EFFECT OF SILICA MODULUS ON COMPRESSIVE STRENGTH OF VOLCANIC TUFF BASED GEOPOLYMER CONCRETE

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Abstract - The aim of this present research is to examine effect of silica modulus (Ms), curing temperature and liquid/binder ratio (l/b) on the compressive strength of geopolymer concrete samples produced from volcanic tuff. Volcanic tuff used as raw material was activated with NaOH+ Na2SiO3 according to 0.8 and 0.6 of Ms meaning mass molar ratio of Na_2O to SiO_2. During the production phase of the sample, three different cure temperatures (90, 105 and 120 °C) and two different alkali liquid/binder (l/ b) ratio (0.5 and 0.6) were used. To each sample produced using this paremeters, changes in compressive strength values of 3, 7, 28 and 90 day sample were determined. The optimum values were determined as 0.8 for silica modulus, 105 °C for curing temperature and 0.6 for l/b ratio. Test results demonstrated that curing temperature and l/b ratio have a significant effect on geopolymerization reaction. Also, the majority of the ultimate compressive strengths of geopolymer concrete samples were obtained as a result of heat curing process.

Keywords - Geopolymer Concrete, Volcanic Tuff, Compressive Strength, Silica Modulus

I. INTRODUCTION

Traditional portland cement is an indispensable building material in terms of building applications. The usage of cement which has an annual production capacity of 4 billion tons, brings with it many problems (environmental deterioration by the emission of CO_2 upon burning of limestone and combustion of fossil fuel, the ability to survive is limited to aggressive environments and higher production cost especially in countries that import petroleum-based fuels.[1, 2]. The rapid increase in the tendency to rapid industrialization and urbanization in recent years has led to an increase in the use of cement [3]. Especially in recent years, many studies have been carried out to search alternative biomaterials to cement and to change production techniques of cement with more environmentally friendly methods[4]. However, approximately 60% of the CO_2 emissions caused by cement production is due to calcination of the limestone ($CaCO_3$) which is the main component of the cement [5]. Therefore, only changing the production techniques was not considered sufficient and alternative binding materials to cement were investigated. As a result of these alternative quests, geopolymer materials originally introduced by Davidovits at the end of 1970s have become increasingly popular in the literature [6]. Geopolymers are a member of three-dimensional inorganic polymer family obtained by reaction of an aluminosilicate based raw material (volcanic tuff, fly ash, silica fume, etc.) with Na and K based alkaline solution (NaOH, Na_2SiO_3, KOH, K_2SiO_3) [7].

Volcanic tuff in the natural pozzolans class is the oldest pozzolan type with the greatest reserve capacity [8]. Volcanic tuffs are generally the result of changes in volcanic glass under hydrothermal conditions, and that this structure is rich in tectosilicate minerals, zeolites and feldspars [5]. Depending on the mineralogical composition physical and mechanical properties of the volcanic tuffs there are many areas of use; in agriculture and garden works, In the concrete industry as lightweight aggregate, in wastewater treatment, in minimizing the heavy elements in the soil, in the process of separation of nitrogen from air, in the elimination of the radioactive elements (Cs and Sr) of nuclear waste, etc [9]. In terms of volcanic tuff and marble, Turkey has very rich land resources. It is stated that there are approximately 155,000 km^2 natural pozzolan reserve Turkey [10]. Also, Nevsehir region, which has a volcanic area of approximately 1000 km^2, has rhyolitic and dacitic tuffs [11].

In this study, volcanic tuff obtained from Nevşehir Region was used. Volcanic tuff was activated with $NaOH+Na_2SiO_3$, as silica modulus will be 0.6 and 0.8. Three different curing temperatures (90, 105 and 120°C) were applied to the produced geopolymer concrete samples. According to the results of tests carried out, the optimum values were determined as 0.8 for silica modulus, 105 °C for curing temperature and 0.6 for l/b ratio. Also, results demonstrated that curing temperature and l/b ratio have a significant effect on compressive strength.

II. MATERIALS AND METHODS

Volcanic tuff is supplied from Böltas Engineering where natural stones are processed in Nevşehir Region. In order to increase the pozzolanic reactivity of this material, first the material is dried at 105°C for 24 hours and then grinded in Portland cement slurry. The chemical composition of volcanic tuff is presented in Table 1. NaOH and Na_2SiO_3 were selected as a alkaline activator for the formation of geopolymerization reaction. The silica modulus (Ms) meaning molar ratio of Na_2O to SiO_2 of liquid alkali activator was selected as 0.6 and 0.8. Produced samples were cured at 90, 105 and 120 °C for 72 hours. Compressive strengths were tested in accordance with the ASTM C109 standard.

Table 1. Chemical composition of volcanic tuff

Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3
Volcanic Tuff	68.50	14.00	3.00	1.50	1.40	3.25	3.50	0.25	0.002

III. RESULTS AND DISCUSSION

3.1. Compressive Strength

3, 7 and 28-day compressive strength of geopolymer concrete samples at different silica moduluss and curing conditions are tabulated in Table 2 and demonstrated in Figs. 1-2. As clearly seen Figs. 1-2, the optimum values were determined as 0.8 for silica modulus, 105°C for curing temperature and 0.6 for l/b ratio.

It has been observed that the majority of the ultimate strengths of geopolymer concrete activated using Ms 0,8 and 0,6 are obtained as a result of heat curing applied for the first 3 days. Also, almost all of the values of compressive strength increased with increasing sample age.

Also, the results show that the silica modulus has a significant effect on the compressive strength. Similarly, it is said that obtaining the optimum concentration of the alkali-activating solution would contribute to the performance of the resulting products [12]. Fig3. shows the changes in the compressive strength with the silica modulus dropping from 0.8 to 0.6. As a result of the reduction of the silica modulus from 0.8 to 0.6, the highest loss of compressive strength was observed in the samples cured at 90°C with l/b ratio of 0.6. In parallel with the results, it has been observed that there is an increase in the compressive strength with the increase of the silica modulus [13].

Table 2. Compressive strength values of geopolymer concrete samples.

Ms	l/b	Curing Temperature, (°C)	Compressive Strength, (MPa)			
			3 Day	7 Day	28 Day	90 Day
0,8	0,6	90	11.9	12.6	14.8	16.0
		105	12.4	13.6	16.7	17.4
		120	9.8	10.4	12.2	13.6
	0,5	90	10.7	13.3	13.0	14.6
		105	11.5	12.0	14.4	16.1
		120	10.1	12.3	12.0	13.6
0,6	0,6	90	11.0	12.8	11.6	15.7
		105	12.6	13.5	13.8	15.2
		120	9.5	10.9	12.4	13.8
	0,5	90	10.4	11.3	12.0	13.6
		105	12.8	13.5	15.4	15.8
		120	8.5	8.7	9.6	10.3

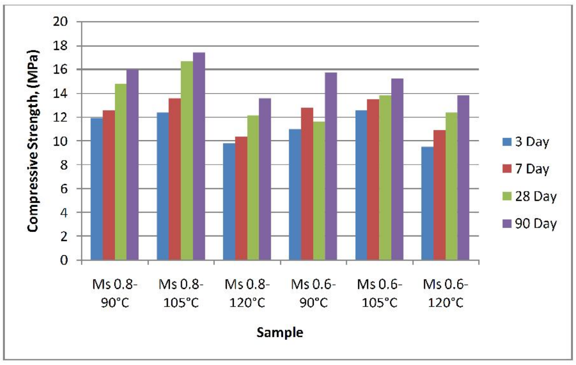

Fig 1. The compressive strength values of geopolymer concrete samples with l/b ratio of 0.6

Fig.4 shows that while increasing the curing temperature from 90 to 105°C increased the compressive strength of the samples, curing temperature applied above 105°C bring about decrease in compressive strength values of geopolymer concrete samples. This result shows that the optimum temperature for the geopolymerization reaction to be attained is 105 °C, and that the increased temperature after this temperature value has negative effects on the internal structure of the geopolymer concrete. Similarly, Yuan et al. (2016) stated that curing temperature plays a vital role in improving the microstructure and mechanical properties of geopolymers and that an optimum curing temperature application will contribute to the increase in mechanical properties by forming a compact structure in the geopolymer matrix [12]. Besides, in another study, it is stated that during long-term curing period, maximum compressive strength was obtained at 75°C rather than at the highest curing temperature of 90°C [14].

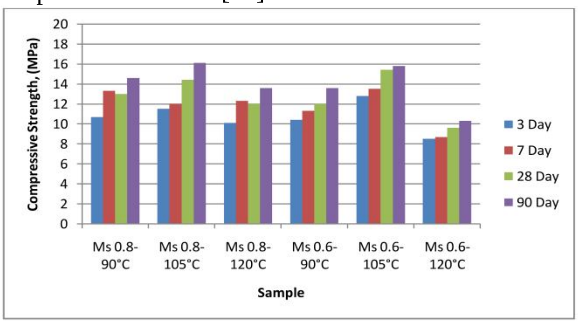

Fig 2. The compressive strength values of geopolymer concrete samples with l/b ratio of 0.5

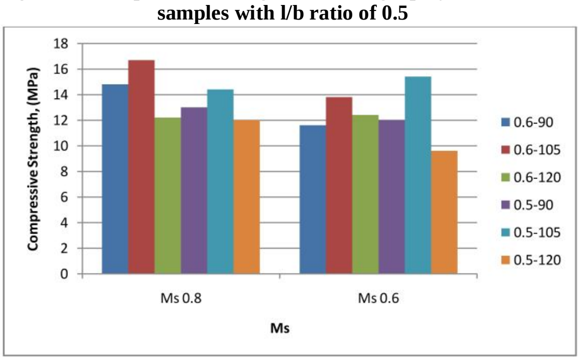

Fig 3. 28 days compressive strength values of geopolymer concrete samples cured at 105 °C

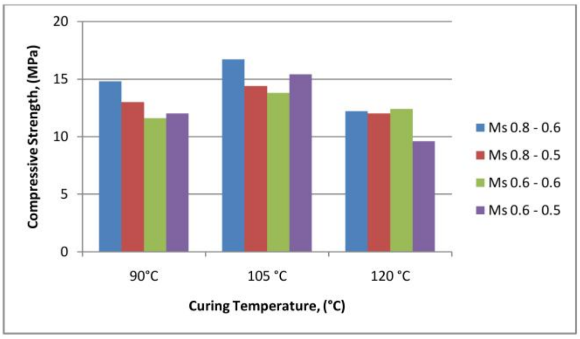

Fig. 4. Effect of curing temperature on 28 day compressive strength values of geopolymer concrete samples

CONCLUSIONS

The aim of this present research is to examine effect of silica modulus (Ms), curing temperature and liquid/binder ratio (l/b) on the compressive strength of geopolymer concrete samples produced from volcanic tuff. Experimental study results revealed the following results:

1. For the geopolymerization of the volcanic tuff raw material supplied from Nevşehir Region, optimum curing temperature and silica modulus (Ms) were determined 105°C and 0.8, respectively.
2. The decrease of Ms value from 0,8 to 0,6 resulted in 13% and 2% loss of compressive strength in geopolymer concrete with l/b values of 0,6 and 0,5 respectively.
3. For all samples, a significant portion of the final compressive strength was achieved at the end of the first three days of heat curing following production.

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