±2 °C in laboratory conditions for 7 and 28 days. For the flexural strength test, 40×40×160 mm for all ages (7 and 28 days) and three for each sized prismatic samples were produced and tested separately for geopolymer mortar samples containing each nanomaterial. In addition to flexural strength, compressive strength analysis was also performed in accordance with ASTM C349 [37] on prismatic samples of the same age, which were subjected to flexural strength tests with the 3-point bending method according to ASTM C348 [36]. The samples used in the compressive strength tests are the samples subjected to the flexural strength test and divided into two for each sample.

Table 3. Properties of nanomaterials used

Nanomaterials Used	**M-CNT**	**NS**	**NZ**
Formula	MWCNT-OH^-	SiO_2	ZnO
Color	Black	White	White
Purity (%)	92	99.95	99.99
Average particle diameter (nm)	8-28	13-22	18
Length (µm)	10-35	-	-
Surface area (m_2/g)	220	165-195	20-65
Type	Industrial	Non-porous	-
Chemical structure	Stable	Amorphous	Crystal
Shape	-	Spherical	Near spherical

FA and MK were first mixed in a mixer for approximately one minute. Then, the fine aggregate was added to them and mixed for about three minutes. Nanomaterials were prepared by adding them to the alkali activator solution and mixing until homogeneous for about 1 hour in an ultrasonic bath with pure water at the bottom. Then, the alkali activator solution containing nanomaterials was added to the dry mixture. After the dry ingredients were added, mixing continued for four minutes. Then, a plasticizer was added to the geopolymer mortar mixture, and mixing was continued for about two more minutes. In total, the mixing time was about ten minutes.

In this study, the alkali activator solution/binder (AAS/B) ratio was kept at 0.8126 for all mixtures. The percentage of FA was determined to be 50% of the binder weight, added to the dosage, and used. Fine aggregate with a maximum aggregate size (Dmax) of 0.600 mm was used. The plasticizer ratios were chosen at 1% of the binder amount. Abbasi et al. [38] obtained the highest compressive strength results in samples containing 0.5% M-CNT in their study. Zidi et al. [39] also obtained the highest compressive strength results in samples containing 0.5% NZ compared to control samples. For this reason, a 0.5% volumetric ratio was determined in the study, and geopolymer mortar samples were produced by using each nanomaterial at this ratio. The casting parameters of the experimental study as a whole are given in Table 4.

Table 4. Raw materials used for geopolymer mortars by mass ratio

Binder	**FA**	**MK**	**Aggregate**	**SH***	**SM***	**AAS/B**	**Plasticizer**	**Nanomaterial**
1	0.5	0.5	2.57	0.25	0.5626	0.8126	0.01	0.005

SH*: Sodium Hydroxide solution, SM*: Sodium metasilicate

3. Experimental Results

In this study, fly ash-metakaolin based 40×40×160 mm sized geopolymer mortars were produced. The produced geopolymer mortar samples were cured at 20±2 °C in laboratory conditions for 7 and 28 days, and their mechanical strength properties were investigated. For this purpose, samples were subjected to bending and compressive strength tests. Prismatic specimens subjected to flexural strength tests with the 3-point flexural method according to ASTM C348 [36] were tested at the end of 7 and 28 days, with three samples from each series. The test results are shown in the study by taking the average of all three samples for each batch. In all of the samples, there was an increase in mechanical strength in the 28-day test results compared to the 7-day test results.

3.1. Flexural Strength Results of Geopolymer Mortars

The flexural strength test results of geopolymer mortar samples are given in Figure 1.

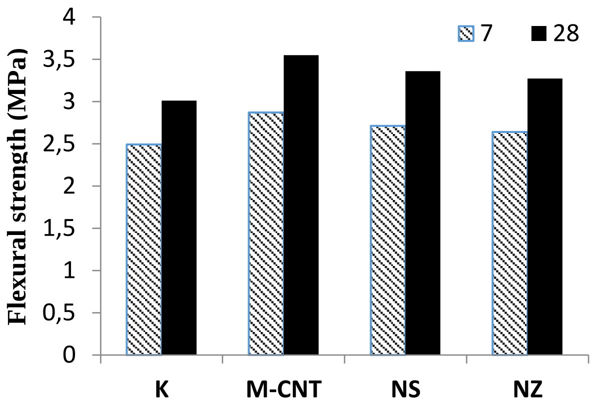

Figure 1. Flexural strength test results of geopolymer mortar samples

When Figure 1 is examined, the flexural strengths of the geopolymer mortar control samples at 7 and 28 days were found to be 2.49 and 3.01 MPa, respectively. The 7-day and 28-day flexural strengths of geopolymer mortar samples containing 0.5% volumetric multi-walled carbon nanotubes (M-CNT) were found to be 2.87 and 3.55 MPa, respectively. The 7-day and 28-day flexural strengths of the geopolymer mortar samples containing nano silicon dioxide (NS) and nano zinc oxide (NZ) were found to be 2.71, 3.36 MPa, and 2.64, 3.27 MPa, respectively. When the 7-day flexural strength results were examined, the flexural strengths of the samples containing nanomaterials showed an increase of 15.26%, 8.84%, and 6.02%, respectively, compared to samples containing 0% nanomaterials. When the 28-day flexural strength results were examined, compared to the samples without nanomaterials the flexural strengths of the samples containing nanomaterials (M-CNT, NS, and NZ) increased by 17.94%, 11.63%, and 8.64%, respectively. The highest flexural strength results were obtained from geopolymer mortar samples containing multi-walled carbon nanotubes (M-CNT) in both 7-day and 28-day test results. In the literature, similar flexural strength increase rates have been observed in composites containing multi-walled carbon nanotubes (M-CNT) [40], [41]. Kotop et al. [41] reported that in the 28-day flexural strength results, a 15.8% increase in strength was obtained in the samples containing M-CNT compared to the samples containing 0% nanomaterials, while an 18% increase in strength was obtained in this study. In the literature, similar rates of flexural strength increase have been observed in samples containing higher volumetric NS ratios [42]. These results were obtained using a 0.5% lower NS volume ratio in the study. Quercia et al. [43] achieved an increase of 9.1% in the 28-day flexural strength test results in samples containing 3.8% NS. Saini et al. [44] achieved an increase of approximately 7% in the 28-day flexural strength test results in samples containing 2% NS compared to samples containing 0% nanomaterials. But, in this study, with the use of one-fourth of the ratio NS, a 12% increase in the flexural strength test results compared to samples containing 0% nanomaterials was obtained. Nuaklong et al. [42] obtained a 19% increase in the 28-day flexural strength test results in samples containing 1% NS compared to the control samples, while using 0.5% NS in the study showed an increase of 12% in flexural strength compared to samples containing 0% nanomaterials. In all samples containing nanomaterials, the 28-day flexural strength results showed an increase of approximately 24% compared to the 7-day flexural strength results. The fact that nanomaterials fill the existing voids by creating a filler effect in geopolymer mortar mixtures and creating a more impermeable microstructure causes an increase in strength [14], [33].

In the geopolymer mortar samples containing three different nanomaterials, the flexural strength values were respectively M-CNT, NS, and NZ compared to the control mortar samples without nanomaterials. The 7-day and 28-day flexural strength results of the M-CNT-containing geopolymer mortar samples increased by approximately 5.9% and 5.65%, respectively, compared to the NS-containing geopolymer mortar samples. The 7-day and 28-day flexural strength results of the geopolymer mortar samples containing M-CNT were approximately 8.71 and 8.56% higher, respectively, than the geopolymer mortar samples containing NZ.

3.2. Compressive Strength Results of Geopolymer Mortars

Compressive strength test results of geopolymer mortar samples are given in Figure 2.

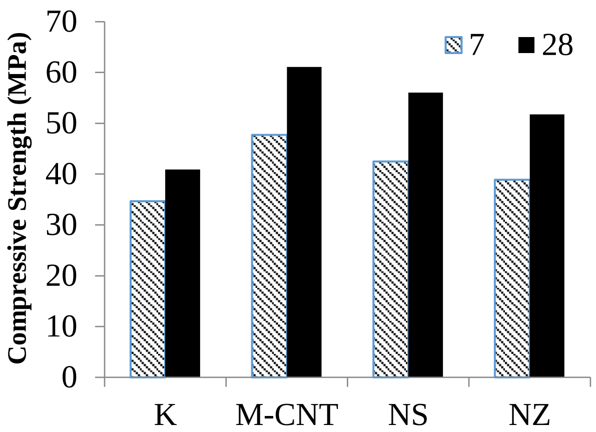

Figure 2. Compressive strength test results of geopolymer mortar samples

Compressive strength results showed parallelism with flexural strength results. As shown in Figure 2, the 7-day compressive strength of the geopolymer mortar control samples was found to be 34.69 MPa. The 7-day compressive strength results of geopolymer mortar samples containing multi-walled carbon nanotubes (M-CNT), nano silicon dioxide (NS), and nano zinc oxide (NZ) were found to be 47.75 MPa, 42.5 MPa, and 38.89 MPa, respectively. When the 7-day compressive strength results were examined, the compressive strengths of the samples containing nanomaterials showed an increase of 37.65%, 22.51%, and 12.11%, respectively, compared to the control samples. The 28-day compressive strength of geopolymer mortar samples without nanomaterials is given in Figure 2 as 40.94 MPa. The 28-day compressive strength results of geopolymer mortar samples containing nanomaterials were given as 61.07, 56.05, and 51.79 MPa, respectively. When the 28-day compressive strength results were examined, the compressive strengths of the samples containing M-CNT, NS, and NZ showed an increase of 49.18, 36.92, and 26.52%, respectively, compared to the samples without nanomaterials. The highest compressive strength results were obtained from geopolymer mortar samples containing multi-walled carbon nanotubes (M-CNT) in both 7-day and 28-day test results. In the literature, similar compressive strength increase rates have been observed in composites containing multi-walled carbon nanotubes (M-CNTs) [45], [46]. Alvi et al. [46] stated that it increased the 28-day compressive strength by 45.12% compared to samples containing 0% nanomaterials. Rovnanik et al. [45] achieved the highest compressive strength results in samples containing 0.5% M-CNT. The increase in strength in geopolymer mortar samples containing nanomaterials is due to the high specific surface area and high reactivity of the nano-sized material. In addition, it is observed that the strength increase of the nanomaterial-containing geopolymer mortar samples has become more evident over time as a result of the 28-day-long pozzolanic reactions. While the highest compressive strength was recorded at 61.07 MPa in geopolymer mortar samples containing multi-walled carbon nanotubes, the rate of increase in strength was 49.18%. According to many studies in the literature, the rate of increase in compressive strength was higher in geopolymer mortar samples containing multi-walled carbon nanotube (M-CNT) [47]-[49]. Collins et al. [49] obtained an average 25% increase in compressive strength compared to control samples in mortar samples containing 0.5% M-CNT; in the mortar samples produced in the study, with the same volumetric ratio of M-CNT, an increase in compressive strength was obtained almost twice as much as in this study.

In the literature, similar compressive strength increase rates have been observed in the samples produced using NS [26]. Adak et al. [50], in their study investigating the structural performance of NS-modified fly ash-based geopolymer concrete, increased the 28-day compressive strength of samples containing 1% NS by 34% compared to the control samples. Wu et al. [26] showed that the effect of NS and nano-CaCO3 on the mechanical properties of ultra-high performance concrete increased the 28-days compressive strength of the samples containing 1% NS by 35% compared to samples containing 0% nanomaterials in their study. With the use of 0.5% NS in the study, the 28-day compressive strength increase was 37% compared to samples containing 0% nanomaterials. Compared to many studies in the literature, the compressive strength performances of geopolymer mortar samples produced using a much lower volumetric ratio (0.5%) NS were much higher. Mustakim et al. [51] obtained the highest compressive strength test result of 63 MPa with samples containing 1.5% NS, in their study on increasing the fresh, mechanical, and microstructural properties of FA-blast furnace slag-based geopolymer concrete with the addition of nano and micro silicon dioxide. In the study, the compressive strength of 28 days was obtained as 56.05 MPa in the samples produced using 0.5% NS. Nuaklong et al. [42] stated that the 28-day compressive strength of the samples containing 2% NS increased by 29% compared to samples containing 0% nanomaterials. With samples containing 3% NS, Behfarnia et al. [52] increased the 28-day compressive strength by 12% compared to samples containing 0% nanomaterials, and Mahboubi et al. [53] increased the 28-day compressive strength by 44% compared to samples containing 0% nanomaterials. 28-day compressive strength increases in the samples were 37% compared to samples containing 0% nanomaterials. While İbrahim et al. [54] increased the 28-day compressive strength by 25% with the samples containing 5% NS compared to samples containing 0% nanomaterials, this increase was 37% compared to samples containing 0% nanomaterials with only 0.5% NS content in the study. Assaedi et al. [55] found the compressive strengths of the samples formed by adding 1% and 2% NS to the samples without nanomaterials with a compressive strength of 37.2 MPa, to be 47.3 MPa, and 44.9 MPa, respectively. Patel et al. [56] increased the compressive strength by approximately 10% by adding 1.5% NS to the control samples, which did not contain NS and had a compressive strength of 39 MPa, and obtained a 28-day compressive strength of 43 MPa in samples containing 1.5% NS. In the study, the compressive strength value of the sample without nanomaterials, which was 40.94 MPa, increased to 56.05 MPa with the addition of 0.5% NS. Therefore, with the addition of fewer nanomaterials, higher strength was achieved in this study. While the 7-day and 28-day compressive strengths of samples containing 4% NS increased by 24% and 26%, respectively [57], in another study containing NS at the same volumetric ratio [58], they increased by 25% and 49%, respectively. The 7-day and 28-day compressive strengths of the samples containing 2% NS increased by approximately 25% [20], and in another study containing 1% NS [59], the 7-day and 28-day compressive strengths of the samples increased by 21% and 28%, respectively. In this study containing 0.5% NS, the 7-day and 28-day compressive strengths of the samples increased by 22% and 37%, respectively. This result is attributed to the high performance in the early wet compressive strength of the low NS content.

The number of studies investigating the mechanical properties of NZ-containing geopolymers is very limited in the literature. Zidi et al. [38] increased the compressive strength by 26.67% in samples containing 0.5% NZ compared to samples containing 0% nanomaterials. Strength increase rates and nanomaterial content showed similar results to our study. Zailan et al. [60] investigated the mechanical properties of the geopolymer mortar containing 2.5%-10% NZ in their study and obtained the highest 28-day compressive strength value of 51.61 MPa in the samples containing 2.5% NZ. In this study, a 28-day compressive strength of 51.79 MPa was obtained for the samples containing only 0.5% NZ at a much lower volumetric ratio.

28-day compressive strength results in samples containing nanomaterials (M-CNT, NS, and NZ) showed an increase of 27.9, 31.88, and 33.17%, respectively, compared to 7-day compressive strength results. In the geopolymer mortar samples containing three different nanomaterials in the same weight ratio, the mechanical performances of M-CNT, NS and NZ were respectively the highest to the lowest compared to the control mortar samples without nanomaterials. The 7-day and 28-day compressive strength results of the geopolymer mortar samples containing M-CNT were found to be approximately 12.35%, 22.78%, 8.96%, and 17.92% higher than the geopolymer mortar samples containing NS and NZ, respectively.

4. Conclusion

In this study, the strength properties of geopolymer mortars containing MW-CNT, NS, and NZ were investigated. Geopolymer mortar samples without nanomaterials were determined as control samples and geopolymer mortar samples containing 0.5% by weight of % MW-CNT, NS, and NZ were produced. The results obtained in this study are given below:

-When the flexural strength test results are examined, in both 7-day and 28-day strength results, flexural strengths increased in all samples containing nanomaterials and control samples. These increases were 15.26%, 8.84%, and 6.02% in the samples containing nanomaterials (M-CNT, NS, and NZ) compared to samples containing 0% nanomaterials in the 7-day strengths, respectively. At 28 days, it was 17.94%, 11.63% and 8.64% in the samples containing nanomaterials (M-CNT, NS, and NZ) compared to samples containing 0% nanomaterials, respectively.

-When the compressive strength test results were examined, both 7-day and 28-day strengths increased in all geopolymer mortar samples containing nanomaterials compared to the control samples without nanomaterials. This increase was 37.65%, 22.51%, and 12.11% in samples containing nanomaterials (M-CNT, NS, and NZ) compared to control samples cured at ambient conditions for 7 days, respectively. Compared with samples without nanomaterials cured for 28 days, samples containing nanomaterials (M-CNT, NS, and NZ) had an increase of 49.18%, 36.92%, and 26.52%, respectively. While the highest compressive strength value was obtained at 61.07 MPa in multi-walled carbon nanotube (M-CNT) geopolymer composites, the lowest compressive strength value was obtained at 51.79

MPa in geopolymer composites containing nano-ZnO (NZ).

When the data obtained are examined, it is seen that the use of different nanomaterials in very low volumetric ratios in the production of geopolymer mortars shows a good performance in the mechanical strength of geopolymer mortars. In addition, it is seen that more economical and higher-strength geopolymer mortars can be produced by mixing the expensive nanomaterials with the wet method and using them in lower volumetric ratios. Finally, it will be meaningful to carry out studies on the durability properties of the produced geopolymer mortars and to bring them to the literature by comparing the research made in terms of both strength and durability.

Contributions of the authors

Maksut SELOĞLU: Literature, Conceptualization, Methodology, Investigation, Writing-review& editing. Harun TANYILDIZI¸: Conceptualization, Methodology, Investigation, Writing-review& editing. Mehmet Emin ÖNCÜ¸: Methodology, Investigation, Writing-review& editing.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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