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FFECT OF POZOOLANIC MATERIALS ON COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

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ABSTRACT

The development that has occurred in industries and technologies after the Industrial Renaissance and beyond has led to consume a large amount of raw materials. The huge consumption of these materials is hard to be compensated. Therefore, it is necessary to find materials that can be recycled and environmentally friendly materials. Hence, the idea of sustainability, which states, the ability to meet our current needs without compromising the ability of future generation to meet theirs. It has become an urgent to produce materials that called environmentally friendly or sustainable materials.

In the field of civil engineering, an important role has been played in producing of environmentally friendly concrete by using pozollanic materials. Using environmentally friendly concrete instead of traditional concrete can participate in reducing the effect of global warming. In this research, local materials like metakaolin and pozollanic materials such as, fly ash and grand granulated blast furnace slag GGBFS were used in the production of an environmentally friendly concrete which they are called Geopolymer concrete. The effect of pozzolanic material type and mixing ratios on compressive strength at 7, 28 and 60 days were studied.

KEYWORDS: Sustainable, Geopolymer, Fly ash, Metakaolin, GGBFS.

1. INTRODUCTION

Concrete is an essential building material which it is commonly used in the construction of infrastructures such as buildings, bridges, highways, dams, and many other facilities (Sumajouw et al., 2006) . Cement is usually used as a bonding agent in all types of concrete. Cement production requires a large amount of energy to be consumed. Furthermore, production of cement emits a carbon dioxide into the atmosphere which it is considered as the main contribution to greenhouse gases (GHG). For example, producing a kilogram of cement emits about 0.66 to 0.82 kg of carbon dioxide (CO_2) (Louise and Frank, 2013). Therefore, production of cement must meet the requirements of global sustainability because it causes a consumption of a considerable amount of raw materials and energy, GHG emission, and polluting the air with dust (Zhang et al., 2014). For these reasons, it is necessary to use environmentally friendly cement-free concrete, which it is called "Geopolymer Concrete". (Duxson et al., 2007). Geopolymer concrete reduces the emission of CO_2 up to 80% (Davidovites, 1994, Gartner, 2004). Consequently, using geopolymer concrete in infrastructure can reduce the effect of global warming.

The term "Geopolymer" coined by Davidovits to represent these binders. The polymerization process is a fast chemical reaction between alkali liquid and pozzolanic materials, which produces two or three-dimensional chain of polymer with a ring structure of Si-O-Al-O bonds (Davidovits, 1994, Davidovits, 1999).

The content of alumina in pozzolanic material has a major role in controlling the setting time of the Geopolymer concrete but it decreases the resistance of concrete. It is observed that increasing the percent of Al leads to increase the setting time. It is also found that increasing the Si/Al ratio to a certain amount is responsible for increasing the resistance to compression (Silva et al., 2007). The ratios of Si/Al and Na/Al influence the mechanical properties of metakaolin based geopolymer. Increasing Si/Al ratio in pozzolanic material leads to increasing the compressive strength due to the formation of the strong chain Si-O-Si. It is noted that the existence of Na/Al within the reactions of the geopolymer improves the mechanical properties. However, the Na/Al ratio must not exceed 1. This is because after this ratio Na ion is accessed and resulted in decreasing the compressive strength (Najet et al., 2013).

The curing time has a great influence on the physical and mechanical properties of geopolymer concrete. Many research papers showed that increasing the curing temperature improves the compressive stress. For example, Rovnaník, 2010 showed that the compressive strength of some types of Geopolymer concretes increase with curing temperature up to 100°C. Other researchers reported that the compressive strength enhanced at curing temperature up to 90°C (Duxson et al., 2007). Beyond this temperature (100 or 90°C), the compressive strength tends to decrease. This can be attributed to the rapid loss of moisture from the geopolymer which it causes occurring of cracks and voids inside the structure. Emergence of defects inside structure reduces the compressive strength (Okoye et al., 2015).

The objective of this paper is to make a comparison among the three types of geopolymer concrete and to investigate the effect of mixing proportions on the compressive strength.

2. MATERIALS AND SPECIMENS

2.1. Source Materials

Three types of materials, namely, fly ash, Metakaolin, and GGBS (Table 1) are used in this work. The fly ash from power station Iskenderun in Turkey and local kaolin clay were used in this study. They were burnt at 700°C for an hour to change it to Metakaolin. GGBS is the by-product of iron, which collected from BASF Co.

2.2. Aggregate

Crushed gravel with (12.5mm) maximum size was used as a coarse aggregate. Natural graded sand was the fine aggregate according to ASTM C33 (ASTM, 2003), as shown in Tables 2 and 3.

Table 1. Oxide composition.

Oxides %	Fly ash	Metakaolin	GGBS
SiO_2	63.0	56.77	30.7
Al_2O_3	27.1	30.85	13.3
Fe_2O_3	4.12	2.48	0.35
CaO	1.20	0.58	42.4
MgO	0.74	0.59	6.89
Others	3.71	8.73	6.32
Specific surface area (m^2/kg)	778	17250	681

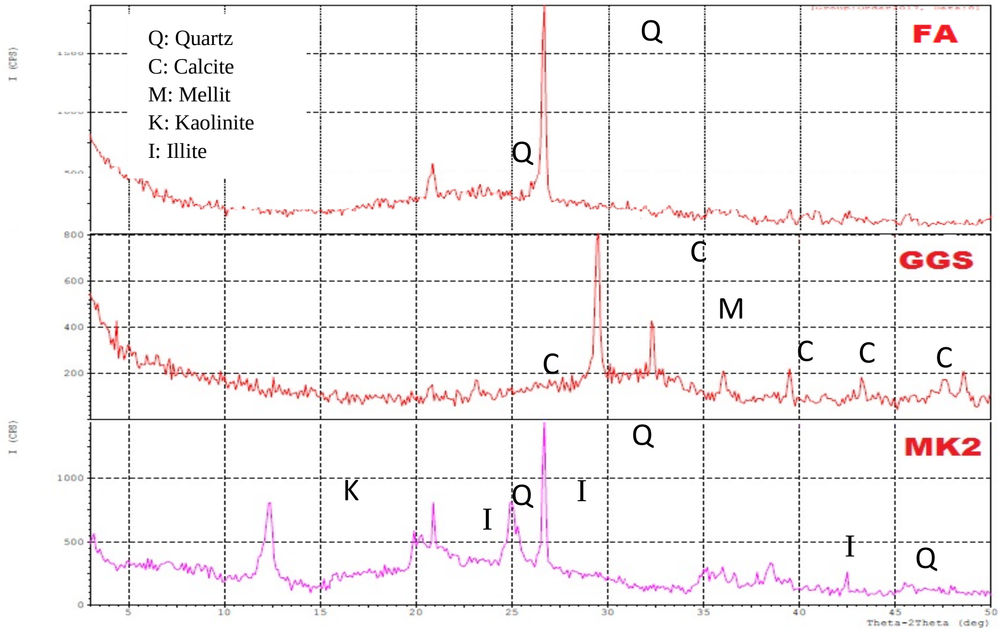

Fig. 1. XRD of three types of pozzolanic materials.

Table 2. Sieve analysis of coarse aggregate.

Sieve size (mm)	**Passing (%)**	**Requirements gradation ASTM C-33**
19	100	100
12.5	98.5	90-100
9.5	63.9	40-70
4.75	2.7	0 – 15
2.36	0.2	0 – 5
Percentage materials less than 75 micron	0.66	1 % upper limit

2.3. Combined Alkaline Liquid

The alkaline liquid was obtained by blending sodium silicate and sodium hydroxide solutions. Industrial type of sodium silicate with a chemical composition of Na_2O = 13.5%, SiO_2 = 32.5%, and H_2O = 54%. The sodium hydroxide NaOH flakes with a purity of 97-98% were used. The sodium hydroxide solution was prepared by dissolving the NaOH flakes in water with different concentration as required.

2.4. High-Range Water Reducer

A high range of water reducer superplasticizer (KUT PLAST SP400) based on modified sulfonated naphthalene formaldehyde condensate was used to enhance the workability of geopolymer concrete.

Table 3. Sieve analysis of fine aggregate.

Sieve size (mm)	Passing (%)	Requirements gradation ASTM C-33
9.5	100	100
4.75	98.2	95 – 100
2.36	90.8	80 – 100
1.18	73.3	50 – 85
0.6	52.3	25 – 60
0.3	15.1	5 – 30
0.15	4.2	0 – 10
Percentage materials less than 75 micron	1.98	3% upper limit

3. MIX DESIGN

Five types of geopolymer concrete mixtures were implemented for each type of pozzolanic materials, as shown in Tables 4, 5, and 6.

Table 4. Mix proportion of Fly Ash based geopolymer concrete.

Materials (kg/m3)	F1 8M/400FA	F2 10M/400FA	F3 12M/400FA	F4 12M/500FA	F5 12M/300FA
Fly Ash	400	400	400	500	300
NaOH	19	23	26	32	19
Sodium Silicate	103	110	114	134	83
Water	54	50	47	57	36
Fine aggregate	650	650	650	650	650
Coarse aggregate	1200	1200	1200	1200	1200
S.P	12	12	12	12	12

Table 5. Mix proportion of Metakaolin based geopolymer concrete.

Materials (kg/m3)	MK1 8M/400MK	MK2 10M/400 MK	MK3 12M/400 MK	MK4 12M/500 MK	MK5 12M/300 MK
Metakaolin	400	400	400	500	300
NaOH	26	32	36	46	27
Sodium Silicate	200	200	200	250	150
Water	73	70	64	81	48
Fine aggregate	650	650	650	650	650
Coarse aggregate	1200	1200	1200	1200	1200
S.P	18	18	18	18	18

Table 6. Mix proportion of GGBS based geopolymer concrete.

Materials (kg/m^3)	GBS1 8M/400 GBS	GBS2 10M/400 GBS	GBS3 12M/400 GBS	GBS4 12M/500 GBS	GBS5 12M/300 GBS
GGBFS	400	400	400	500	300
NaOH	26	32	36	46	27
Sodium Silicate	150	150	150	185	120
Water	73	70	64	81	48
Fine aggregate	650	650	650	650	650
Coarse aggregate	1200	1200	1200	1200	1200
S.P	18	18	18	18	18

4. PREPARATION OF TEST SPECIMENS

The mixed materials were weighed and mixed in dry condition for 3-4 minutes. Then the alkaline solution, which is a combination of sodium hydroxide and sodium silicate, and the super-plasticizer was added to the dry mixture. The concrete placed in (100x100x100) mm steel molds and vibrated for two minutes on the vibration table to remove entrapped air. After casting, the molds placed in an oven for 16 hours. Then, the specimens removed from their molds. After that, they additionally cured in an oven for another 20 hours. Fly ash based geopolymer, GGBS based geopolymer cured in 65±5 °C (Alhifadhi, 2015, Ramani and

Chinnaraj, 2015), and the metakaolin based geopolymer cured in 45±5 °C (Al-Shathr et al., 2016). Finally, the specimens were taken out and allowed to cure at room temperature until the day of testing.

5. RESULTS

The compressive strength of geopolymer concrete obtained from the test after 7, 28, and 60 days are shown in Table 7 and Fig. 2.

Table 7. Compressive strength of mixes.

Mix type	**Compressive strength (MPa)**		
	7 days	28 days	60 days
F1	44.73	59.4	65.27
F2	43.14	66.20	67.12
F3	37.11	46.59	52.12
F4	40.94	57.72	60.25
F5	38.77	55.20	57.09
MK1	22.70	35.44	36.10
MK2	19.77	28.44	29.78
MK3	15.32	18.55	22.67
MK4	17.79	24.31	26.93
MK5	24.95	34.44	37.19
GBS1	40.00	52.66	51.96
GBS2	34.23	41.09	45.12
GBS3	32.41	39.72	40.21
GBS4	28.65	30.16	36.08
GBS5	39.17	47.21	48.81

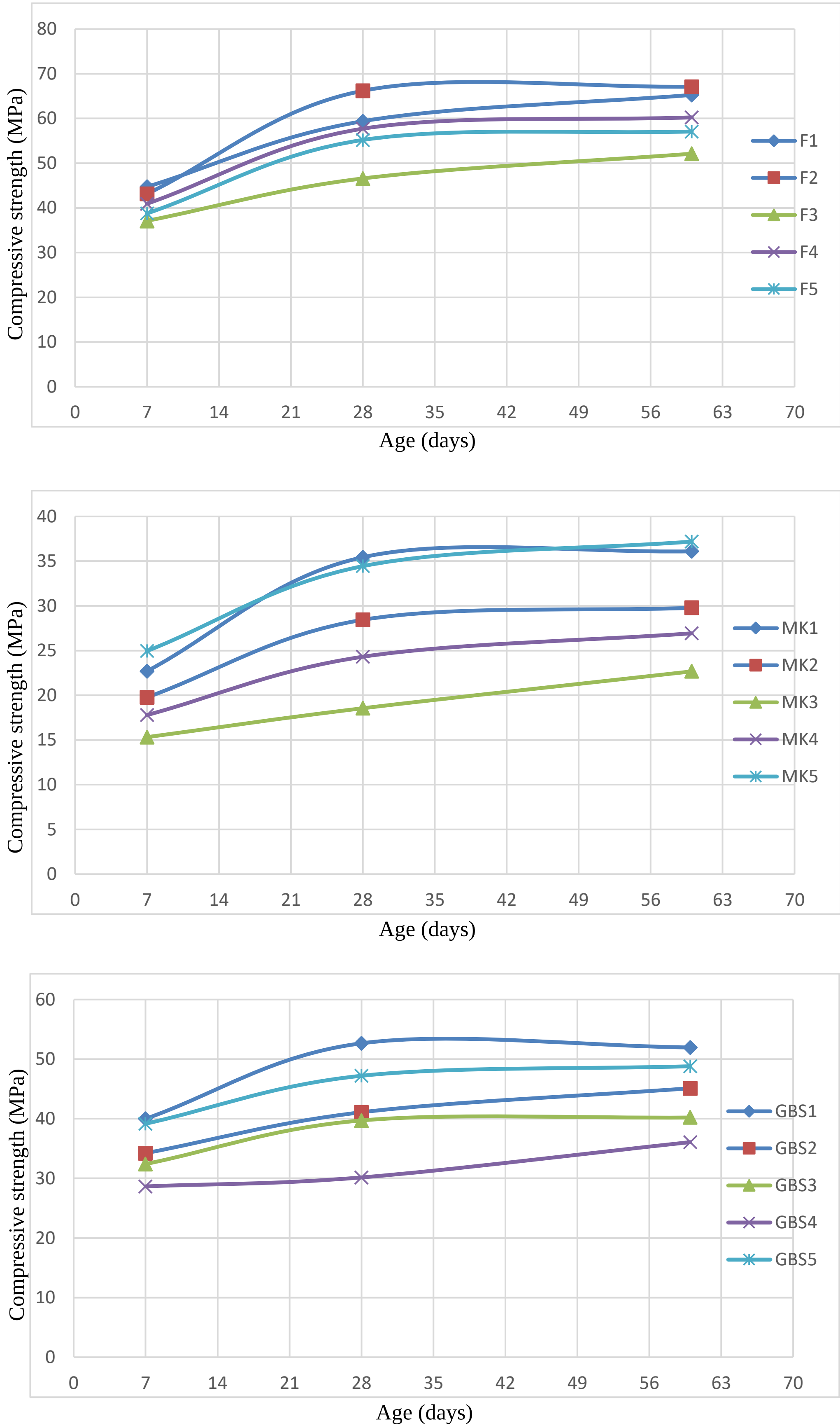

Fig. 2. Compressive strength of geopolymer concrete.

6. DISCUSSION

The compressive strength of concrete is a very important property of concrete. In this work, only geopolymer concrete cubes used for testing compressive strength. From the test results, it was observed that the compressive strength of the specimens tested for 7, 28 and 60 days to determine their early age. It was noted that the test performed after 7 days is about 65% for fly ash and metakaolin based geopolymer and about 78%, for GGBS based geopolymer.

In the geopolymer concrete, there are several factors that affect the compressive strength. These factors include the molarity of the alkali liquid, the ratio of the pozzolanic material, the percentage of amorphous silica and alumina found in the pozzolanic material, and the curing temperature

Increasing the proportion of molarity to a certain amount within the allowed ratio of pozzolanic lead to reduced compression resistance.

The relationship between the pozzolanic material and alkaline liquid is similar to the ratio of water to cement in the conventional concrete. Increasing the proportion of water in cement leads to decrease the compressive strength.

As for geopolymer concrete, increasing the percentage of molarity to a certain ratio leads to the reaction of most silica and alumina and the survival of a percentage of alkaline liquid, which it leads to a decrease in the resistance ratio as noted in the mixture No. 3 of each type of geopolymer concrete.

The increase in the ratio of pozzolanic material and its effect on compressive strength depends on the chemical analysis of the material and the ratio of amorphous silica and alumina (Silva et al., 2007, Najet et al., 2013). The process of polymerization between the alkaline liquid and pozzolanic material only obtained with the amorphous materials found therein (silica and alumina). From the obtained results, it was noted that the percentage of silica and alumina in the fly ash is more than the metakaolin and the GGBS, at the same time, most of them are amorphous materials, so increasing the ratio of fly ash does not increase the compressive strength. In a mixture of metakaolin, the silica and alumina in which there is a large proportion of crystallized so that increasing the proportion of metakaolin in the mixtures cause an increase in the proportion of amorphous materials and therefore seen an increase in the resistance of compression by increasing the proportion of the metakaolin.

As for the GGBS mix, the silica in the material is amorphous (as evident from the absence of quartz in the analysis of XRD), and the presence of CaO in the chemical composition of the material has a significant role in the development of resistance. The higher content of CaO thought to be the additional causes that lead to the strength improvement. The formation of calcium silicate, calcium aluminate hydrates (Davidovites, 1994), and calcium–silico–aluminates (Fernandez-Jimenez, 2006) is possible, and in many cases, the high early strengths reached with blended geopolymeric cements contributes to the consistence of these components. Therefore, increasing the proportion of the substance in the mixture increases the CaO ratio and increases compressive strength.

7. CONCLUSION

- The resistance of the geopolymer concrete reaches to 65-70% for the fly ash and metakaolin, and up to 80% for the GGBS.
- Increasing the alkali solution while maintaining the ratio of the pozzolanic material in the mixture leads to a decrease in resistance.
- Increasing the amorphous silica and alumina in pozzolanic material increases the compressive strength of the geopolymer concrete.
- The presence of CaO in slag (GGBS) has a significant role in increasing the compressive strength of the geopolymer concrete.

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