THE EFFECTS OF DIRECT AND ALTERNATIVE CURRENT TYPES IN NANO ALUMINUM OXIDE MODIFIED MORTARS

İSMAİL HOCAOĞLU *
Afyon Kocatepe University, Bolvadin Vocational School, Construction Department, 03300, Afyonkarahisar, Turkey

New construction materials have begun to be produced by using nano-technology. Nano aluminum oxide (nano-Al_2O_3) is known to have high electrical conductivity. In addition, nano-Al_2O_3 can increase the material's physical features and mechanical strength by spreading perfectly into cementitious composites like other nanomaterials. In this study, direct current (20V-DC) and alternating current (20V-AC) were applied to the nano-Al_2O_3-added to 300 dosage mortars (when they were fresh situation) for one day. It also investigated the mechanical-physical properties and microstructure of the mortars when nano-Al_2O_3 (0%, 1%, 1.5%, and 2% by weight instead of cement) was added. To determine the changes in the mortar's internal temperatures depending on DC and AC, the hydration temperatures of the mortars were measured every 60 seconds. It was observed that the optimum nano-Al_2O_3 ratio was 1%. It was also concluded that AC application was more effective in increasing the hydration temperature of the mortar. In terms of mechanical strength, It was seen that when DC-applied mortars were cured for 7 days and AC-applied mortars were cured for 28 days, they took higher values. Another result obtained from the study is that alternating cure improves the microstructure better than the direct current in cement-based materials.

Keywords: *Nano aluminum oxide; Alternating current; Direct current; Internal temperature; Microstructure*

1. Introduction

Technological developments enable new-generation products in cementitious systems [1-3]. For this purpose, substituting nano-sized materials for cement has begun to be used in cement-based mortar and concrete production. Today, the cost of producing nano-sized materials is high. However, since these products are more functional and have a high surface area, high performance can be achieved even if they are used in tiny quantities [4]. Moreover, using nanomaterial in cementitious systems reduces porosity and increases mechanical strength [4]. Bargegol et al. [5] determined that the mechanical strength can be increased using nano CuO and nano SnO_2 in asphalt. Previous research has shown that nano-sized materials significantly improve the microstructure [6-10]. Some nano-materials preferred in cementitious systems are nano-aluminum oxide, nano-zinc oxide, nano-fiber, nanotubes, nano-carbon, graphene oxide, nano-clay, nano-silica, etc. [11-12]. Alumina silicates are materials with amorphous structures whose principal oxides are Al_2O_3 and SiO_2 [13]. Some scientists have conducted various studies on using nano-Al_2O_3 in cementitious systems. Li et al. [14] did not observe a significant increase in compressive strength with adding 5% nano-Al_2O_3 in cementitious mortars. However, they found that the elastic modulus increased rapidly [14]. Barbhuiya et al. [15] determined that nano-Al_2O_3 slowed down hydration reactions. Gowda et al. [16] concluded that the physical properties of the nano-Al_2O_3-added mortars were similar to the reference mortars. Ansari et al. [17] observed that when 0.5%, 1%, and 1.5% by weight nano-Al_2O_3 were substituted for cement, the compressive strengths decreased by approximately 7.00%, 10.60%, and 11.40% compared to the reference mortar. However, some studies have determined that the flexural and compressive strength can be increased using nano-Al_2O_3 in cementitious systems [18]. This study investigated the effects of DC and AC in mortars with nano-Al_2O_3 at different rates.

Previous studies have investigated the effects of nano-Al_2O_3 added in cement-based mortars and concrete on physical, mechanical, and microstructure features. However, limited studies investigated the effects of DC and AC applications on mortars with nano-Al_2O_3 additives. This research aimed to research the effects of nano-Al_2O_3, DC, and AC on the fresh and hardened properties of the mortars.

2. Materials and methods

2.1. Materials

2.1.1. Cement

CEM I 42.5R cement, suitable TS EN 197-1 [19] standard, was used in the experiments (Table 1). Afyon Çimsa Factory (Turkey) supplied the cement used in the experiments, and its specific we-

* Autor corespondent/*Corresponding author*,
E-mail: ihocaoglu@aku.edu.tr

ight was determined as 3.10.

2.1.2 Aggregate

The largest grain size of 4 mm crushed sand was used in the study. The crushed sand was obtained from Afyon Yeşilay ready-mixed concrete company (Turkey). The sieve analysis results of the crushed sand used in the experiments are shown in Table 2.

2.1.3 Water

Afyonkarahisar (Turkey) tap water was used.

2.1.4 Nano-Al_2O_3

In the experiments, aluminum oxide nanoparticles produced by the Nanografi company [20] were used. Scanning Electron Microscopy (SEM) analysis was made for the nano-Al_2O_3 (Fig. 1)

Table 2

Sieve analyses results of crushed sand

Sieve no	Percent passing sieve (%)
16 (1.18 mm)	*100*
30 (600 µm)	*99*
40 (425 µm)	*69*
50 (300 µm)	*28*
100 (150 µm)	*4*

XRD (X-ray Diffraction) analysis was also performed to investigate whether the material used in the experiments was nano-Al_2O_3 (Fig. 2). The graphic obtained in this study overlapped with the graphic obtained in previous studies for Al_2O_3 (Fig. 2). As a result of XRD analysis, $2\theta=25.5$, $2\theta=35.08$, $2\theta=43.46$, and $2\theta=57.4$ peaks were observed. According to the research of Peters et al. [21], similar peaks were observed. Observation of similar peaks means that nano-Al_2O_3 particles were formed. The physical and chemical properties of nano-Al_2O_3 used in the experiments are shown in Table 3.

Table 3

Physical and chemical analyses of nano-Al_2O_3 [18]

Physical Analysis		Chemical Analysis	
Property	Value	Element	Value
Purity (%)	99.99	B_2O_3	≤0.002
Bulk Density (g/cm^3)	4.00	CaO	≤0.01
Average Particle size (nm)	290	SiO_2	≤0.02
Specific Surface (m^2/g)	>5	Fe_2O_3	≤0.01
Color	White	MgO	≤0.02

Table 1

Physical and chemical features of cement.

Components	CaO	Al_2O_3	SiO_2	MgO	Fe_2O_3	K_2O	Na_2O	TiO_2	SO_3	Fineness, cm^2/g	Blaine, cm^2/g
Content, %	63.5	4.72	19.6	1.91	3.26	1.05	0.34	0.41	4.72	3307	3051

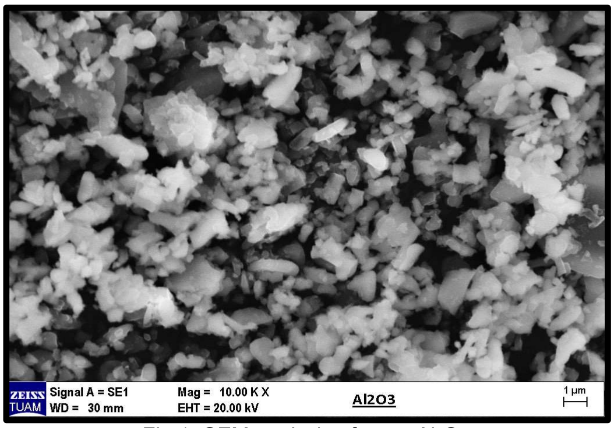

Fig.1- SEM analysis of nano-Al_2O_3.

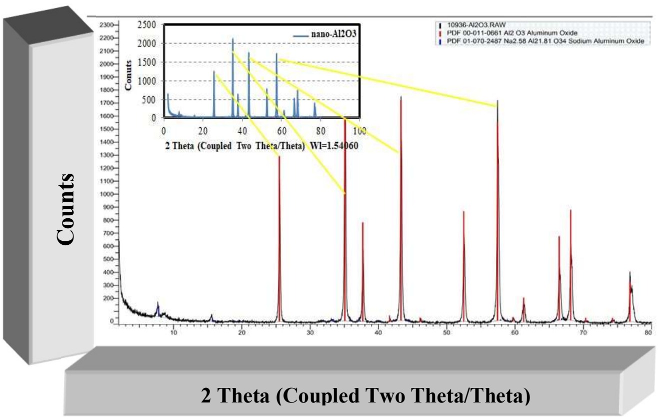

Fig.2- XRD analysis of nano-Al_2O_3.

2.2 Preparation of mortars and experiments

Three hundred dosages (the amount of cement used to produce 1 m^3 of mortar (kg)) mortars were produced with a 0.70 (constant) water/cement (w/c) ratio. The reason for using a high w/c ratio in the experiments is that nano-Al_2O_3 has a high water absorption capacity. Another reason is that the hydration water may evaporate due to AC and DC application on mortars, which can raise the hydration temperatures. While preparing the mortars, fine aggregate (crushed sand) and cement were mixed for three minutes. Then water was added to the dry mixture in three stages and mixed for about five minutes. Finally, according to ASTM C305- 20 [22] standard, nano-Al_2O_3 was added and mixed for one minute. The mortar mix calculation is shown in Table 4. For each series, six samples were produced. The prepared mortars were placed in 40mm x 40mm x 160mm molds. The stress intensity of 20V was applied to the fresh mortars for approximately one day using an AC power source and a DC power source. The temperature values of the DC-AC-applied and reference (electrical current was not applied) mortars were measured every 60 seconds. The hydration temperature changes of the specimens were recorded in two (for DC and AC applied mortars separately) data loggers. Reference mortar's humidity contents were also recorded every minute for comparison.

2.3 Experiments on fresh and hardened mortars

After removing the mortars from the wooden molds, they were cured for 7 and 28 days at approximately 20 degrees. Afterward, porosity tests were performed on the specimens cured for 28 days according to TS EN 12390-7 [23] standards. The porosities of the mortars were calculated with the help of Equation 1.

$$Porosity = \left[\frac{W_2 - W_0}{W_2 - W_1}\right] X100 \qquad (1)$$

In the formula, W_0 is the oven-dry weight (g), W_1 is the weight in water (g), and W_2 is the saturated surface dry weight (g). After the porosity tests, the samples were applied to the flexural (3-point) test. Then, compressive strength tests were performed according to the ASTM C348 [24] standard.

Micro-examination analyses were performed on the mortars that had the highest compressive strength. Some pieces of 5-7 mm in size were taken from the mortar, which were subjected to flexural and compressive strength tests for micro-examination analyses. Then, the mortar's surface was coated with carbon (Fig. 3). After that, the mortar specimens were placed in an SEM device. Afterward, mortars were examined by zooming 10000x (times). In addition, Energy-Dispersive X-ray (EDX) and XRD analyses were performed on the same samples. Experiments performed on fresh and hardened samples are shown in Fig. 3.

Table 4

Mortar mix calculation (1m^3)

Nano-Al_2O_3, %	Cement, kg/m^3	Sand, kg/m^3	Nano-Al_2O_3, kg/m^3	Water, lt/m^3
0	375.00	2238.00	-	263.00
1.00	371.25	2238.00	3.75	259.87
1.50	369.37	2238.00	5.62	258.56
3.00	363.75	2238.00	11.25	254.62

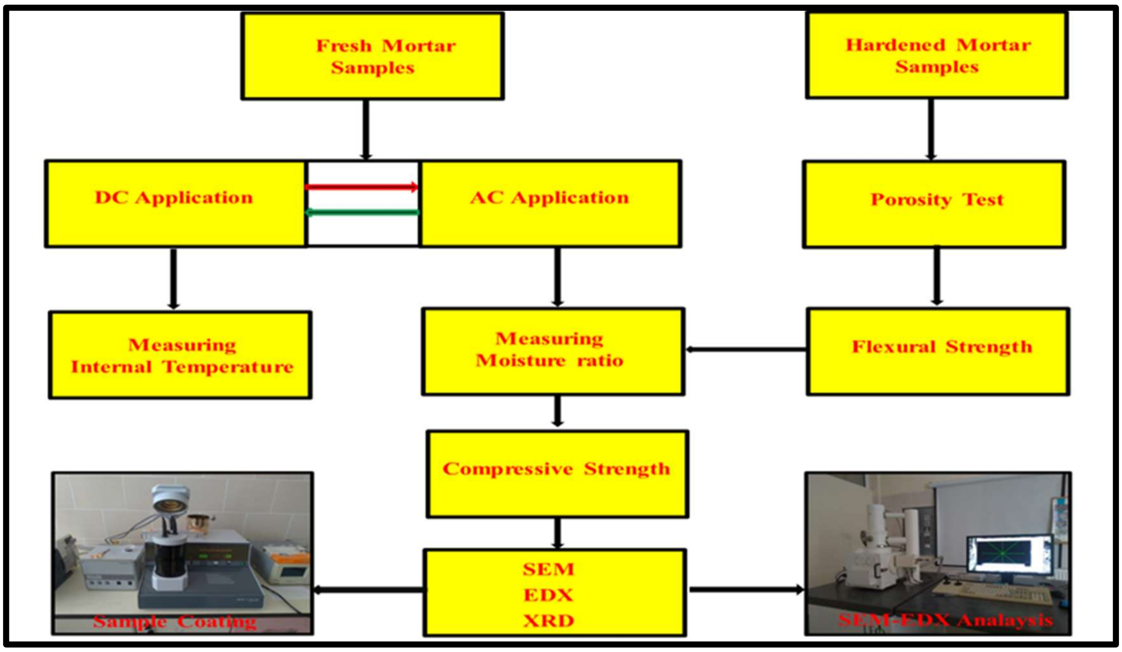

Fig.3- Experiments on mortars.

3 Results and discussion

3.1 The effect of nano-Al_2O_3 on temperature

Fig. 4 was prepared to compare the hydration temperatures of the mortars with nano-Al_2O_3 (0%, 1%, 1.5%, and 2%) at different rates. The initial hydration temperatures of the mortars added with nano-Al_2O_3 at 0%, 1%, 1.5%, and 2% ratios, respectively, were measured as approximately 18.80 °C, 20.91 °C, 22.01 °C, and 22.91 °C (Fig. 4). It was seen that the internal temperatures of the reference (nano-Al_2O_3 was not added) mortar increased with the following stages of hydration. However, it was concluded that the internal temperatures of nano-Al_2O_3-added mortars decreased over time. With this result, it has been commended that nano-Al_2O_3 can be used as a set retarder in cementitious composite materials. Zhang et al. [25] researched the setting times of mortars nano-Al_2O_3 with 0%, 0.5%, 1%, and 2% rates. They observed that the setting (final) time increased as the nano-Al_2O_3 ratio increased in the mixture. They also observed that when the cement and nano-Al_2O_3 were replaced by 1.5% in the mortars, it was more effective in decreasing the hydration temperature than the mortars with other ratios of nano-Al_2O_3 [25]. Ali and Shadi [26] examined the change in the heat of hydration. They investigated the hydration change in the first 70 hours of mortars with 0%, 1%, 2%, 3%, and 4% nano-Al_2O_3 [26]. They found that adding nano-Al_2O_3 in cementitious materials drops the heat release [26]. They also observed that the highest reduce in heat release was reached when 3% nano-Al_2O_3 was added to cement pastes [26].

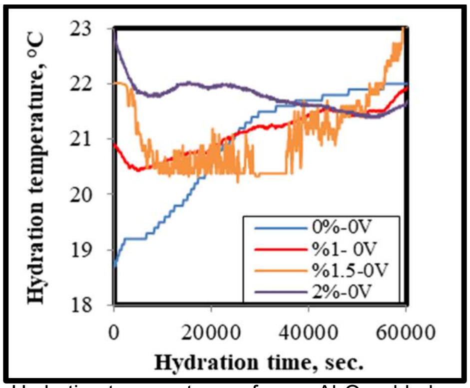

Fig.4- Hydration temperatures of nano-Al_2O_3 added mortars.

3.2 The effects of DC and AC on temperature

Fig. 5 was prepared to compare the effects of current type (DC-AC) and nano-Al_2O_3 on the mortar hydration temperature. For all nano-Al_2O_3 ratios (when DC and AC were applied), the highest hydration temperature values were reached when 1.5% of the cement was replaced with nano-Al_2O_3. It was reported that when 20V (DC) was applied and 1.5% Al_2O_3 was added, the hydration temperature value of the mortar increased by approximately 1.5 °C compared to the initial hydration temperature. It was also seen that when 20V (AC) was applied to the same ratio (1.5%) of nano-Al_2O_3 added mortar, the internal temperature increased by approximately 12 °C. It was seen that the hydration temperature values decreased with the increase of nano-Al_2O_3 ratio in the mortar when both DC and AC were applied to mortars. The high water absorption capacity of nano-sized Al_2O_3 can explain this situation.

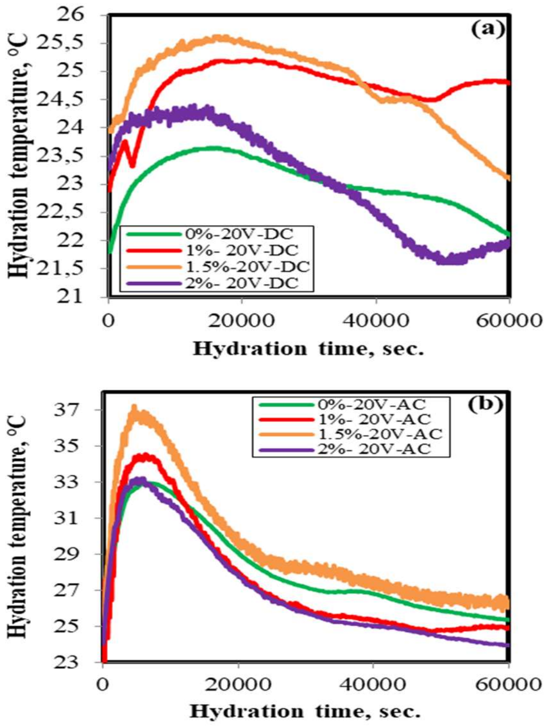

Fig.5- Variation of hydration temperature according to nano-Al_2O_3 ratio, a-DC, and b-AC application.

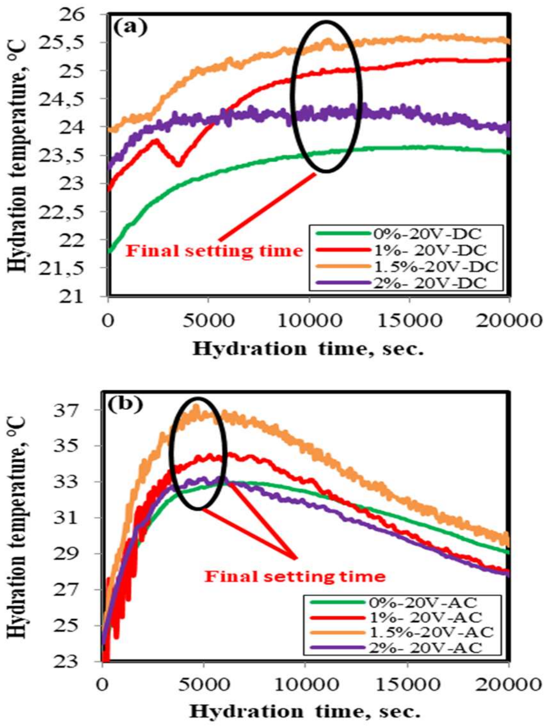

Fig.6- Variation of the final setting time according to nano-Al_2O_3 ratio, a-DC, and b-AC application.

3.3 The effects of nano-Al_2O_3-DC-AC on setting time

Previous studies have determined that setting almost ends when the internal temperature of cementitious composite materials reaches the highest values [27]. Fig. 6 was prepared to research the effects of DC and AC on the setting (final) time of nano-Al_2O_3-added mortars. When Fig. 6 was examined, it was seen that DC did not significantly affect the final setting time. The discernible change was also not observed in the setting time when AC was applied on nano-Al_2O_3-added cementitious mortars. However, it was concluded that the setting (final) time of the mortars with nano-Al_2O_3 was shorter than the reference (without nano-Al_2O_3 additive) mortars. As a result of adding 1%, 1.5%, and 2% nano-Al_2O_3 instead of cement and applying 20V (AC), the mortars were set for approximately seventy-second minutes. When 20V (DC) was applied to the reference sample, it was observed that the final setting time occurred in the ninety-sixth minute. As a result, it can be interpreted that nano-Al_2O_3 can show more electrical conductivity in AC than in DC.

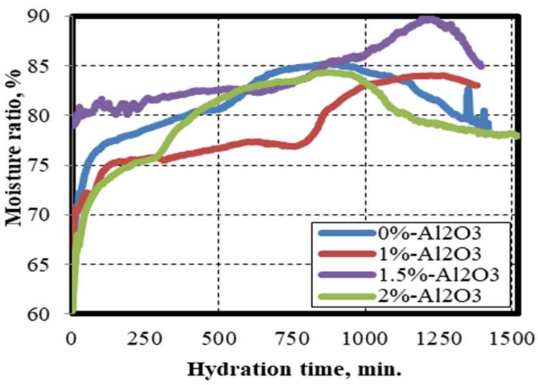

Fig.7- Comparison of moisture content of nano-Al_2O_3 added mortars.

3.4 The effect of nano-Al_2O_3 on humidity

Fig. 7 compares the humidity contents of 0%, 1%, 1.5%, and 2% nano-Al_2O_3 added fresh mortars. While measuring the humidity content of the mortars, the internal humidity content of the samples was not measured. Only the surface humidity was measured. In the initial hydration phase, an increase in humidity content was observed for all mortars. The reason for these increases can be explained by some of the hydration water coming to the surface of the mortar and sweating in the mortars at the beginning of hydration [28]. In the following minutes of hydration, it was reported that the surface humidity content decreased slightly for all mixtures. In cement-based materials, the decreasing humidity content means the drying and hardening of the material [29]. It was concluded that the humidity content decreased with the increase of nano-Al_2O_3 substituted for cement. The high water absorption capacity of nano-Al_2O_3 can explain this situation [30]. The highest surface humidity rates were obtained when the cement was replaced with 1.5% nano-Al_2O_3 at the beginning of the hydration in the following minutes (Fig. 7).

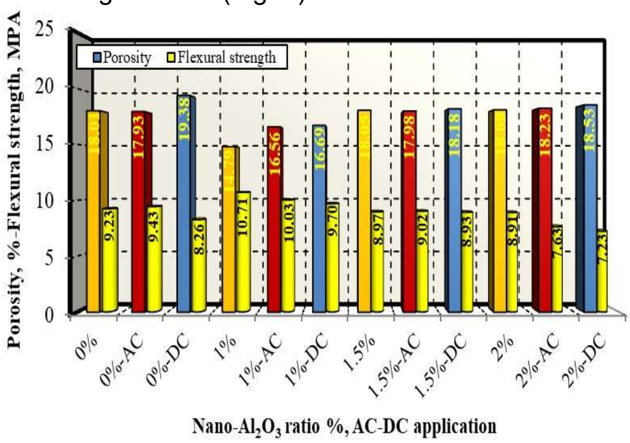

Fig.8- Effects of nano-Al_2O_3, DC-AC on porosity and flexural strength.

3.5 The effect of nano-Al_2O_3-DC-AC on the porosity and flexural strength

Fig. 8 prepared to compare the effects of nano-Al_2O_3 on the porosity and flexural strength with DC and AC application. Fig. 8 represents the 28-day cured mortars' porosity and flexural strength. A decrease in porosity was observed with the application of AC to reference mortar. However, an increase (2.05%) in porosity was observed with DC application to the reference mortar. By replacing the cement with nano-Al_2O_3 at the rate of 1%, the lowest porosity was achieved (It was seen that the porosity decreased by approximately 17.87% compared to the reference sample). It was observed that the porosity of the mortar increased as the nano-Al_2O_3 ratio increased. In mortars with different ratios (1%, 1.5%, and 2%) of nano-Al_2O_3, it was observed that porosity increased when both DC and AC were applied. Lower porosity rates were obtained with the AC application compared to the DC application in mortars.

It was observed that, by replacing the cement with 1% nano-Al_2O_3 and applying AC-DC, the porosity decreased by approximately 8.05% and 7.32%, respectively, compared to the reference (0% nano-Al_2O_3-0V) sample. When 1% by weight of nano-Al_2O_3 was added, it was seen that flexural strength increased by 16.03% compared to the reference mortar. When 1.5% and 2% by weight nano-Al_2O_3 was substituted for cement, the 28-day flexural strength of the mortars decreased by 2.81% and 3.46%, respectively.

It was observed that the application of electric current (both DC and AC) to the fresh mortars for one day adversely affected the 28-day flexural strength of the mortars. For example, when DC and AC were applied to 1% nano-Al_2O_3-added mortars, the 28-day flexural strengths decreased by approximately 9.43% and 6.34%, respectively (Fig. 8).

3.6 The effects of nano-Al_2O_3-DC-AC on the compressive strength

Fig. 9 examines the effect of nano-Al_2O_3, DC-AC application on the compressive strength of 7-day cured mortars. It was observed that by replacing the cement with 1%, 1.5%, and 2% nano-Al_2O_3, the compressive strength of the mortars increased by approximately 63.50%, 64.83%, and 61.14%, respectively. It was seen that the DC application was more effective in terms of compressive strength in 7-day cured mortars with nano-Al_2O_3 additives. Especially with the addition of 1% by weight of nano-Al_2O_3 instead of cement and the application of 20V (DC), the compressive strength of the 7-day cured mortar increased by approximately 112.48% compared to the reference sample (Fig. 9).

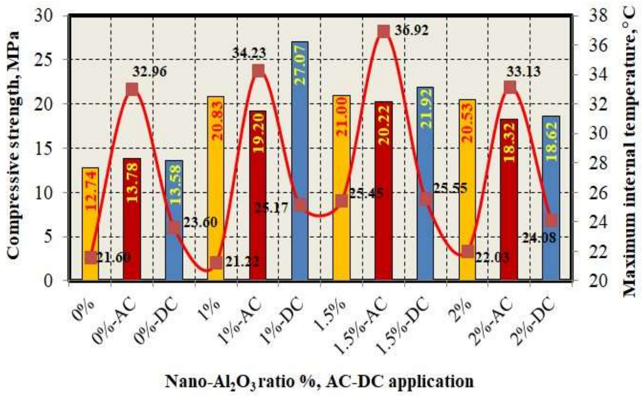

Fig.9- Maximum internal temperatures and 7-day compressive strengths of the mortars.

Fig. 10 examines the effect of nano-Al_2O_3, DC-AC on the 28-day compressive strength of the mortars. The highest compressive strength was obtained when the cement was replaced with 1% nano-Al_2O_3. It was concluded that the compressive strength of 1% nano-Al_2O_3 added mortar was 16.77% higher than that of reference mortar (Fig. 12). Li et al. [14] observed an increase in the compressive strength of mortars with 0%, 3%, and 5% nano-Al_2O_3 additives when cured for seven days. They observed an increase in the 7-day compressive strength and a decrease in the 28-day compressive strength of mortars [14]. This study obtained similar results that were obtained Li et al. Dişçi and Polat [13] produced cement pastes containing nano-Al_2O_3 at 0%, 1%, 2%, and 3% rates. They observed that 7 and 28 days compressive strength could be increased by adding nano-Al_2O_3 up to 2% [13]. Zhang et al. [25] compared the 3-day and 28-day compressive strengths of 0.5%, 1%, 2%, and 3% nano-Al_2O_3 added mortars. They observed a noticeable improvement in the 3-day compressive strength of the mortars by adding 0.5% to 2% nano-Al_2O_3 instead of cement [25].

It was seen that adding more than 1% nano-Al_2O_3 in 28-day cured samples affected the compressive strength negatively [25].

Dişçi and Polat [13] concluded that the short-term curing (7-day) process was improved the compressive strength in nano-Al_2O_3-added cementitious composites. In this study, similar results were obtained from the investigation conducted by Dişçi and Polat [13]. It was also observed that AC was more effective in increasing the hydration temperature of the mortars (Fig. 11).

While DC did not increase the hydration temperature so much in nano-Al_2O_3-added mortars, AC significantly increased the temperature values of the mortars. The polarization effect of DC might cause this situation [31]. It was observed that the internal temperature increased by approximately 11.47 °C, especially with the application of AC to the 1.5% nano-Al_2O_3-added mortar.

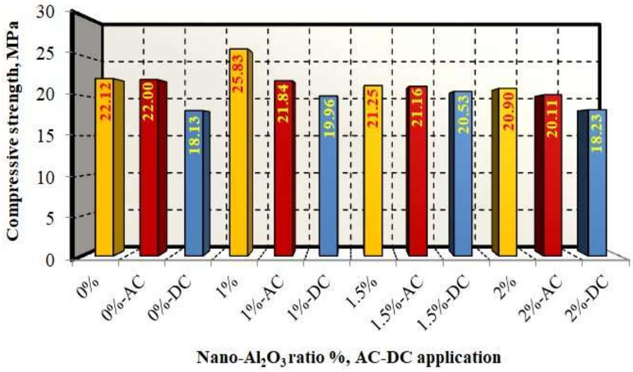

Fig.10- 28-day compressive strengths of the mortars depending upon nano-Al_2O_3, DC-AC.

This study obtained the highest compressive strength when 1% of the cement was replaced with nano-Al_2O_3 in mortars. It was observed that electric current (AC and DC) adversely affected the 28-day compressive strength of the mortars in all series. However, when AC-applied, the sample's compressive strength was higher than the DC-applied samples. This is because when AC was applied to cement-based mortars, it increased the hydration temperature more than DC-applied samples.

3.7 Micro examination

The most effective phases in the strength of cementitious composite materials are CH and CSH gels [4]. In particular, the degree of firmness of CSH gels is directly proportional to the mechanical strength [4]. Fig. 11a represents the SEM image of 1% nano-Al_2O_3-added mortar cured for 28 days. Fig. 11b: shows the SEM view of the mortar, which was added 1% nano-Al_2O_3 instead of cement, subjected to electrical curing (20V-AC applied) for 1-day, and cured in lime water for the 27 days. Fig. 11c: shows the mortar that subjected electrical curing (20V-DC applied) for 1-day, and cured in lime water for the remaining 27 days.

Adding nano-Al_2O_3 to cement-based mortars leads to a firmer formation of CSH gels due to its high surface area [32]. Iskra-Kozak and Konkol [33] investigated the microstructure of 1% nano-Al_2O_3-added mortars. They concluded that C-S-H crystals were formed when 1% nano-Al_2O_3 was placed instead of cement [33]. It was seen that CSH gels were firmly formed when 1% nano-Al_2O_3 was added instead of cement in the mortar (Fig. 11a). Barbhuiya et al. [15] researched the microstructure of cement pastes with 2% and 4% nano-Al_2O_3 additives, designed as 0.40 water/cement ratios. They observed agglomerations when more than 2% of nano-Al_2O_3 was added to cementitious materials [15]. It was not observed agglomerations because high water/cement (0.70) was used while producing the mortars in this study. It was observed that the microstructure had more pore structure when 1% nano-Al_2O_3 was substituted for cement and 20V AC was applied, compared to the reference (without electrical current application) mortar (Fig. 11b). It was also observed that the porous structure increased when 1% nano-Al_2O_3 was substituted for cement and 20V DC was applied (Fig. 11c). These results coincide with those obtained in mortars' physical and mechanical experiments. EDS analysis can give an idea about the extent to which CSH gels are formed. The EDS appearances of the mortars that 1% by weight of nano-Al_2O_3 added instead of cement are shown in Fig. 12.

It is known that the most effective components in increasing the durability properties and mechanical strength of cementitious components are CaO and SiO_2. In previous studies, it was determined that a high CaO/SiO_2 ratio caused high porosity as a result of EDS analysis [34]. Hu [35] investigated the CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratios of fly ash-added cement pastes. He observed that fly ash reacts with CaO due to its pozzolanic reaction [35]. He also determined that CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratios decreased with the decrease of CaO during cement hydration [35].

The ratios of CaO, SiO_2, and Al_2O_3 obtained as a result of EDS analyses are summarized in Table 5. Lower CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratios were achieved in the sample without the electrical current application. On the other hand, in the DC-applied sample, higher CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratios were realized compared to the AC-applied sample. A lower CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratio means tighter C-S-H gels are formed. The results obtained in Table 5 confirm the results obtained in the SEM analysis.

Table 5.
Comparison of CaO/SiO_2 and CaO/(SiO_2+Al_2O_3) ratios in 28-day cured mortars

nanoAl_2O_3 DC-AC	CO_2	CaO	SiO_2	Al_2O_3	CaO/ SiO_2	CaO/(SiO_2 +Al_2O_3)
1% – 0V	35.11	49.18	10.85	2.14	4.53	3.78
1%–AC	27.96	52.42	11.49	2.30	4.56	3.80
1%–DC	21.09	49.16	6.61	3.50	7.43	4.86

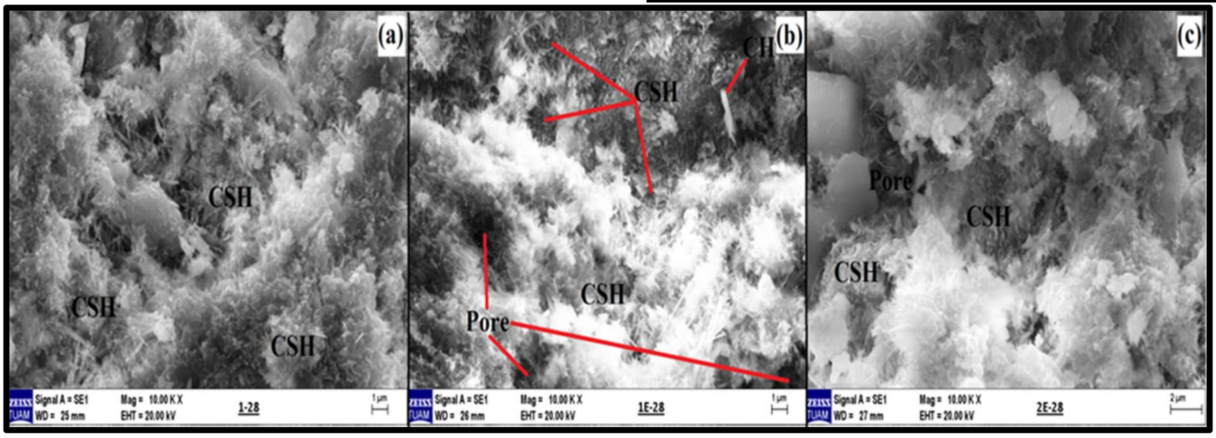

Fig.11- SEM analyses of mortars (a-0% nano-Al_2O_3-0V, b-1% nano-Al_2O_3-20V (AC), c-1% nano-Al_2O_3-20V (DC).

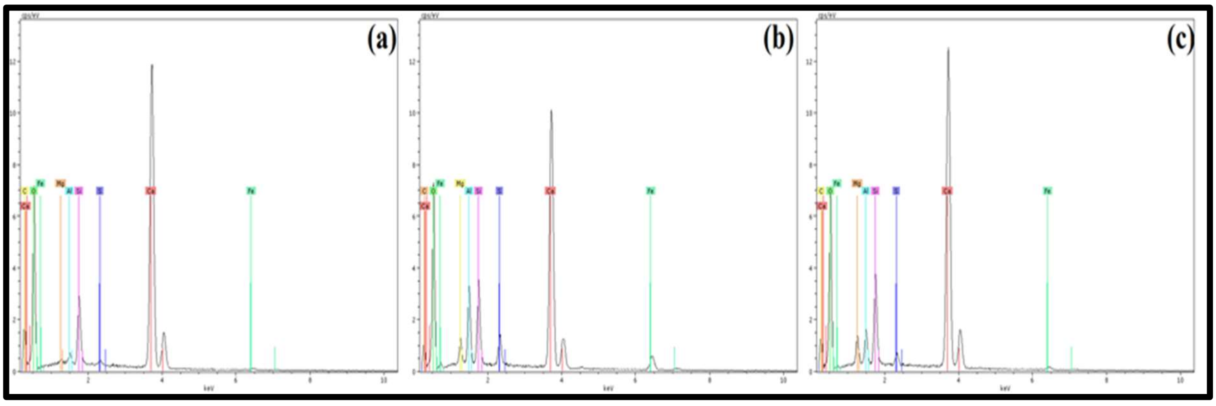

Fig.12- EDS analayses of mortars (a-0% nano-Al_2O_3-0V, b-1% nano-Al_2O_3-20V (AC), c-1% nano-Al_2O_3-20V (DC).

Within the scope of the study, XRD analyses were also performed on 1% nano-Al_2O_3-added mortars (Fig. 13). As a result of XRD analyses, it was observed that peaks occurred at two theta = 1438°. These peaks mean that CH gels were formed. When the formation degrees of CH were compared, it was seen that the peak of the curve formed for CH in the 1% nano-Al_2O_3 added mortar without electrical current application had the highest value. On the other hand, it was observed that more CH was formed in the AC-applied sample compared to the DC-applied mortar. The results obtained in the XRD analyses support those obtained in other parts of the study.

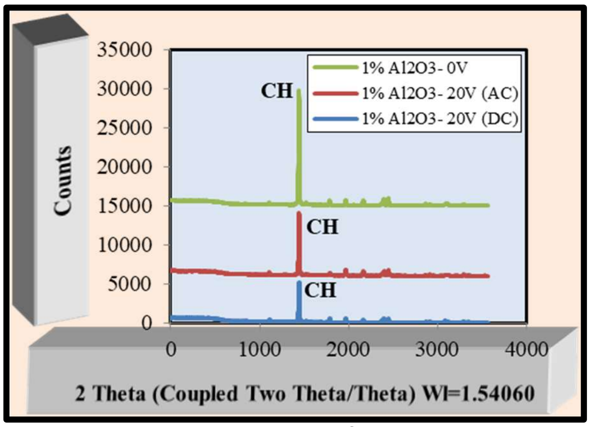

Fig. 13- XRD analyses of the mortars.

4. Conclusions and comments

Previous studies have investigated the effects of nano-Al_2O_3 on the physical, mechanical, and durability of cement-based mortars and concrete. This study investigated the effects of DC and AC applications on the physical, mechanical, and microstructure of nano-Al_2O_3-added mortars. The results obtained in the study are presented as follows:

- Nano-Al_2O_3 can be used as a set retarder in cementitious systems.
- It was observed that the alternating current is more effective than the direct current in increasing the hydration temperature in cement-based composite materials. This is thought to be due to the polarization effect of DC.
- The highest internal temperatures were obtained when 1.5% nano-Al_2O_3 was substituted for cement in the mortars in both DC and AC applications. It was seen that when DC was applied to 1.5%, Al_2O_3 added mortars, the internal temperature increased by approximately 1.5 °C; when AC was applied, the internal temperature raised by about 12 °C.
- It was concluded that the internal temperature decreased with the increase of the nano-Al2O3 ratio when both DC and AC were applied to mortars.
- It was observed that DC and AC were ineffective on final setting time in nano-Al_2O_3 added mortars.
- It was seen that the optimum nano-Al_2O_3 ratio was 1% in terms of physical and mechanical strength.
- It was observed that applying both DC and AC increased the porosity in nano-Al_2O_3-added mortars cured for 28 days.
- Lower porosity rates were obtained with the AC application compared to the DC application in mortars.
- When 1.5% and 2% by weight nano-Al_2O_3 was substituted for cement, the 28-day flexural strength of the mortars decreased by 2.81% and 3.46%, respectively.

REFERENCES

[1] F. Pacheco-Torgal, S. Jalali, Nanotechnology: advantages and drawbacks in the field of construction and building materials, Construction and Building Materials, 2011, **25**, 582–590. https://doi.org/10.1016/j.conbuildmat.2010.07.009

[2] F. Sanchez, K. Sobolev, Nanotechnology in Concrete—A Review, Construction and Building Materials, 2010, **24**, 2060–2071. https://doi.org/10.1016/j.conbuildmat.2010.03.014

[3] I. Hocaoğlu, Self-heating mortars with using graphene oxide and increasing CSH gel formation with the direct current application, Revista de la Construcción. Journal of Construction, 2021, **20**(3), 559-575. https://doi.org/10.7764/RDLC.20.3.559

[4] S. Chuah, Z. Pan, J. G. Sanjayan, C. M. Wang, W. H. Duan, Nano reinforced cement and concrete composites and new perspective from graphene oxide, Construction and Building Materials, 2014, **73,** 113-124. https://doi.org/10.1016/j.conbuildmat.2014.09.040

[5] I. Bargegol, F. Sakanlou, M. Sohrabi, G. H. Hamedi, Investigating the effect of metal nanomaterials on the moisture sensitivity process of asphalt mixes, Periodica Polytechnica Civil Engineering, 2021, **65**(1), 15–25.

[6] K. Chintalapudi, R. M. R. Pannem, An intense review on the performance of graphene oxide and reduced graphene oxide in an admixed cement system, Construction and Building Materials, 2020, **259,** 120598. https://doi.org/10.1016/j.conbuildmat.2020.120598

[7] A. S. Nik, A. Bahari, Nano-particles in concrete and cement mixtures. Applied Mechanics and Materials, 2011, 110–116,3853–3855. https://doi.org/10.4028/www.scientific.net/amm.110116.3853

[8] A. Nazari, S. Riahi, The effects of zinc dioxide nano particles on flexural strength of self-compacting concrete, Comp: Part B, 2011, **42**(2), 167-175. https://doi.org/10.1016/j.compositesb.2010.09.001.

[9] H. Kawashima, P. Hou, D. J. Corr, S. P. Shah, Modification of cement based materials with nanoparticles, Cement and Concrete Composite, 2013, **36**, 8-15.

[10] J. Zhang, C. Shen, G. Diao, Application and microstructure properties of nanomaterials in new concrete materials, Journal of Nanomaterials, 2022, 7396295. https://doi.org/10.1155/2022/7396295

[11] A. Bahari, A. Sadeghi Nik, M. Roodbari, Effect of silicon carbide nano dispersion on the mechanical and nano structural properties of cement, National Academy Science Letters, 2915, **38**, 361–364. https://doi.org/10.1007/s40009-014-0316-6

[12] A. K. Mukhopadhyay, Next generation nano-based concrete construction products: a review, Nanotechnology in Civil Infrastructure, 2011, 207–223.

[13] E. Dişçi, R. Polat, The influence of nano-CaO and nano-Al_2O_3 and curing conditions on perlite based geopolymer concrete produced by the one-part mixing method, Construction and Building Materials, 2022, **346**, 128484. https://doi.org/10.1016/j.conbuildmat.2022.128484

[14] Z. Li, H. Wang, S. He, Y. Lu, M. Wang, Investigations on the preparation and mechanical properties of the nano-alumina reinforced cement composite, Materials Letters, 2006, **60**, 356–359. https://doi.org/10.1016/j.matlet.2005.08.061

[15] S. Barbhuiya, S. Mukherjee, H. Nikraz, Effects of nano-Al_2O_3 on early-age microstructural properties of cement paste, Construction and Building Materials, 2014, **52**, 189–193. https://doi.org/10.1016/j.conbuildmat.2013.11.010

[16] R. Gowda, H. Narendra, B. M. Nagabushan, D. Rangappa, R. Prabhakara, Investigation of nano-alumina on the effect of durability and microstructural properties of the cement mortar, Materials Today: Proceedings, 2017, **4**(11), 12191–12197. https://doi.org/10.1016/j.matpr.2017.09.149

[17] R. T. Ansari, J. Tanzadeh, A. Pourdada, Laboratory evaluation of self-compacting fiber-reinforced concrete modified with hybrid of nanomaterials, Construction and Building Materials, 2020, **232**, 117211. https://doi.org/10.1016/j.conbuildmat.2019.117211

[18] J. Szymanowski, L. Sadowski, The development of nanoalumina-based cement mortars for overlay applications in concrete floors, Materials, 2019, **12**(21), 3465. https://doi.org/10.3390/ma12213465

[19] TS EN 197-1, "Cement. Composition, specifications and conformity criteria for common cements", Turkish Standards Institute. 2011, Ankara, Turkey.

[20] Nano-particles. https:// https://nanografi.com/popular-products/. 31 March 2023.

[21] C. R. Peters, M. Bettman, J. W. Moore, M. D. Glick, Refinement of the structure of sodium β-alumina, Acta Crystallographica Section B, 1971, **27**, 1826-1834. https://doi.org/10.1107/S0567740871004862

[22] ASTM C305-20, "Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency", ASTM International, West Conshohocken, PA, 2020. www.astm.org.

[23] TS EN 12390-7, "Concrete-hardened concrete tests - Part 7: Determination of hardened concrete density", Turkish Standards Institute. 2010, Ankara, Turkey.

[24] ASTM C348, "Standard Test Method for Flexural Strength of Hydraulic-Cement", ASTM Int West Conshohocken, PA. 2014. www.astm.org.

[25] A. Zhang, Y. Wencui, G. Yong, D. Yuanbo, L. Penghuan, Effects of nano-SiO_2 and nano-Al_2O_3 on mechanical and durability properties of cement-based materials: A comparative study, Journal of Building Engineering, 2021, 34, 101936. https://doi.org/10.1016/j.jobe.2020.101936

[26] N. Ali, R. Shadi, Effects of Al_2O_3 nanoparticles on properties of self compacting concrete with ground granulated blast furnace slag (GGBS) as binder, Science China Technological Sciences, 2011, **54**(9), pp. 2327–38. https://doi.org/10.1007/s11431-011-4440-y

[27] P. Taylor, S. Kosmatka, G. Voigt, Integrated materials and construction practices for concrete pavement, A state-of-the-practice manual, Center for Transportation Research and Education Iowa State University, U.S.A, 2007, 69–104.https://intrans.iastate.edu/app/uploads/2019/05/IMCP_manual.pdf

[28] I. Hocaoğlu, Self-cooling mortar production with zinc oxide nanoparticles additive and investigation of the DC application when early-age hydration, European Journal of Environmental and Civil Engineering, 2022. https://doi.org/10.1080/19648189.2022.2144464

[29] I. Hocaoğlu, Investigation of the effects of dosage and direct current intensity in new generation mortars with graphene oxide additives, Journal of the Faculty of Engineering and Architecture of Gazi University, 2023, **38**(1), 421-434. https://doi.org/10.17341/gazimmfd.940271

[30] M. Oltulu, R. Şahin, Effect of nano-SiO_2, nano-Al_2O_3 and nano-Fe_2O_3 powders on compressive strengths and capillary water absorption of cement mortar containing fly ash: A comparative study, Energy and Buildings, 2013, **58,** pp. 292-301, 2013. https://doi.org/10.1016/j.enbuild.2012.12.014

[31] Y. Hirose, J. Sagawa, Y. Sibamoto, Y. Kukita, Coping with electrode polarization for development of DC-Driven electrical impedance tomography, Flow Measurement and Instrumentation, 2021, **81**, 102006. https://doi.org/10.1016/j.flowmeasinst.2021.102006

[32] E. Mohseni, M. M. Khotbehsara, F. Naseri, M. Monazami, P. Sarker, Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina, Construction and Building Materials, 2016, **111**, 429–439. https://doi.org/10.1016/j.conbuildmat.2016.02.124

[33] W. Iskra-Kozak, J. Konkol, The impact of nano-Al_2O_3 on the physical and strength properties as well as on the morphology of cement composite crack surfaces in the early and later maturation age, Materials, 2021, **14**, 4441. https:// doi.org/10.3390/ma14164441

[34] H. Zibara, R. D. Hooton, M. D. A. Thomas, K. Stanish, Influence of the C/S and C/A ratios of hydration products on the chloride ion binding capacity of lime-SF and lime-MK mixtures, Cement and Concrete Research, 2008, **38**(3), 422–426. https://doi.org/10.1016/j.cemconres.2007.08.024

[35] C. Hu, Microstructure and mechanical properties of fly ash blended cement pastes, Construction and Building Materials, 2014, **73**, 618-625. https://doi.org/10.1016/j.conbuildmat.2014.10.009

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