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Compressive and Flexural Strength Behaviors of Metakaolin Based Geopolymer Mortars Manufactured by Different Procedures

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Abstract. Geopolymers nowadays represent one of the most effective environmental friendly alternatives to the conventional Portland cement bindings. Totally manufactured using wastes and by-product industrial materials, geopolymer binding systems achieve both goals of less greenhouse gas emissions and feasible use of waste materials. In this paper, metakaolin based geopolymer mortars were manufactured using different procedures and their flexural and compressive strength properties were investigated in to determine the most useful manufacturing process in terms of strength, energy saving and sustainability.

INTRODUCTION

In recent years, geopolymer materials, which are more environmentally friendly and sustainable, have been produced as alternatives to materials that have cement characteristics (Rattanasak and Chinaprasirt) [1]. During polymerization, a strong alkaline medium is required to dissolve a certain amount of silica and alumina contained in the materials and to increase the surface hydrolysis of the raw material particles. Alkaline activator solutions play an important role in dissolving Si and Al oxides. It has been reported that geopolymer is synthesized by mixing aluminosilicate reagent materials with strong alkaline activators such as sodium hydroxide (NaOH), potassium hydroxide (KOH), potassium silicate or sodium silicate (Palomo et al.) [2]. Geopolymerization is described as a chemical process that changes glass structures in well-concentrated and cement-based composites (De Vargas et al. 2011) [3].

Metakaolin is one of the basic components of today, together with the fly ash used in geopolymer production. The most important reason for its use in the production of geopolymers is to gain fast strength and to react strongly with alkali activators [4-8]. Davidovits [9-13] studied different numbers of pozzolanic materials for geopolymer production, and the results show that metakaolin-slag based geopolymers exhibit high mechanical and durability performance in addition to being environmentally friendly.

Pelisser et al. [14] investigated the mechanical behaviors of metakaolin based geopolymer mortars. Experimental studies have been carried out to determine the elastic modulus, toughness, compressive and flexural strength, and microstructural properties. According to the results obtained, geopolymer mortars were found to provide higher

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strength and modulus of elasticity than portland cement mortars. In addition, geopolymer mortars showed similar performance to the micromechanical properties of normal Portland cement mortars.

Rovnaník [15] conducted tests to investigate the effect of temperature on the curing conditions of metakaolin-based geopolymers. Different temperatures (10, 20, 40, 60 and 80 ° C) and different periods were applied for setting. Compressive strengths of the resulting samples were compared. The study showed that the relationship between increased pore size and cumulative pore volume with increasing temperature.

Zhang et al. [16] conducted fire resistance tests on metakaolin-fly ash based geopolymer binders. Flexural strength and compressive strength tests were carried out at room temperature after applying high temperature test. Mechanical properties and thermogravimetric analysis results were taken into account when determining the most suitable Metakaolin-Fly Ash mixture. According to these results, metacaolin-fly ash based geopolymer can be used as an alternative to traditional Portland cement in construction applications.

Lahoti et al. [17] investigated the effects of Si / Al, water / binder, Al / Na and H_2O / Na_2O ratios on the mechanical properties of metakaolin-based geopolymers. According to the results of the study, water / binder ratio is the most important factor in normal Portland cement, whereas Si / Al ratio is the most important factor in metakaolin based geopolymers.

Burciaga-Díaz et al. [18] examined how curing temperature alters the properties of metakaolin-slag-based geopolymer. They examine how and to what extent the resulting reactions are affected by the curing temperature, and how this affects the behavior of the binding agent in the long run. Cube samples were cured at different temperatures up to 520 days. The best results were obtained at 20 ^oC in the long run while the strength increase was high at early ages.

Al-mashhadani et al. [19] studied the effect of slag as a calcium source on fly ash based geopolymer binders. A constant ratio of slag helps geopolymer for gaining strength.

In this study, the compressive strength and flexural strength results of retaining the produced metakaolin-based geopolymers at different curing temperatures (40, 60, 80 ^oC) for different durations (2, 24, 72 hours) The oven was used for curing. Furthermore, in addition to these, it has been tested whether the geopolymer mortar is put into the furnace in two forms with and without plastic bags. According to the results obtained, the effects of the curing temperature, duration and the use of the plastic bags on the mechanical properties of the produced geopolymer are explained.

MATERIAL PROPERTIES AND EXPERIMENTAL PROCEDURE

Within the scope of this study, metakaolin and ground granulated blast furnace slag, respectively, have been provided from Kaolin Endustriyel Mineraller A.S. (Istanbul, Turkey), and Bolu Cement Company (Bolu /Turkey). The slag has a specific gravity of 2.91 g / cm^3 whereas the specific gravity of metakaolin is 2.52 g / cm^3. Also, the pozzolanic index of metakaolin is 1359 $MgCa(OH)_2$/g. The chemical components of the two materials used for geopolymer mortar production are given in Table 1. Metakaolin, Ground Granulated Blast Furnace Slag (GGBS), denotes MK and GGBS, respectively.

In the scope of the work as an aggregate, standard sand according to Rilem Cembureau standard and BS EN 196-1 added. As the alkali activator, a mixture of sodium hydroxide solution prepared the day before the experiment and sodium silicate was used. Sodium silicate and sodium hydroxide were added as an alkali activator. Sodium silicate and sodium hydroxide were supplied by Merck. The molar ratio of the sodium silicate solution is 3.29 (SiO_2 = 27%, Na_2O = 8.2%). Using NaOH particles in 99% purity, 12M solution was prepared.

TABLE 1. Chemical composition of Metakaolin and Ground Granulated Blast Furnace Slag (%).

Chemical analysis, %	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**B_2O_3**	**L.O.I.**
MK	56.10	40.23	0.85	0.55	0.19	0.16	0.51	0.24	-	1.10
GGBS	40.55	12.83	1.10	0.75	35.58	5.87	0.68	0.79	-	0.03

The quantities used in preparing the mixtures are given in Table 2. It has been benefited from the work done before in this subject [17, 18, 20-24]. 450 g of metakaolin was first mixed with the previously prepared mixture of sodium hydroxide and sodium silicate. The incorporated alkali activator mixture was added such that the binder material/ alkali activator ratio was 1: 1. Then, 60 g of slag was added as a mixed calcium source. Lastly, Rilem sand was added so that the binder material / aggregate ratio would be 1: 2.5. The mixture was exposed to vibration after being placed in molds.

As curing conditions, different conditions have been tried in this study. Within the scope of the study, all samples were removed from the molds after 2 hours. All specimens were put in oven after 24 hours. As curing time, 2, 24, 72 hours were determined. Half of the samples were placed in the oven without a plastic bag. Three different curing temperature (40, 60, 80 ^{o}C) were tested. 50x50x50 mm cube samples for compressive strength and 40x40x160 mm prism samples for flexural strength were produced (Fig. 1). Flexural and compressive tests were made after 3 days from removed out of molds.

Table 2. Geopolymer mortar mixing proportions (g).

Metakaolin	Rilem Sand	Slag	NaOH (12M)	Na_2SiO_3
450	1125	60	150	300

a)



b)



FIGURE 1. a) Metakaolin 50x50x50 mm cube specimens and metakaolin 40x40x160 mm cube specimens b) Metakaolin specimen with plastic bags in the oven

Results and Discussions

The ideal curing temperature and curing time were determined for both the bending strength and the compressive strength in the tests carried out in the scope of the study. In addition, the other factor that affect the strength is to put the specimen with plastic bag in the furnace. The specimens cured at 60°C curing temperature for 72 hours were obtained with a compressive strength of 59.65 MPa and flexural strength of 10.05 MPa. According to the test results, 40 ° C curing temperature results are better than 80 ° C curing temperature results. The lowest compressive strength and flexural strength were obtained at 25.14 MPa and 7.76 MPa respectively under curing conditions at 80°C temperature for 2 hours without plastic bag. Compressive and flexural strength results are given in Table 3-4. This situation seems to be compatible with other studies in the literatüre [17, 18, 20-24]. It is seen from the results that the plastic bag enhances the strength of the sample as an obstacle to water loss in the oven.

TABLE 3. Geopolymer mortar compressive strength results (MPa).

	40° with plastic bags (2 hours)	40° without plastic bags (2 hours)	40° with plastic bags (24 hours)	40° without plastic bags (24 hours)	40° with plastic bags (72 hours)	40° without plastic bags (72 hours)
Mix 1	36.56	32.19	43.27	39.14	52.24	50.46
	60° with plastic bags (2 hours)	60° without plastic bags (2 hours)	60° with plastic bags (24 hours)	60° without plastic bags (24 hours)	60° with plastic bags (72 hours)	60° without plastic bags (72 hours)
Mix 2	41.26	38.78	49.58	44.72	59.65	54.69
	80° with plastic bags (2 hours)	80° without plastic bags (2 hours)	80° with plastic bags (24 hours)	80° without plastic bags (24 hours)	80° with plastic bags (72 hours)	80° without plastic bags (72 hours)
Mix 3	33.68	25.14	38.37	34.46	44.32	41.79

TABLE 4. Geopolymer mortar compressive strength results (MPa).

	40° with plastic bags (2 hours)	40° without plastic bags (2 hours)	40° with plastic bags (24 hours)	40° without plastic bags (24 hours)	40° with plastic bags (72 hours)	40° without plastic bags (72 hours)
Mix 1	8.66	8.45	9.33	9.20	9.61	9.48
	60° with plastic bags (2 hours)	60° without plastic bags (2 hours)	60° with plastic bags (24 hours)	60° without plastic bags (24 hours)	60° with plastic bags (72 hours)	60° without plastic bags (72 hours)
Mix 2	9.13	8.85	9.55	9.34	10.05	9.73
	80° with plastic bags (2 hours)	80° without plastic bags (2 hours)	80° with plastic bags (24 hours)	80° without plastic bags (24 hours)	80° with plastic bags (72 hours)	80° without plastic bags (72 hours)
Mix 3	7.94	7.76	8.82	8.63	9.32	9.08

CONCLUSIONS

Studies have been helpful in determining ideal curing conditions for metakaolin-based geopolymer mortar. According to the results obtained, the following results were obtained.

- The ideal curing temperature for geopolymer mortars is 60°C. As the temperature increases from 60°C, the strength values decrease.
- The 72 hour curing time is ideal for geopolymer mortars. The lowest values were obtained for a 2-hour curing time.
- It is seen that the plastic bag enhances the strength of the sample as an obstacle to the loss of the oven.

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