Effect of Crashed Stone on Properties of Fly Ash Based-Geopolymer Concrete with Local Alkaline Activator in Egypt

O. M. Omar, G. D. Abd Elhameed, A. M. Heniegal H. A. Mohamadien

***Abstract*—**Green concrete are generally composed of recycling materials as hundred or partial percent substitutes for aggregate, cement, and admixture in concrete. To reduce greenhouse gas emissions, efforts are needed to develop environmentally friendly construction materials. Using of fly ash based geopolymer as an alternative binder can help reduce CO_2 emission of concrete. The binder of geopolymer concrete is different from the ordinary Portland cement concrete. Geopolymer Concrete specimens were prepared with different concentration of NaOH solution M10, M14, and, M16 and cured at 60ºC in duration of 24 hours and 8 hours, in addition to the curing in direct sunlight. Thus, it is necessary to study the effects of the geopolymer binder on the behavior of concrete. Concrete is made by using geopolymer technology is environmental friendly and could be considered as part of the sustainable development. In this study, the Local Alkaline Activator in Egypt and crashed stone as coarse aggregate in fly ash based-geopolymer concrete was investigated. This paper illustrates the development of mechanical properties. Since the gained compressive strength for geopolymer concrete at 28 days was in the range of 22.5MPa – 43.9MPa.

***Keywords*—**Geopolymer, molarity, sodium hydroxide, sodium silicate.

I. Introduction

IN recent years, green concrete has seriously drawn researchers and investigators attention in the light of the concept thinking environmentally thinking and investigators because a concept of thinking environment "Environmentally friendly" [1]. The contribution of ordinary Portland cement production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth's atmosphere. To keep the global environment safe from consequences of cement production, it is essential to explore the alternative materials that can completely or partially eliminate the use of cement in concrete and cause no environmental destruction [2].

In 1978, Davidovits introduced the word 'geopolymer' to describe an alternative cementitious material, which has ceramic-like properties. As opposed to ordinary Portland cement, the manufacture of fly ash-based geopolymer does not consume high levels of energy, as fly ash is already an industrial by-product. This geopolymer technology has the potential to reduce emissions by 80% [3].

Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. As a result, the chemical reaction that takes place in this case is a polymerization process, he coined the term "Geopolymer" to represent these binders. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds [4]. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide KOH and sodium silicate or potassium silicate [4].

II. Research Program

This experimental study program was designed to achieve the research objectives of the study. The program consists of two phases; phase I with fly ash based geopolymer concrete in fly ash content 350 kg/m3. One mix was controlled (normal concrete mix) with Portland cement. Furthermore, the effect of the different content of sodium hydroxide or sodium silicate on the properties of concrete mixes was studied and the most suitable mixes to be considered concrete were chosen. Phase II, the above experiment is repeated with the same components but with different content of fly ash and cement. This content is 450 kg/m3. The fresh properties of green concrete containing fly ash based-geopolymer concrete were measured in terms of consistency by (traditional slump cone test), compacting factor using test of compaction factor apparatus, and air content according to ASTM C231 Air content, pressure method. The mechanical properties of green

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concrete containing fly ash based-geopolymer concrete were measured in terms of compressive strength for all mixes at Several cases curing at 3,7,and 28 days. The following properties were measured on the chosen mixes: indirect tensile strength at 28 days, flexural strengths at 28 days, static modulus of elasticity test at 28 days, sorptivity test at 56 days, water absorption test, apparent volume of permeable voids test and heat resistance test at 200ºC and 500ºC for 1 hour, for all the selected mixes.

III. Materials Properties

Test specimens were prepared from available materials which complying with Egyptian Code No. 203-2008 [5]. These include natural siliceous sand from Suez area, clean and rounded fine aggregate with size 0.15 to 5 mm was used. Physical properties of fine aggregate as shown in Table I. Coarse aggregates used in this research were crushed stone aggregate from (Attaka Quarries, EL Suez area), according to the requirement of ESS 1109/2002 [6]. Two sizes of coarse aggregate as 10 mm by percentage 50 %, and 14 mm by percentage 50% was used, Physical and mechanical properties of crashed stone aggregate, as shown in Table II. CEMI 42.5N was used from Suez Cement Company, Physical properties of ordinary Portland cement, as shown in Table III. Sodium silicate solution "S.S.S.," obtained from Egypt Global Silicates Company was also used, the chemical and physical properties of the sodium silicate solution as shown in Table IV. Sodium hydroxide solution "S.H.S.," analytical grade sodium hydroxide in flake form "NaOH with 98-99% purity", from. The fly ash used in this research is classified as class F fly ash according to the requirement of ASTM C618 Class F [7]. Its physical properties and XRF analysis are given in as Tables V and VI, respectively.

TABLE I
Physical Properties of Fine Aggregate

Property	Results	Limits
Specific Weight	2.63	2.5-2.75 **
Bulk Density (t/m^3)	1.78	-----
Fineness Modulus	2.89	-----
Clay and Fine Dust Content (% By Volume)	0.85	Not more Than 3 **

** Egyptian Code No. 203-2008 [5].

IV. Mixing, Molding, and Curing

Table VII represents the mix proportions of the tested mixes by weigh quantities for phase I and phase II for geopolymer concrete. Mixing was done in a standard drum-type mixer.

The preparation of chemicals and the mixing of fly ash based-geopolymer concrete involves two alkaline products, one of which "sodium hydroxide" is classified as a corrosive product which has the potential to seriously burn eyes, skin and internal organ, therefore special care has been taken during handling and working with the substance. These precautions included using a fume cabinet during the preparation of the sodium hydroxide solution and the mixing of mortar specimens, using high-density polyethylene container for storage, and wearing rubber gloves and goggle when handling the chemical and wet mix [8].

TABLE II
Physical and Mechanical Properties of Crashed stone Aggregate

Property	Results	% Limits
Specific Weight	2.65	-----
Bulk Density (t/m^3)	1.65	-----
Water Absorption %	2.05	Not more than 2.5**
Clay and Fine Dust Content %	0.92	Not more than 4*
Flakiness Index %	21.5	Not more than 25**
Crushing Coefficient %	22.00	Not more than 30%*
Elongation Index %	10.3	Not more than 25**
Abrasion Index (loss Anglos apparatus) %	18.4	Not more than 30**
Impact Value %	11.63	Not more than 45**

**Limits of ECCS 203-2008 [5].
*Limits of ESS 1109/2002 [6].

TABLE III
Physical Properties of Ordinary Portland Cement

Property		Results	Specifications Limits*
Compressive Strength of Standard Mortar (Mpa)	3 days	21.4	Not less than 18
	28 days	39.7	Not less than 36
Fineness in terms of S.S.A** (cm^2/gm)		3185	>2750
Setting Time (min)	Initial	75	Not less than 45
	Final	480	Not more than 600

*Limits of ECCS 203-2008 [5].

TABLE IV
Chemical and Physical Properties of Sodium Silicate Solution

Product Name	Data
SiO2/Na2O ratio	2.00
%Na2O	14.70
%SiO2	29.70
% Total solid	44.40
% Water content	55.55
% Water insoluble	0.05
Baume	50
Specific gravity at (20°C) g/cm3	1.526
Color and appearance	Clear white liquid
PH	12.7

TABLE V
Physical Properties of the Used Fly Ash

Property	Test Results
Specific surface area (cm^2/gm)	3950
Bulk density (kg/m^3)	1250
Specific gravity	2.5
Color	Light gray

TABLE VI
XRF Analysis for the used fly ash

Oxide	Content %	Limitation % *
SiO_2	61.30	
Al_2O_3	29.40	Min. 70%
Fe_2O_3	3.27	
CaO	1.21	-----
MgO	0.75	-----
K_2O	1.20	-----
SO_3	0.003	Max. 3%
TiO_2	0.01	-----
Na_2O	0.73	Max. 1.5%
Cl	0.04	Max. 0.05%
LOI	0.67	Max. 6%

* According to the requirement of ASTM C618 Class F [6].

The mixing for all specimens was undertaken using manual mixing as following:

1- Added fly ash to sand then mixed for dry materials about 2 minutes.
2- Sodium hydroxide and sodium silicate added to dry materials with good mixing for 5 minutes.
3- Add the required water and mixing for 3 minutes again.
4- The mixtures were then placed in 10 cm cubic molds and compacted manually. The surface of the samples were covered with plastic bags before placing in the oven to prevent rapid evaporation of liquids at different temperatures. Duplicate sets of specimens were then subjected to three curing regimes, the first curing at Heat of direct sunlight, second curing at 60°C even 8 hours in oven curing, and another one at 60°C even curing for 24 hours.
5- After that, all specimens were stored in room temperature prior to testing.

V. Details of Specimen

Compression test at 3, 7, 28, and 91 days was carried out on 100*100*100 mm cubes. Splitting test at 28 days was carried out on 150*300 mm cylinder [5]. Flexural strength test at 28 days was carried out on 100*100*500 mm prisms [5]. Static modulus of elasticity at 28 days was carried out on 150*300 mm cylinder [5]. Heat resistance test at 56 days, was carried out on 100*100*100 mm cubes. Sorptivity test at 56 days was carried out on 100*50 mm cylinder, and Water Absorption and Apparent Volume of Permeable Voids test at 56 days, was carried out on 100*50 mm cylinder, for all mixes, for cement and geopolymer concrete.

VI. Results and Discussions

A. Properties of Fresh of Cement Concrete and Geopolymer Concrete

Concrete slump, compacting factor, air content, were measured in accordance to the Egyptian Code No. 203-2008 [5].

The geopolymer concrete in fresh state observed to be highly viscous and good in workable. The investigation values obtained revealed that the geopolymer concrete is highly viscous and workable. However, the slump was 140 mm for mix containing M16 to, 175 mm for mix containing M10. From Table VIII, it can be observed that the molarity (M) increase the slump value decrease about 20%, and it can be observed that the slump value decrease with increasing in ratio of sodium silicate solution to sodium hydroxide solution.

The value of compacting factor about 0.88 for mix containing M16 to 0.95 for mix containing M10, as shown in Table VIII, it can be seen from Table VIII that the compacting factor increased as the content of molarity M decreased.

The color of the geopolymer concrete is dark similar to that of the OPC concrete.

TABLE VII
THE MIX PROPORTIONS OF THE TESTED MIXES BY WEIGH QUANTITIES FOR CEMENT AND GEOPOLYMER CONCRETE

Mix NO:	Mix ID:	FA (kg)	cement (kg)	Total Aggregate (kg)		Alkaline Liquid (kg)	
				F.A	C.A	SSS	SHS
1	D.OPC.350	0	350	784	1176	0	0
2	D.OPC.450	0	450	702	1054	0	0
3	D.M10-350-1:1	350	0	777	1167	88.39	88.39
4	D.M10-350-1:2	350	0	777	1167	118.09	59.22
5	D.M10-350-1:3	350	0	777	1167	133.18	44.39
6	D.M14-350-1:1	350	0	777	1167	88.39	88.39
7	D.M14-350-1:2	350	0	777	1167	118.09	59.22
8	D.M14-350-1:3	350	0	777	1167	133.18	44.39
9	D.M16-350-1:1	350	0	777	1167	88.39	88.39
10	D.M16-350-1:2	350	0	777	1167	118.09	59.22
11	D.M16-350-1:3	350	0	777	1167	133.18	44.39
12	D.M10-450-1:1	450	0	700	1051	112.58	112.58
13	D.M10-450-1:2	450	0	700	1051	150.52	75.48
14	D.M10-450-1:3	450	0	700	1051	169.83	56.61
15	D.M14-450-1:1	450	0	700	1051	112.58	112.58
16	D.M14-450-1:2	450	0	700	1051	150.52	75.48
17	D.M14-450-1:3	450	0	700	1051	169.83	56.61
18	D.M16-450-1:1	450	0	700	1051	112.58	112.58
19	D.M16-450-1:2	450	0	700	1051	150.52	75.48
20	D.M16-450-1:3	450	0	700	1051	169.83	56.61

D = Crashed stone , M = molarity, SHS = sodium hydroxide solution, SSS = sodium silicate solution, FA = fly ash, OPC = ordinary Portland cement.

During the mixing of concrete, layers of air are trapped between the in-folding surfaces of paste. These layers are broken up quickly and dispersed as bubbles collide and tend to coalesce in the presence of agitation. Coalescence is a natural tendency for air bubbles because it is accompanied by a reduction of interfacial area and pressure within the bubbles; thus a reduction in the energy of the system results. From Table VIII it can be seen that the air content decreased about 8%, as the content of molarity M increased, from M10 to M16 in fly ash content 350 kg/m^3.

B. Properties of Hardened of Cement Concrete and Geopolymer Concrete

1. Effect of Cement Content

The compressive strength was studied at 3, 7, 28, and 90 days. From Table IX and Fig. 1, the effect of the cement content on the compressive strength of similar mixes can be seen. According to these results, the compressive strength of mix containing cement content of 450 kg/m^3 is higher than the strength of mix prepared with 350 kg/m^3. The increase in the cement content resulted in an increase in the compressive strength of the normal concrete mixes as expected. About 34% strength gain was obtained when the cement content increased from 350 kg/m^3 to 450 kg/m^3 at 28 days, similar findings have been reported in earlier studies [1].

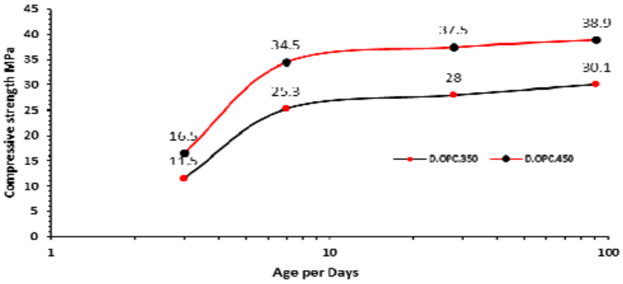

Fig. 1 Effect of cement content in mix control on the compressive strength, water curing

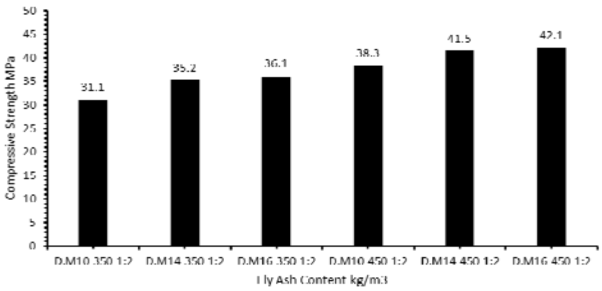

Fig. 2 Effect of fly ash content in the compressive strength of geopolymer concrete

TABLE VIII
PROPERTIES OF FRESH OF CEMENT CONCRETE AND GEOPOLYMER CONCRETE

Mix NO:	Mix ID:	(Water/ solid) ratio	slump (mm)	Compressive. Factor %	Air content %
1	D.OPC.350	0.5	109	91	4.7
2	D.OPC.450	0.5	90	92	4.5
3	D.M10-350-1:1	0.4	180	—	—
4	D.M10-350-1:2	0.35	175	95	5.1
5	D.M10-350-1:3	0.30	160	—	—
6	D.M14-350-1:1	0.4	160	—	—
7	D.M14-350-1:2	0.35	155	90	4.8
8	D.M14-350-1:3	0.30	140	—	—
9	D.M16-350-1:1	0.4	155	—	—
10	D.M16-350-1:2	0.35	150	88	4.7
11	D.M16-350-1:3	0.30	140	—	—
12	D.M10-450-1:1	0.4	170	—	—
13	D.M10-450-1:2	0.35	170	95	4.8
14	D.M10-450-1:3	0.30	160	—	—
15	D.M14-450-1:1	0.4	155	—	—
16	D.M14-450-1:2	0.35	165	91	4.5
17	D.M14-450-1:3	0.30	150	—	—
18	D.M16-450-1:1	0.4	165	—	—
19	D.M16-450-1:2	0.35	150	89	4.6
20	D.M16-450-1:3	0.30	145	—	—

D = Crashed stone, M = molarity, SHS = sodium hydroxide solution, SSS = sodium silicate solution, FA = fly ash, OPC = ordinary Portland cement.

2. Effect of Fly Ash Content in Geopolymer Concrete

The compressive strength was studied at 3, 7, 28, and 90 days. From Table IX and Fig. 2, the compressive strength of similar mixes can be seen. According to these results, the compressive strength of geopolymer concrete mix containing fly ash content of 450 kg/m^3 with M10, M14 and M16 is higher than the strength of mix prepared with 350 kg/m^3 with M10, M14 and M16.

The increase in the fly ash content resulted in an increase in the compressive strength of the geopolymer concrete mixes as expected. About 23%, 17%, and 16% strength gain was obtained when the fly ash content increased from 350 kg/m^3 to 450 kg/m^3 at 28 days, for mix containing molarity of sodium hydroxide solution M10, M14, and M16, respectively, with the ratio of sodium hydroxide to sodium silicate solution 1:2. In addition, the increase in the fly ash content resulted in an increase in the compressive strength of the geopolymer concrete mixes as expected.

3. Effect of Concentration NaOH on Compressive Strength

The ratio of alkaline liquid-to-fly ash, by mass, was not varied. This ratio remained approximately around 0.5. From Table IX and Mixtures 4, 7, and 10 Fig. 3, and mixtures 13, 16, and 19 Fig. 4, in fly ash content 350 kg/m^3 and 450 kg/m^3 respectively. It can be observed from Figs. 3 and 4. That the compressive strength of geopolymer concrete increased with increase in molarity of NaOH up to a value of 14 and on further increase of molarity of NaOH, the compressive strength slightly decreases.

Figs. 3 and 4 illustrate the effect of sodium hydroxide concentration on the compressive strength of geopolymer concrete. The test results shown in Figs. 3 and 4 demonstrate that the compressive strength of geopolymer concrete increases with the increase in the concentration of sodium hydroxide. Compressive strength of concrete specimens increases as sodium hydroxide concentration in the aqueous phase increases from M10 to M16; however, it slightly increases with the further increase in sodium hydroxide concentration from M14 to M16. However, there is variation in the strength between M10 and M14. It is accepted that an increase in alkali concentration enhanced geopolymerization process resulting to an increase in the compressive strength of geopolymer concrete. Their study indicated that when activator concentration increased above M16, a lower rate of polymer formation was produced resulting in the slightly decrease of mechanical strength. The obtained results are in agreement with the published literatures [9]-[11].

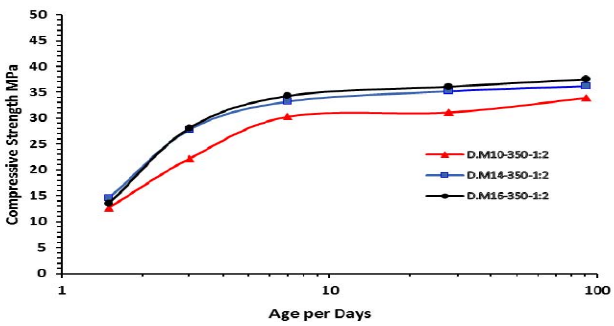

Fig. 3 Effect of molarity (M) of NaOH in compressive strength of geopolymer concrete, FA content 350kg/m3, 60ºC oven curing 24 hr

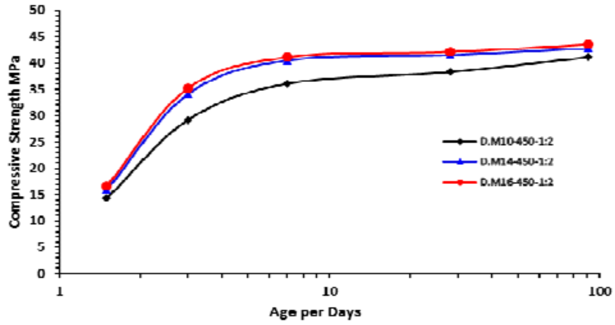

Fig. 4 Effect of molarity (M) of NaOH in compressive strength of geopolymer concrete, FA content 450kg/m3, 60ºC oven curing 24 hr

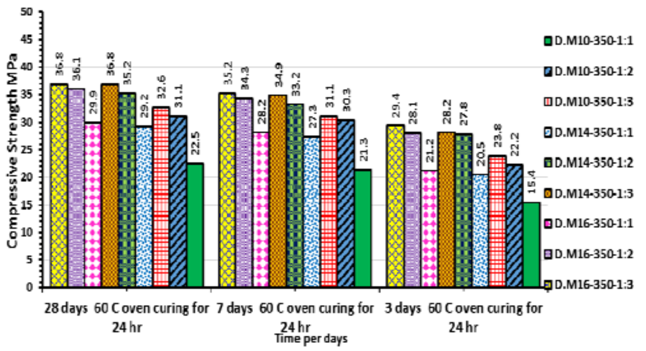

Fig. 5 Effect of sodium hydroxide solution to sodium silicate solution in compressive strength of geopolymer concrete, FA content 350 kg/m^3, at 60ºC oven curing 24 hr

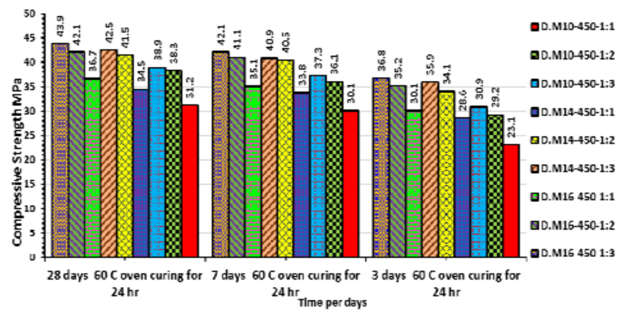

Fig. 6 Effect of sodium hydroxide solution to sodium silicate solution in compressive strength of geopolymer concrete, FA content 450 kg/m^3, at 60ºC oven curing 24 hr

4. Effect of Ratio of SSS to SHS on Compressive Strength of Geopolymer Concrete

The compressive strength was studied at 3, 7, 28, and 91 days. From Table IX and Fig. 5, the compressive strength of similar mixes can be seen. According to these results, the compressive strength of geopolymer concrete mix containing sodium silicate solution-to-sodium hydroxide solution ratio 1:3 with M10 is higher than the strength of mix prepared with sodium silicate solution-to-sodium hydroxide solution ratio 1:1, and 1:2 with M10, about 44%, and 4%, at 28 days, respectively. From this resulting, it can be observed that the big difference between the sodium silicate solution-to-sodium hydroxide solution ratio 1:1, and this difference is much lower than with sodium silicate solution-to-sodium hydroxide solution ratio 1:2. The same trend happened in the mix containing molarity M14, and M16 in the strength gain of compressive strength with the time.

From Figs. 5 and 6, it can be seen that the increase of sodium silicate solution to sodium hydroxide solution ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete up to a value of 2 and then it slightly increases at ratio 3 in some mixes. However, when the sodium silicate solution-to-sodium hydroxide solution ratio was 3, the strength started to slightly increase due to the difficulty in compaction. It should be noted here that sodium hydroxide cost less than sodium silicate and the mix should therefore contain low sodium silicate solution-to-sodium hydroxide solution ratio while still giving the required strength and workability. For that purpose has been selected mixtures that contain 1:2 ratio between sodium hydroxide solution and sodium silicate solution, respectively. Further, increase in compressive strength is mainly due to the change in microstructure of geopolymer, which was influenced by the quantity of sodium silicate [12].

5. Effect of Curing Condition on Compressive Strength of Geopolymer Concrete

From Table IX, Figs. 7 and 8 it can be seen that the comparison between the three types of curing condition for geopolymer concrete. Figures show that the maximum compressive strength can be obtained when the concrete is curing in the 60ºC for 24 hours about 42.1 Mpa, for mix containing 450 kg/m^3 fly ash, and molarity M14, with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and when oven curing for 8 hours at 60ºC decreased the compressive strength about 30% as the same mix. In addition, as the same time when curing of geopolymer concrete in the direct sunlight the compressive strength of geopolymer concrete dropped about 37%. The compressive strength of oven cured concrete is much higher than that of sunlight cured concrete. In sunlight curing, the compressive strength increases as the age of concrete increases from 3, 7, and 28 days.

6. Density of Cement and Geopolymer Concrete

Variations of density of geopolymer concrete 3, 7 and 28 days. Average of density of geopolymer concrete approximately 2186, 2190, and 2226 for mix containing 350 kg/m^3 fly ash, and molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, respectively. However, the mix containing 450 kg/m^3 fly ash, and molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, the average of density it was 2206, 2273, and 2310, respectively. From the Fig. 9, it can be observed that the unit weight of geopolymer concrete decreased about 5% and 6%, from OPC at the same content of cement 350 kg/m^3 and 450 kg/m^3, respectively. As the age of concrete increases, there is a slight decrease in density. Variation of density is not much significant with respect to age of concrete and curing conditions. The average density of fly ash based geopolymer concrete is similar to that of OPC concrete. Similar observations were reported by investigators earlier [13].

TABLE IX
The Mechanical Properties for Selected Mixes of Cement and Geopolymer Concrete

Mix NO:	Mix ID:	Compressive Strength Mpa					Curing condition
		1	3	7	28	90	
1	D.OPC.350	0	11.5	25.3	28	30.1	Water curing
2	D.OPC.450	0	16.5	34.5	37.5	38.9	Water curing
3	D.M10-350-1:1	0	15.4	21.3	22.5	0	oven curing at 60ºC for 24 hr
4	D.M10-350-1:2	12.7	22.2	30.3	31.1	33.9	oven curing at 60ºC for 24 hr
4	D.M10-350-1:2	0	8.1	13.8	17.3	0	oven curing at 60ºC for 8 hr
4	D.M10-350-1:2	0	7.5	11.2	14.3	0	Sun light curing
5	D.M10-350-1:3	0	23.8	31.1	32.6	0	oven curing at 60ºC for 24 hr
6	D.M14-350-1:1	0	20.5	27.3	29.2	0	oven curing at 60ºC for 24 hr
7	D.M14-350-1:2	14.6	27.8	33.2	35.2	36.2	oven curing at 60ºC for 24 hr
7	D.M14-350-1:2	0	14.3	19.6	24.1	0	oven curing at 60ºC for 8 hr
7	D.M14-350-1:2	0	10.5	17.5	22.6	0	Sun light curing
8	D.M14-350-1:3	0	28.2	34.9	36.8	0	oven curing at 60ºC for 24 hr
9	D.M16-350-1:1	0	21.2	28.2	29.9	0	oven curing at 60ºC for 24 hr
10	D.M16-350-1:2	13.5	28.1	34.3	36.1	37.5	oven curing at 60ºC for 24 hr
10	D.M16-350-1:2	0	13.5	19.2	24.8	0	oven curing at 60ºC for 8 hr
10	D.M16-350-1:2	0	12.7	18.2	22.3	0	Sun light curing
11	D.M16-350-1:3	0	29.4	35.2	36.8	0	oven curing at 60ºC for 24 hr
12	D.M10-450-1:1	0	23.1	30.1	31.2	0	oven curing at 60ºC for 24 hr
13	D.M10-450-1:2	14.3	29.2	36.1	38.3	41.1	oven curing at 60ºC for 24 hr
13	D.M10-450-1:2	0	16.2	22.4	25.1	0	oven curing at 60ºC for 8 hr
13	D.M10-450-1:2	0	15.1	20.4	23.2	0	Sun light curing
14	D.M10-450-1:3	0	30.9	37.3	38.9	0	oven curing at 60ºC for 24 hr
15	D.M14-450-1:1	0	28.6	33.8	34.5	0	oven curing at 60ºC for 24 hr
16	D.M14-450-1:2	15.9	34.1	40.5	41.5	42.8	oven curing at 60ºC for 24 hr
16	D.M14-450-1:2	0	18.5	23.5	28.5	0	oven curing at 60ºC for 8 hr
16	D.M14-450-1:2	0	16.1	20.2	25.1	0	Sun light curing
17	D.M14-450-1:3	0	35.9	40.9	42.5	0	oven curing at 60ºC for 24 hr
18	D.M16-450-1:1	0	30.1	35.1	36.7	0	oven curing at 60ºC for 24 hr
19	D.M16-450-1:2	16.6	35.2	41.1	42.1	43.5	oven curing at 60ºC for 24 hr
19	D.M16-450-1:2	0	20.4	24.6	29.2	0	oven curing at 60ºC for 8 hr
19	D.M16-450-1:2	0	17.1	22.2	26.3	0	Sun light curing
20	D.M16-450-1:3	0	36.8	42.1	43.9	0	oven curing at 60ºC for 24 hr

D = Crashed stone, M = molarity, SHS = sodium hydroxide solution, SSS = sodium silicate solution, FA = fly ash, OPC = ordinary Portland cement.

7. The Effect of (H2O)-to-(Na2O) on the Compressive Strength of Geopolymer Concrete

For calculation the water content in the geopolymer concrete mix, the ratio of water (H_2O)-to-sodium oxide (Na_2O) was calculated in terms of molar ratio of the oxides. Note that both H_2O and Na_2O are identified in both the activator liquids used in this study. That is, the sodium silicate solution is a composed of H_2O, SiO_2 and Na_2O. In addition, the sodium hydroxide flake (NaOH), which was dissolved in water, can be expressed as $2NaOH \Longrightarrow Na_2O + H_2O$. In addition, the fly ash also contained a small trace of Na_2O.

For a given geopolymer mixture, the moles of H_2O and Na_2O from sodium silicate solution, sodium hydroxide solution, and fly ash can therefore be summed together and hence the molar ratio of H_2O-to-Na_2O can be calculated. In addition the adding extra water to mix. In general, it can be seen from Fig. 10 that the compressive strength is decreasing with increasing H_2O-to-Na_2O molar ratio. It can be seen from Fig. 11 that the compressive strength is decreasing with increasing Na_2O-to-SiO_2 molar ratio.

The effect of water content was also illustrated in Fig. 12 by plotting the compressive strength versus water-to-geopolymer solids ratio by mass. For a given geopolymer concrete, the total mass of water in the mixture is taken as the sum of the mass of water in the sodium silicate solution, the mass of water in the sodium hydroxide solution, and the mass of extra water, if any added to the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide flake, and the mass of sodium silicate solids (the mass of Na_2O and SiO_2 in sodium silicate solution). The test data shown in Fig. 12 demonstrate that the compressive strength of geopolymer concrete decreases as the ratio of water-to-geopolymer solids by mass increases. The test trends shown in Fig. 12 are somewhat analogous to the well-known effect of water-to-cement ratio on the compressive strength of OPC concrete. Similar findings have been reported in earlier studies [10].

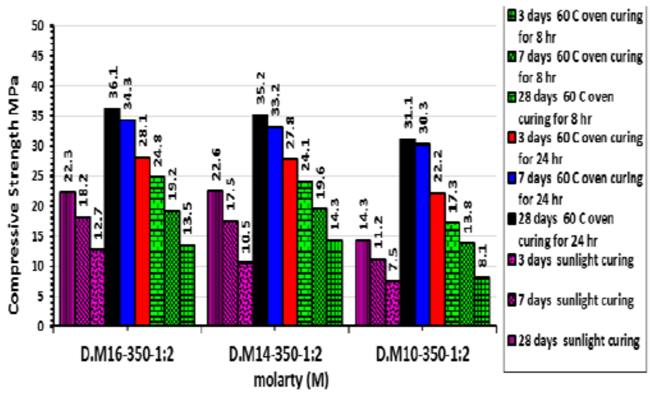

Fig. 7 Effect of curing conditions in the compressive strength of geopolymer concrete fly ash content 350 kg/m^3 at 28 days

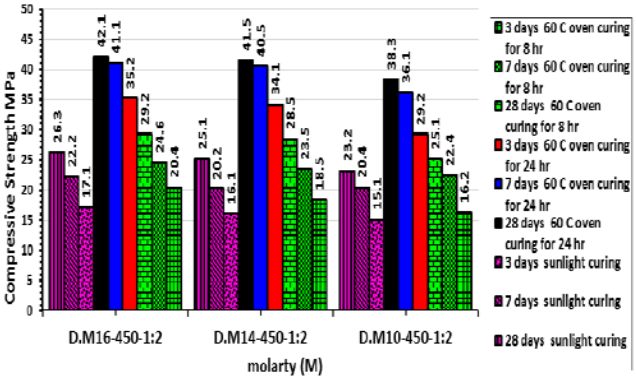

Fig. 8 Effect of curing conditions in the compressive strength of geopolymer concrete fly ash content 450 kg/m^3 at 28 days

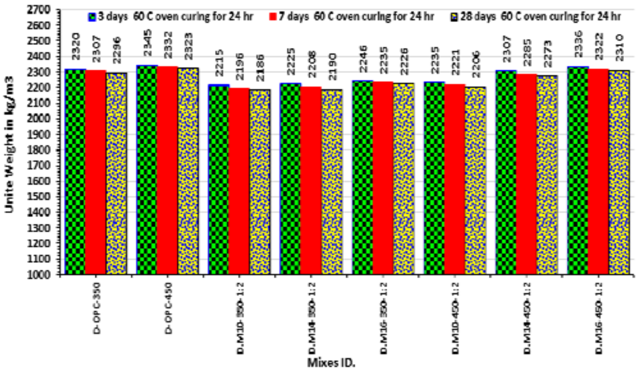

Fig. 9 Density of geopolymer concrete sodium silicate solution to sodium hydroxide solution 2, with crushed stone as coarse aggregate in geopolymer concrete and Molarity (M10, M14, M16)

8. Tensile Strength

Table X and Fig. 13 show the results of the splitting tensile strength for normal concrete specimens and geopolymar concrete specimens. The above experiment is being done on the concrete containing crushed stone as a coarse aggregate in geopolymer concrete. The splitting tensile strength of geopolymer concrete is compared with the splitting tensile strength of conventional concrete at same age.

Splitting tensile strength of geopolymer concrete with M14 at different contents from fly ash are presented in Fig. 13 and Table X. It can be observed that, the splitting tensile strength markedly increased with increasing in compressive strength at 28 days. The mix containing molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2 and 450 kg/m3 fly ash, the splitting tensile strength about 11.8%, 13.4%, and 14.4% from compressive strength at 28 days, as the same trend was happen in the mix containing 450 kg/m3 fly ash. From Table X, it can be observed that, the splitting tensile strength for OPC at 28 days about 8.5%, and 10.4% from compressive strength, for mix containing cement 350kg/m3, and 450 kg/m3, respectively. Generally, the test results are given in Table X. These test results show that the tensile splitting strength of geopolymer concrete is only a fraction of the compressive strength, as in the case of Portland cement concrete [14].

9. Flexural Strength

Table X and Fig. 14 show the results of the Flexural strength for OPC specimens in cement content 350kg/m3 and 450 kg/m3, respectively. Also, Table X and Fig. 14 show the results of the Flexural strength for geopolymer concrete specimens having molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2 and 350 kg/m3 fly ash. The above experiment of geopolymer concrete is being done on the fly ash content 450 kg/m3. Flexural strength of geopolymer concrete with molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, with 350 kg/m3, and 450kg/m3 fly ash, respectively, are presented in Fig. 14 and Table X. It can be observed that, the flexural strength markedly increased at fly ash content 450 kg/m3. Using molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and fly ash 350 kg/m3 increased the Flexural strength about, 18%, from compressive strength at the same age for geopolymer concrete. On the other hand using molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and fly ash 450 kg/m3 increased the Flexural strength about, 20%, from compressive strength at the same age for geopolymer concrete.

10. Static Modulus of Elasticity

Table X and Fig. 15, show that the results of modulus of elasticity of geopolymer concrete is increased with increasing the concentration of sodium hydroxide solution in 450 kg/m^3 fly ash content compared to geopolymer mix containing 350 kg/m^3 fly ash.

The limited gain of the modulus of elasticity in mix containing molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, with 450 kg/m3, fly ash were 4.3%, 4.6% and 3.8% as compared with mix containing molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, with 350 kg/m3, fly ash, respectively. On the other hand, the limited gain of the modulus of elasticity for geopolymer concrete was up to 22.9%, and 7.6% as compared with OPC mix in cement content 350 kg/m3, and 450 kg/m3, respectively.

11. Water Absorption and Apparent Volume of Permeable Voids

Table X and Fig. 16 show the results of water absorption and apparent volume of permeable voids for OPC specimens in cement content 350kg/m3 and 450 kg/m3, respectively. In addition, Table X and Fig. 16 show the results of the water absorption and apparent volume of permeable voids for geopolymer concrete specimens having molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2 and 350 kg/m3 fly ash. The above experiment of geopolymer concrete is being done on the fly ash content 450 kg/m3. Water absorption and apparent volume of permeable voids of the geopolymer concrete with molarity M10, M14, and M16, sodium hydroxide-to-sodium silicate solution ratio of 1:2 and fly ash content of 350 kg/m^3 and 450 kg/m^3, are presented in Fig. 16, Fig. 17 and Table X. It can be observed that the water absorption and apparent volume of permeable voids decreased at 450 kg/m^3 fly ash content.

Using molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and fly ash 450 kg/m3 decreased the water absorption about, 8%, 8.3%, and 15% from mix containing molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and fly ash 350 kg/m3 at the same age for geopolymer concrete. On the other hand using molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, and fly ash 350 kg/m3, and 450kg/m3 decreased the water absorption about, 33%, and 41.7% from OPC containing cement content 350 kg/m3, and 450 kg/m3, respectively. The same trend happened in the test result for apparent volume of permeable voids. It can be seen from Fig. 17 that the compressive strength of geopolymer concrete increase the apparent volume of permeable voids decrease.

12. Sorptivity

Sorptivity is a property associated with capillary effects. It is defined as the gradient of the volume of water absorbed per unit area of the surface and the square root of the absorption time. The movement of water into concrete is described by the classical square-root-time relationship. In this relationship, water absorption into porous materials increases as the square root of the elapsed time (t). Assuming a constant supply of water at the inflow surface, the following relationship holds [15]. Typical plots of cumulative sorptivity against the square root of time are shown in Fig. 18.

Fig. 18 represents the curve of cumulative mass gained per exposed surface area against square root of time where the slope of the linear portion is the measurement of sorptivity. It shows the value of sorptivity decrease for geopolymer concrete containing molarity M10, M14, and M16 with sodium silicate solution-to-sodium hydroxide solution ratio 1:2, with 450 kg/m3, from the same mixtures of geopolymer concrete, but in fly ash content 350 kg/m3. Furthermore, the concentration of NaOH increase in geopolymer concrete the pore area was non-permeable that up to molarity M16.

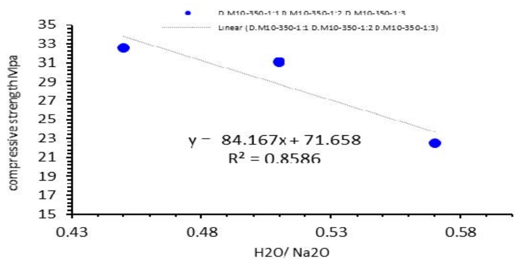

Fig. 10 Effect of water content in compressive strength of geopolymer concrete

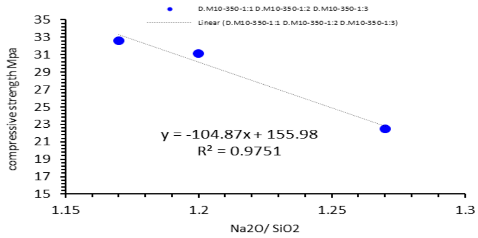

Fig. 11 Effect of Na_2O/SiO_2 ratio in compressive strength of geopolymer concrete

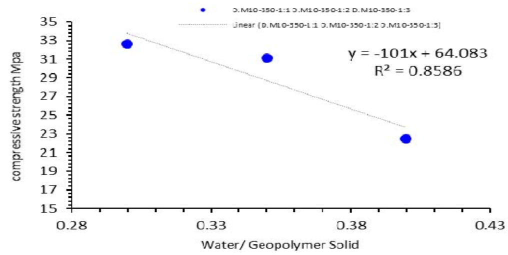

Fig. 12 Effect of water content to geopolymer solids in compressive strength of geopolymer concrete

13. Heat Resistance

The specimens were heated at a rate of 1ºC/min and then kept for 1 h at the peak exposure temperature to establish a stable temperature samples. This heating regime was identical to that previously reported for investigating the residual mechanical and dubility properties of fly ash concretes [16]. It can be seen from Fig. 19 when the concrete is exposed to elevated temperatures, loss in weight of specimen increases for temperatures above 200ºC. With decrease in strength of geopolymer concrete, there is an increase in the loss of weight of specimens due to exposure to elevated temperatures 200 ºC to 600 ºC. In general there are substantial losses of up to values ranging from 6% to 9% in strength, on heating the geopolymer concrete specimens up to 600 ºC, for mixes (D.M10-350-1:2), (D.M14-350-1:2), (D.M16-350-1:2), (D.M10-450-1:2), (D.M14-450-1:2), (D.M16-450-1:2). Also, for maxis (D-OPC-350), (D-OPC-450), there are higher strength losses up to values ranging from 54% to 66%.

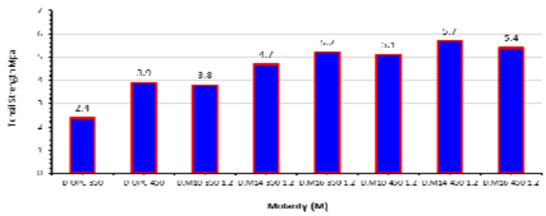

Fig. 13 Effect of Molarity (M10, M14and M16), in splitting tensile strength of geopolymer concrete, FA content 350 and 450kg/m^3

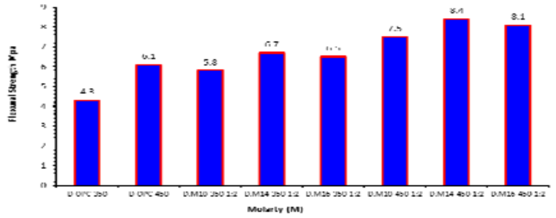

Fig. 14 Effect of Molarity M10, M14 and M16, in flexural strength of geopolymer concrete, FA content 350 and 450kg/m^3

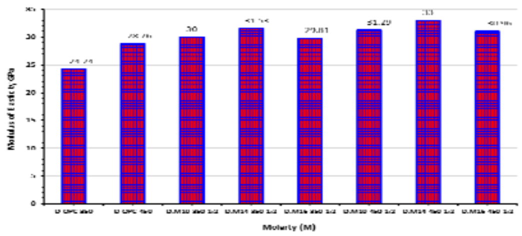

Fig. 15 Effect of Molarity M10, M14and M16, in modulus of elasticity of geopolymer concrete, FA content 350 kg/m^3 and 450kg/m^3 with Molarity M10, M14and M16

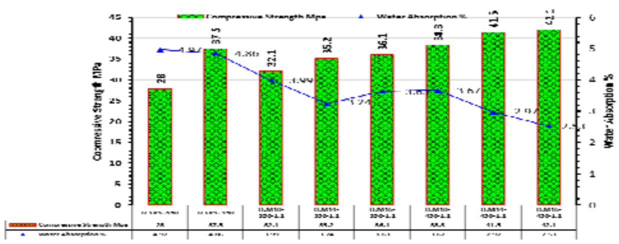

Fig. 16 The relationship between the compressive strength and water absorption %

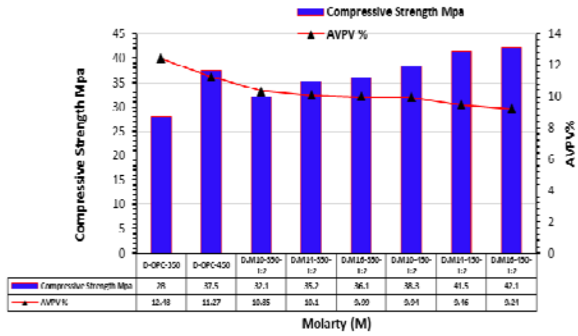

Fig. 17 The relationship between the compressive strength and apparent volume of permeable voids %

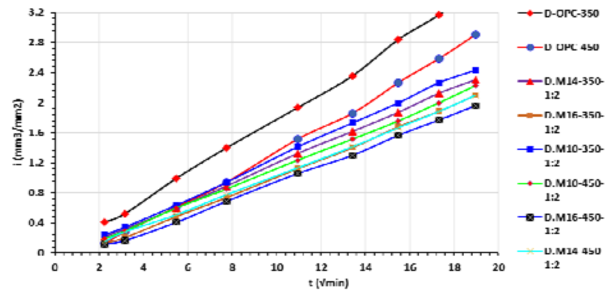

Fig. 18 Cumulative sorptivity per unit area with sqare root time for geopolymer concrete in fly ash continent 350 kg/m3, and 450 kg/m3, with different molarity M

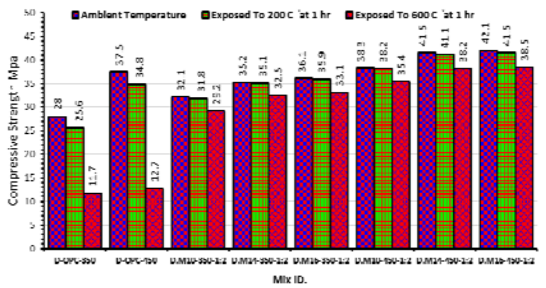

Fig. 19 Effect of elevated temperatures on the compressive strength of geopolymer concrete

TABLE X
MECHANICAL PROPERTIES FOR SELECTED MIXES OF GEOPOLYMER CONCRETE

Mix. NO:	Mix. ID	Compressive Strength Mpa	Tensile Strength Mpa	Flexural strength Mpa	Modulus of Elasticity GPa	fire effect at 200 C̊ at 1 hr on compressive strength Mpa	fire effect at 600 C̊ at 1 hr on compressive strength Mpa	loss of weight at 200 C at 1 hr (%)	loss of weight at 600 C at 1 hr (%)	Water Absorption %	AVPV %
		28 days	28 days	28 days	28 days	28 days	28 days				
1	D-OPC-350	28	2.4	4.3	24.24	25.6	11.7	4.8	11.3	4.97	12.43
2	D-OPC-450	37.5	3.9	6.1	28.76	34.8	12.7	4.3	11.1	4.86	11.27
4	D.M10-350-1:2	32.1	3.8	5.8	30	31.8	29.2	2.9	6.8	3.99	10.35
7	D.M14-350-1:2	35.2	4.7	6.7	31.53	35.1	32.5	2.6	6.6	3.24	10.1
10	D.M16-350-1:2	36.1	5.2	6.5	29.81	35.9	33.1	2.6	5.5	3.33	9.99
13	D.M10-450-1:2	38.3	5.1	7.5	31.29	38.2	35.4	2.5	6	3.67	9.94
16	D.M14-450-1:2	41.5	5.7	8.4	33	41.1	38.2	2.2	6.6	2.97	9.46
19	D.M16-450-1:2	42.1	5.4	8.1	30.96	41.5	38.5	2.3	5.9	2.83	9.24

D = Crashed stone, M = molarity, SHS = sodium hydroxide solution, SSS = sodium silicate solution, FA = fly ash, OPC = ordinary Portland cement.

VII. Conclusions

From the analysis and discussion of test results obtained from this research, the following conclusions can be drawn:

1- Use of fly ash based geopolymer as an alternative binder can help reduce CO2 emission of concrete, and the binder of geopolymer concrete (GPC) is different from that of ordinary Portland cement (OPC) concrete.

2- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geopolymer concrete. Furthermore, higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete. As well as enhancement the mechanical properties such as tensile strength, flexural strength, and modulus of elasticity.

3- As the curing temperature in the range upto 60ºC increases, the compressive strength of fly ash-based geopolymer concrete also increases.

4- As the H2O-to-Na2O molar ratio increases, the compressive strength of fly ash-based geopolymer concrete decreases. In addition, as the ratio of water-to-geopolymer solids by mass increases, the compressive strength of fly ash-based geopolymer concrete decreases.

5- The sorbativity, water absorption, and apparent volume of permeable voids of the hardened fly ash-based geopolymer concrete decreases with the increase of compressive strength of geopolymer concrete.

6- When the concrete is exposed to elevated temperatures, loss in compressive strength of geopolymer concrete specimen increases up to range from 6% to 9%.

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