Geopolymer Concrete Production by Activating Alkaline With Silica Sand, Blast Furnace Slag and Fly Ash

Hanifi Binici[1], Fatih Binici[2], Mustafa Dolaz[3]

[1]Department of Civil Engineering, KSU University, Kahramanmaras, Turkey
[2]Department of Civil Engineering, Erciyes University, Kayseri, Turkey
[3]Department of Environment Engineering, KSU University, Kahramanmaras, Turkey

ABSTRACT

In this paper, it was aimed to manufacture a functional geopolymer structure by activating silica sand, fly ash disposed from Afşin-Elbistan Thermal Power Plant and blast furnace slag obtained from Iskenderun Ferrous & Steel Plant with NaOH. Concrete mortars containing alkaline-activated aggregates were shaped in 4 cm x 4 cm x 16 cm and 10 cm x 10 cm x 10 cm molds. These samples were kept in oven at 75 ^{o}C during 20 hours. Bending resistance, specific weight, thermal conductivity coefficient, compressive strength and ultrasound transmission rate of each sample were measured.

INTRODUCTION

Fly ash generated in Afşin-Elbistan thermal power plant can not be used as an aggregate in cement and concrete production due to its insufficient characteristic properties. It is recognized as a serious environmental pollutant. Transportation and storage costs of this industrial waste are considerably expensive. Fly ash can be activated by being grinded with lime, being treated with alkalies or being cured at high temperatures. It is possible to produce binding agent by activating a material containing free silica and alumina with some alkalies such as sodium silicate, sodium hydroxide or potassium hidroxide. This material is defined as geopolymer [1, 2]. Reactions observed during geopolymer manufacturing are given below [3].
(material containing silica and alümina) + (alkalies) = (inter-component of geopolymer)…(1)
(inter-component of geopolymer) + (alkalies) = (geopolymer)……………………………...(2)

As it is seen from the reactions above, there is no water available in geopolymer structure. It is necessary to use water in order to process mixture. It leaves geopolymer by remaining discontinuous nanoparticles while geopolymer is being cured or dried. This phenomen gains some favourable properties to geopolymer structure such as; lightness, thermal insulation and fire resistance [4].

If mortar or concrete is manufactured with binding agent containing alkaline-activated fly ash, it is observed that end product, geopolymer, has poor dry shrinkage performance, high resistance to environmental conditions and good adhesion with reinforcement.Low thermal conductivity, high volume stability and easily fortifiability are some of other advantages of these geopolymers [5, 6]. Mortars produced by alkaline-activation of industrial wastes containing silica and alumina are lighter than cement mortars. Besides, their mechanical resistance are higher than those of cement mortars [7, 8]. Alkali activation had been succesfully performed in stabilization of toxic wastes and nuclear residues [9].

Blast furnace slag can be easily activated with alkalines at the curing temperature of 20^{o}C. By increasing temperature up to 100 ^{o}C, geopolymers can be clearly removed from the mold after a few hours. Furthermore, cement consumption is declined by using alkaline binding agent instead of cement. By means of limiting cement usage, environmental pollution can be avoided by eliminating CO_2 emission orginated from cement production [10-12].

Atiş et. al. studied on a new binding agent to activate slag without using cement. They preferred to use Na_2SiO_3,Na_2CO_3,and NaOH as alkali activators. It was denoted that starting and finishing setting times of cements activated with sodium silicate and sodium hydroxide were earlier than that of conventional Portland cement. However cement activated with sodium carbonate had nearly the same starting and finishing setting time with conventional portland cement. It was reported that ageous Na_2SiO_3 had an important effect on final compression and bending resistance of end product by means of increasing silica modulus. Also, mortars containing sodium hydroxide activated slag were more brittle than others [13].

Allahverdi et. al. [14] focused on production of geopolymer cement by activating pumice type pozzolana with combination of NaOH and Na_2SiO_3. These chemicals were mixed with each other and appropriate proportion was determined. They clarified that compression resistance of geopolymer cement was 63 MPa after it had been cured during 28 days. Besides it wasresulted that natural pozzolana could not be activated and the quality of geopolymer cement was depend on constitutes of alkaline activator, water/binding agent ratio and quality of pozzolana.

Komljenovic et. al. investigated the effect of alkali-activated fly ash on mechanical and micro-structure properties of geopolymer. NaOH and Na_2CO_3 mixture, NaOH, $Ca(OH)_2$, Na_2SiO_3 and KOH were used as alkaline activators. It was denoted that characteristic properties of alkaline activator, fineness of fly ash and density of alkali agent were demostrated were the most important parameters in alkali-activated fly ash production. The highest compression resistance were observed in sodium silicate activated samples. Compression strength of geopolymers containing alkaline-activated fly ash were strongly related with their Si/Al ratios [15]. In this study, geopolymer structure was manufactured by activating fly ash, blast furnace slag and silica sand with NaOH.

2. MATERIAL AND METHOD

2.1. Blast Furnace Slag: It is the most important and commonly used type among all slags. It is formed in process of pig iron manufacture from combustion residue of coke, iron ore and limestone [16].

2.2. Fly ash: It is a combustion residue containing silica and alumina silica. This fine material consists of sponge-like particles and glassy, hollow and unburnt micelles. Its chemical composition alters according to the amount and type of mineral impurities in coal used in thermal power plant. SiO_2, Al_2O_3, CaO, and MgO chemical compounds occupy85 % of fly ash by weight [17]. In this experimental study, fly ash originated from Afşin-Elbistan thermal power plant was used. This establishment consumes 18.000.000 tones coal and disposes approximately 3.240.000 tones fly ash in a year.

2.3. Silica sand: It consists of at least 98% SiO_2 by weight. Silicone and O_2 are the most abundant elements in the world. The material “silica”, one of the three minerals available in rock formation, exists by means of chemical reaction of these two compounds. In industrial applications, it is generally preferred to use silica sand containing at least 95% silica by weight [18].

2.4. Rilem sand: Standard rilem sand was used in production of reference sample. Chemical and physical properties of materials used in this study were given in Figure 1 and Figure 2, respectively.

Table 1. Chemical contents of aggregates

Element (%age dry weight)	Fly ash	Blast furnace slag	Silica sand
Al_2O_3	19.74	13.77	7.13
CaO	23.50	34.91	0.55
Cl	0.09	0.12	-
Cr_2O_3	0.05	0.04	-
Fe_2O_3	22.17	1.70	0.65
K_2O	0.24	0.35	-
MgO	2.25	2.15	0.15
MnO_2	0.09	0.02	-
Na_2O	0.60	0.79	1.05
NiO	0.03	0.07	-
P_2O_5	0.25	0.33	-
SO_3	11.12	1.45	-
SiO_2	19.25	42.75	87.45
Heat loss	1.56	1.34	3.45

Table 2. Physical properties of materials

Materials	Specific gravity(kg/m^3)	Blaine(m^2/kg)	Sieve analysis (%)	
			Residue on 90 lm	Residue on 200 lm
Fly ash (FA)	2890	3000	0.2	0.09
Blast furnace slag (BFS)	2850	3000	0.1	0.07
Silica sand (SS)	2870	3000	0.1	0.04

3. EXPERIMENTAL STUDIES

3.1 Preparation of Samples

Mixtures were prepared and moulded according to the conditions underlined in TS 802 standard. Amounts of aggregates used for producing geopolymer mortars were shown in Table 3. These aggregates were activated by NaOH activator with 98% purity. Preparation processes of a sample were demonstrated in Figure 1.

Table 3. Proportion of mortars (g)

Specimens	Sand	Water	Alkali	NaOH	Cement
Fly ash	900	225	450	100	-
Blast furnace slag	1080	270	540	100	-
Silica sand	1080	270	540	100	-
River sand (Control sample)	1350	225	-	-	450

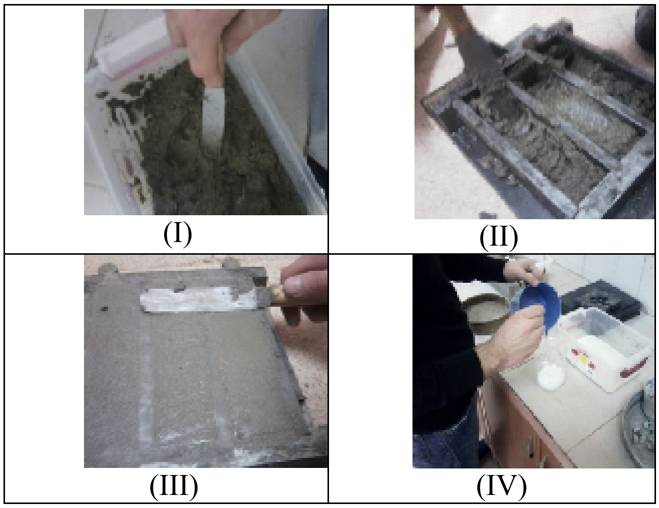

Fig. 1. Preparation of samples

4.2. Determination of Water Absorption Capacity

Water absorption capacities of samples were measured depending on TS 3624 standard. This test was performed on only one of the samples in same group. Samples were penetrated into water bath at 21± 2^{o}C after they had been dried in oven during 24 hours. They were cured in water bath during 24 hours. Dry weight of each sample was determined after removing surface wetness with a dry cloth [19]. Results were illustrated in Figure 2.

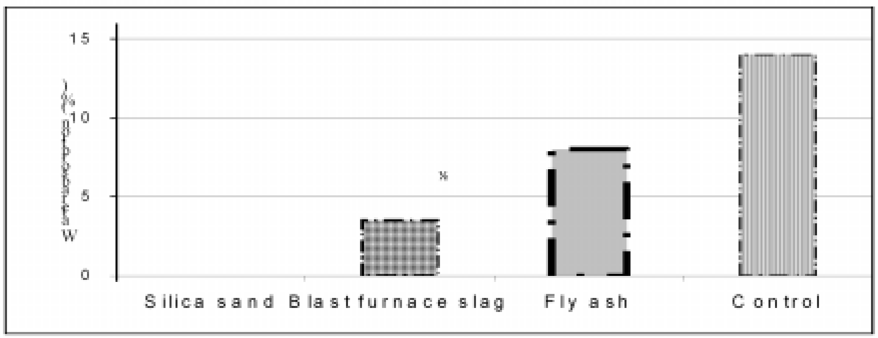

Fig. 2. Water absorption rates of samples

4.3. Testing of Flexural Strength

Flexuralstrengths of concretes were tested by one-point bending method [20]. This method was performed on samples cured during 28 days. Their bending resistance and toughness values were demostrated in Fig.3 and Fig. 4, respectively. Flexural strength of geopolymers containing fly ash were found as the highest value as it was seen in Fig. 4. Generally, all samples had higher bending resistance than that of control sample.

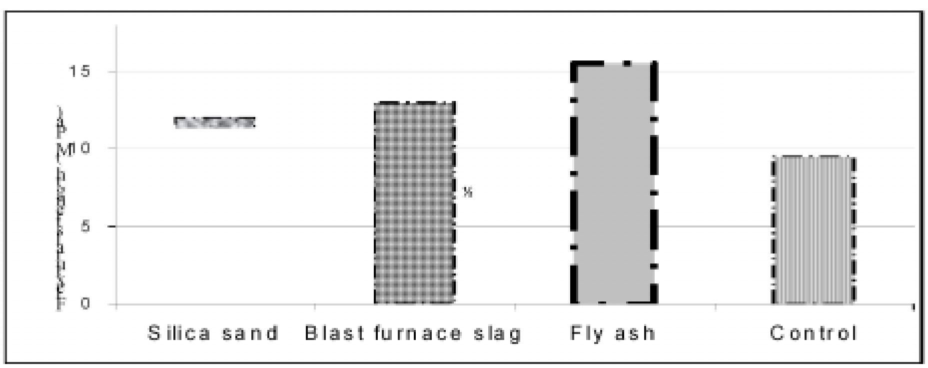

Fig. 3. Comparison of bending resistance values

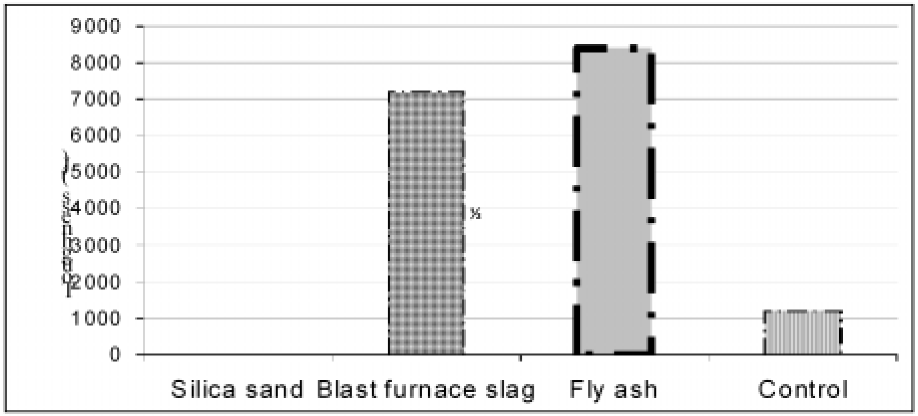

Fig. 4. Toughness values of samples

4.4. Compression Resistance of Geopolymers

Compression resistance of samples were tested with loading speed of 75 kg/min. Obtained test results were given in Fig. 5.

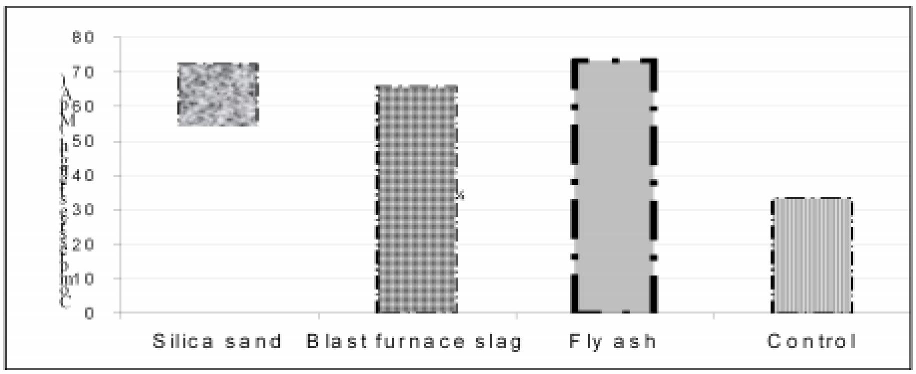

Fig. 5. Compression resistance of samples

The highest compression resistant results were obtained from samples containing silica sand or fly ash. Test results showed that geopolymer samples were generally 2.7 times more resistant to compressing forces than control sample.

4.5. Obtaining of Specific Weights of Samples

In this study, weight per unit volumewas calculted by dividing total weight into total volume for each sample. Graphical representation of test results were given in Fig. 6.

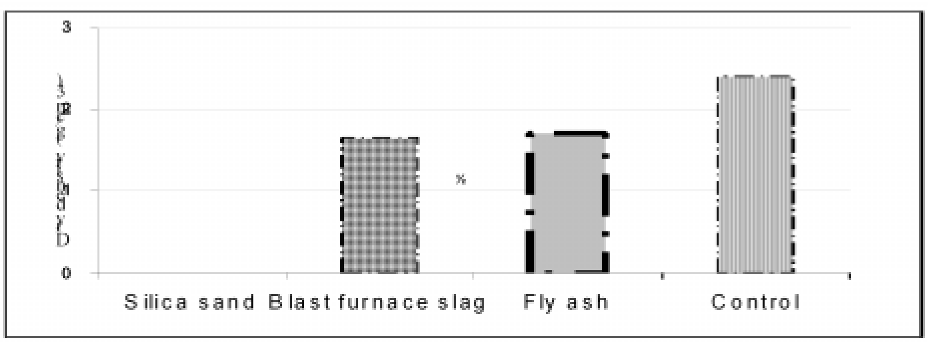

Fig. 6. Specific weights of samples

It was resulted that specific weights of geopolymers with fly ash and blast furnace slag were nearly the same with each other. There could not find a relation between specific weights of samples and other mechanical properties. In Figure 8, it was observed that specific weights of geopolymer samples altered between the values of 1.65 and 1.85 g/cm^3.

4.6. Determination of Ultra Sound Transmission Rates

Sound conductivity properties of concretes and rocks are generally identified by testing corresponding mateiral with ultrasonic testing device. P and S waves are sent into material and then their transmission rates and times wasted for transmission can be determined by means of this method. Correlation among ultrasound transmission rate, compression resistance and other properties of material can be approximately obtained by the formula given below [21, 22]. Ultrasound transmission coefficient of sample is calculated by dividing the lowest value read by testing device to sample width. Results measured by Pandit device were illustrated in Fig. 7.

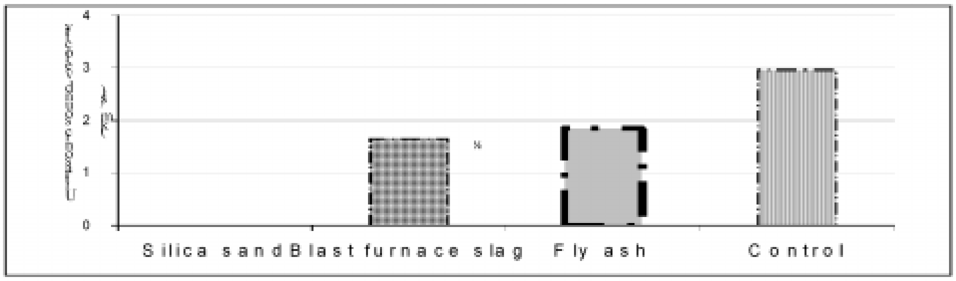

Fig. 7. Ultra sound transmission rates of samples

This test was performed by considering ASTM C 597 standard. There is no relationship between concrete strength and transmission rate of the "wave P" passing through concrete sample [22, 23]. However transmission rate of wave P is strongthly realted with the concrete density. The time wasting for transmitting of wave P is longer in a concrete with low density. In other words, transmission rate of wave P is definitely slower in a porous concrete. The highest ultra sound transmission rate was measured in control sample. Sound transmission performance of geopolymer with silica was considerably poorer that those of others.

Low ultrasound wave velocity can be explained with the presence of a firm structure. On the other hand, ultrasound waves can propagate rapidly in a short time if they are sent to a nonporous structure. It was observed that there was a nonlinear correlation between compression resistance values and ultrasound transmission rates of samples. In short, samples having low ultrasound transmission rates were more resistant to compression. As it was seen in Figure 10,ultra sound transmission rates of geopolymers were measured between the values of 1.54 and 1.85 km/sec.

4.7. Thermal Conductivity Coefficients of Samples

Thermal conductivity of geopolymer samples were determined by ASTM C 1113-90 Hot Wire Method. Thermal conductivity coefficients of geopolymers were found between 0.235 and 0.375 W/mK. These results are compatible with datas obtained in previous studies [24, 25]. Thermal conductivity coefficient of geopolymers were given in Fig. 8.

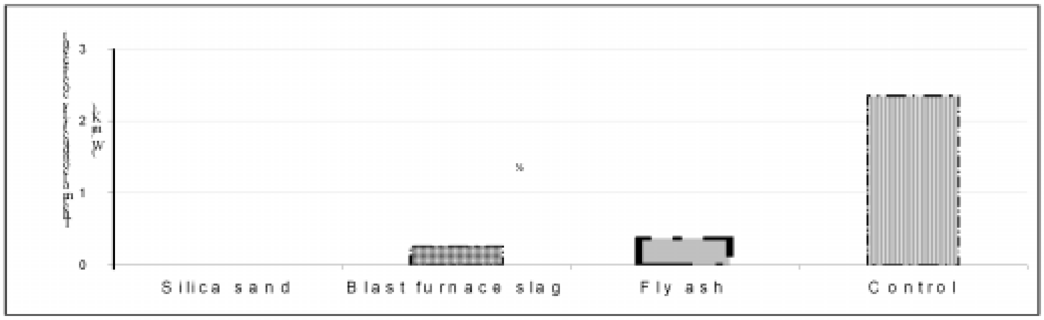

Fig. 8. Thermal conductivity coefficients of geopolymer structures

5. CONCLUSION

Experimental evaluation and results of this study can be summarized as follows.

1. There is not a clear relationship between compression resistance and ultra sound transmission rate. This phenomen clarifies that nonporous structures are more resistant to compressing forces.
2. If water absorption capacity of a sample is high, this sample has low sound transmission rate because of its porous structure.
3. Compression and flexural strengths of all samples are extremely higher than those of control sample. Resistance to compressing and bending forces can be improved by activating concrete with appropriate alkali agent.

In this study, it is aimed to recycle some waste products for decreasing environmental pollution. By this way, it can be possible to minimize incremental costs resulted from transportation and storage of these by-products.

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