

# Effect of Local Steel Slag as a Coarse Aggregate on Properties of Fly Ash Based-Geopolymer Concrete

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

**Abstract**—Local steel slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. Using local steel slag waste as a hundred substitutes of crashed stone in construction materials would resolve the environmental problems caused by the large-scale depletion of the natural sources of crashed stone. This paper reports the experimental study to investigate the influence of a hundred replacement of crashed stone as a coarse aggregate with local steel slag, on the fresh and hardened geopolymer concrete properties. The investigation includes traditional testing of hardening concrete, for selected mixes of cement and geopolymer concrete. It was found that local steel slag as a coarse aggregate enhanced the slump test of the fresh state of cement and geopolymer concretes. Nevertheless, the unit weight of concretes was affected. Meanwhile, the good performance was observed when fly ash used as geopolymer concrete based.

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

## I. INTRODUCTION

IN recent years, green concrete has draws serious attention of researchers 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 [2]. To keep the global environment safe from the consequence 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 [3].

Geopolymers are formed when various alumina and silica containing materials react under highly alkaline conditions and forms a three dimensional network of Si–O–Al–O bonds [4]. The most commonly used raw materials for geopolymer are clay and metakaolin [5]. Electric arc furnace steel slag is an industrial by-product obtained from the steel manufacturing industry during melting of steel scrap from the impurities and fluxing agents. Electric arc furnace steel slag is obtained by cooling the electric arc furnace steel liquid slag in air at production site [18]. The composition of slag varies upon the

type of furnace and charge, the desired grade of steel purity and the furnace operation conditions, [6]. Steel making process in electric arc furnaces generates up to 15% of slag per ton of steel, which is, based on its properties, classified as nonhazardous waste. Major components of steel mill slag include Ca-silicates, Ca-Al-ferrites, and molten oxides of calcium, iron, magnesium, and manganese, [7].

## II. GEOPOLYMERS

Davidovits [8] 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. Because the chemical reaction that takes place in this case is a polymerization process. 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.

Water is released during the chemical reaction that occurs in the formation of geopolymer. This water, expelled from the geopolymer matrix during the curing and further drying periods, leaves behind Nano-pores in the matrix, which provide benefits to the performance of geopolymer. 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 [5].

## III. RESEARCH PROGRAM

The experimental test 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/m<sup>3</sup>. One mix was control (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/m<sup>3</sup>. The chosen mixes was studied as hundred percent substitutes for coarse aggregate using local in cement and fly ash content 350 and 450 kg/m<sup>3</sup> respectively. The fresh properties of green concrete containing fly ash

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based-geopolymer concrete were measured in term of consistency by (traditional slump cone test), compacting factor using test of compaction factor apparatus, and air content according to ASTM C 231, Air content; pressure method [9]. The mechanical properties of green concrete containing fly ash based-geopolymer concrete were measured in term of compressive strength for all mixes at Several cases curing at 3,7, 28 and 91 days. As well as the following properties were measured on the all mixes: indirect tensile (splitting tensile) at 28 days, flexural strengths at 28 days, static modulus of elasticity test at 28 days, sorptivity test at 56 days, and Water Absorption and Apparent Volume of Permeable Voids (A.V.P.V.) test, for all mixes.

#### IV. MATERIALS PROPERTIES

Test specimens were prepared from available materials which complying with Egyptian Code No. 203-2008 [10]. These include natural siliceous sand from Suez area, clean and rounded fine aggregate with size 0.15 to 5 mm was used. Coarse aggregates used in this research were crashed stone aggregate from (*Attaka Quarries, EL Suez area*). Two sizes of coarse aggregate as 10 mm by percentage 50 %, and 14 mm by percentage 50 % was used. CEMI N42.5 was used from Suez Cement Company. The used local steel slag was obtained from Ezz steel industry factory in Suez. The local steel slag is obtained as a by-product during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in electrical arc furnaces. The chemical analyses of the used local steel slag as obtained from the manufacture (Table I).

TABLE I  
CHEMICAL ANALYSIS OF LOCAL STEEL SLAG AGGREGATES

Constituent	Composition %*
SiO <sub>2</sub>	13.10
Fe <sub>x</sub> O <sub>y</sub>	36.80
Al <sub>2</sub> O <sub>3</sub>	5.510
CaO	33.00
MgO	5.030
MnO	4.180
Cr <sub>2</sub> O <sub>3</sub>	0.775
P <sub>2</sub> O <sub>5</sub>	0.743
TiO <sub>2</sub>	0.598
V <sub>2</sub> O <sub>5</sub>	0.104
SO <sub>3</sub>	0.140

\* The data were obtained by the manufacturer data sheet.

The local steel slag was crashed to the size which is similar to the size of the natural coarse aggregate using a crusher in the laboratory. The physical and mechanical properties of the local steel slag coarse aggregate were determined (Table II).

Sodium silicate solution "S.S.S.," obtained from Egypt Global Silicates Company was also used, the chemical and physical properties of the "S.S.S." (Table III).

Sodium hydroxide was in flake form (NaOH with 98-99% purity). The fly ash used in this research is classified as class F fly ash according to the requirement of ASTM C618 Class F

[11]. Its physical properties and XRF analysis (Table IV) and (Table V), respectively.

TABLE II  
PHYSICAL AND MECHANICAL PROPERTIES OF LOCAL STEEL SLAG AGGREGATES

Property	Results	% Limits
Specific Weight	3.48	-----
Bulk Density (t/m <sup>3</sup> )	1.97	-----
Water Absorption %	1.0	Not more than 2.5**
Crushing Coefficient %	11.40	Not more than 30%*
Abrasion Index (loss Anglos apparatus) %	13.5	Not more than 30**

\*Limits of ESS 1109/2002 [12].

\*\*Limits of ECCS 203-2008 [11].

TABLE III  
CHEMICAL AND PHYSICAL PROPERTIES OF SODIUM SILICATE SOLUTION

Product Name	Data
SiO <sub>2</sub> /Na <sub>2</sub> O ratio	2.00
%Na <sub>2</sub> O	14.70
%SiO <sub>2</sub>	29.70
% Total solid	44.40
% Water content	55.55
% Water insoluble	0.05
Baume	50
Specific gravity at (20°C) g/cm <sup>3</sup>	1.526
Color and appearance	Clear white liquid
PH	12.7

TABLE IV  
PHYSICAL PROPERTIES OF THE USED FLY ASH

Property	Test Results
Specific surface area (cm <sup>2</sup> /gm)	3950
Bulk density (kg/m <sup>3</sup> )	1250
Specific gravity	2.5
color	Light gray

TABLE V  
XRF ANALYSIS FOR THE USED FLY ASH

Oxide	Content %	Limitation % *
SiO <sub>2</sub>	61.30	
Al <sub>2</sub> O <sub>3</sub>	29.40	Min. 70%
Fe <sub>2</sub> O <sub>3</sub>	3.27	
CaO	1.21	-----
MgO	0.75	-----
K <sub>2</sub> O	1.20	-----
SO <sub>3</sub>	0.003	Max. 3%
TiO <sub>2</sub>	0.01	-----
Na <sub>2</sub> O	0.73	Max. 1.5%
Cl	0.04	Max. 0.05%
LOI	0.67	Max. 6%

\* According to the ASTM C618 Class F [11].

#### V. MIXING, MOLDING, AND CURING

Table VI represents the mix proportions of the tested mixes by weighing 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 that 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 goggles when handling the chemical and wet mix [13].

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

1. Adding mixing fly ash to sand then mixed for dry materials about 2 minutes.
2. Sodium hydroxide and sodium silicate are added to dry materials with good mixing for 5 minutes.
3. Adding 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 was covered with plastic bags before placing in the oven to

prevent rapid evaporation of liquids at different temperatures. Duplicating sets of specimens were then subjected to heat curing at 60 °C even 24 hours in oven.

5. After that, all specimens were stored in room temperature prior to testing.

#### VII. DETAILS OF SPECIMEN

Compression test at 3, 7, 28, and 90 days was carried out on 100\*100\*100 mm cubes. Splitting test at 28 days was carried out on 150\*300 mm cylinder [11], [13]. Flexural strength test at 28 days was carried out on 100\*100\*500 mm prisms [11]. Static modulus of elasticity at 28 days was carried out on 150\*300 mm cylinder [11]. Water absorption test and apparent volume of permeable voids "A.V.P.V.," at 51 days was carried out on 100\*50 mm cylinder, sorptivity at 51 days was carried out on 100\*50 mm cylinder, for cement and geopolymer concrete.

TABLE VI

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)	
				Sand	D	S	SSS	SHS	(Water/solid) ratio %
1	D.OPC .350	0	350	784	1176	0	0	0	0.5
2	D.OPC .450	0	450	702	1054	0	0	0	0.5
3	S.OPC .350	0	350	784	0	1176	0	0	0.5
4	S.OPC .450	0	450	702	0	1054	0	0	0.5
5	D.M10-350-1:2	350	0	777	1167	0	118.09	59.22	0.35
6	D.M14-350-1:2	350	0	777	1167	0	118.09	59.22	0.35
7	D.M16-350-1:2	350	0	777	1167	0	118.09	59.22	0.35
8	D.M10-450-1:2	450	0	700	1051	0	150.52	75.48	0.35
9	D.M14-450-1:2	450	0	700	1051	0	150.52	75.48	0.35
10	D.M16-450-1:2	450	0	700	1051	0	150.52	75.48	0.35
11	S.M10-350-1:2	350	0	777	0	1167	118.09	59.22	0.35
12	S.M14-350-1:2	350	0	777	0	1167	118.09	59.22	0.35
13	S.M16-350-1:2	350	0	777	0	1167	118.09	59.22	0.35
14	S.M10-450-1:2	450	0	700	0	1051	150.52	75.48	0.35
15	S.M14-450-1:2	450	0	700	0	1051	150.52	75.48	0.35
16	S.M16-450-1:2	450	0	700	0	1051	150.52	75.48	0.35

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



Fig. 1 Fresh Fly Ash Geopolymer Concrete Ready for Placing

#### VIII. TEST RESULTS

##### A. Properties of Fresh Cement and Geopolymer Concrete

The fresh Properties were studied after mixing immediately. Concrete slump test, compacting factor, air content, were measured in accordance to the ESS 1658-1989 Part 2 [14], Egyptian Code No. 203-2008 [11], and. The geopolymer concrete in fresh state are observed to be highly viscous and very good at working.

The investigation outcomes revealed that the geopolymer concrete is highly viscous and workable. However, the slump was 155 mm for mix containing M16 to, 190 mm for mix containing M10. From Table VII, it can be observed that the concentration of sodium hydroxide solution increase the slump value decrease about 18%, Fig. 2.



Fig. 2 Slump Measurement of Fresh geopolymer Concrete



Fig. 3 Compaction Factor Measurement of Fresh Geopolymer Concrete



Fig. 4 Air content for fresh geopolymer concrete

TABLE VII  
RESULTING OF FRESH PROPERTIES FOR CEMENT AND GEOPOLYMER  
CONCRETE

Mix NO:	Mix ID:	Compressive Strength MPa	Compacting factor %	Add water (kg)	Slump (mm)	Air Content %
1	D.OPC.350	28	91	50	109	4.7
2	D.OPC.450	37.5	92	45	120	4.5
3	S.OPC.350	30.9	89	40	80	4.5
4	S.OPC.450	38.9	91	43	95	4.3
5	D.M10-350-1:2	31.1	95	54	175	5.1
6	D.M14-350-1:2	35.2	90	50	155	4.8
7	D.M16-350-1:2	36.1	88	44	150	4.7
8	D.M10-450-1:2	38.3	95	60	170	4.8
9	D.M14-450-1:2	41.5	91	58	165	4.5
10	D.M16-450-1:2	42.1	89	55	150	4.6
11	S.M10-350-1:2	39.8	82	63	180	3.8
12	S.M14-350-1:2	41.6	79	50	170	3.5
13	S.M16-350-1:2	42.8	80	33	165	3.4
14	S.M10-450-1:2	40.9	86	61	190	3.6
15	S.M14-450-1:2	43.8	83	58	175	3.3
16	S.M16-450-1:2	44.9	80	43	155	3.1

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

From Fig. 3 and Table VII it can be observed that the compacting factor increased with the slump value, this increasing may be related to the decreased of concentration of sodium hydroxide solution and increasing in water ratio in the mixtures. In addition, it can be seen from Table VII that the compacting factor increased as the content of added water in the mixtures increased similar findings have been reported in earlier studies [19]. The color of the geopolymer concrete is dark similar to that of the OPC concrete. The fresh fly ash-based geopolymer concrete was dark in color as shown in Fig. 1.

From Fig. 4 and Table VII, it can be seen that the air content decreased as the content of added water in the mixtures decreased. Also, the geopolymer concrete was stuck hard to the moulds so oiling the moulds are very important to release each cube specimen, while casting in three layers by compacting manually.

### B. Properties of Hardened of Cement and Geopolymer Concrete

#### 1. Effect of Cement Content and Local Steel Slag as a Coarse Aggregate in Cement Concrete

The compressive strength was studied at 3, 7, 28, and 91 days. Table VIII and Fig. 5 show the compressive strength of similar mixes. According to these results, the compressive strength of mixes containing 450 kg/m<sup>3</sup> cement content is higher than the strength of mix prepared with 350 kg/m<sup>3</sup>.

The increase in the cement content resulted in an increase in the compressive strength of the normal concrete mixes as expected. About 34% and 26% for crashed stone and local steel slag mix strength gain was obtained when the cement content increased from 350 kg/m<sup>3</sup> to 450 kg/m<sup>3</sup> at 28 days, respectively, similar findings have been reported in earlier studies [1]. Also, the mixes containing local steel slag as a coarse aggregate recorded that the compressive strength higher than about 10% and 4% for cement content 350 kg/m<sup>3</sup> and 450 kg/m<sup>3</sup> respectively, similar findings have been reported in earlier studies [15].

#### 2. Effect of Fly Ash Content in Geopolymer Concrete

The compressive strength was studied at 3, 7, 28, and 91 days. Table VIII and Fig. 6 show the compressive strength of similar mixes. According to these results, the compressive strength of geopolymer concrete mixes containing 450 kg/m<sup>3</sup> fly ash content with M10, M14 and M16 is higher than the strength of mix prepared with 350 kg/m<sup>3</sup> 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 19% strength gain was obtained when the fly ash content increased from 350 kg/m<sup>3</sup> to 450 kg/m<sup>3</sup> at 28 days, for mix containing molarity of sodium hydroxide solution M10, while keeping the ratio of sodium silicate solution constant 1:2, and the mixes containing crashed stone as a coarse aggregate. In addition, the increase in the fly ash content resulted in an increase in the compressive strength of the geopolymer concrete mixes as expected. About 17% and

16% strength gain was obtained when the fly ash content increased from 350 kg/m<sup>3</sup> to 450 kg/m<sup>3</sup> at 28 days, for mix containing molarity of sodium hydroxide solution M14 and M16, respectively.

TABLE VIII  
THE MIXTURES RESULTING IN COMPRESSIVE STRENGTH FOR CEMENT AND GEOPOLYMER CONCRETE

Mix NO:	Mix ID:	Compressive Strength Mpa				Curing
		3 days	7 days	28days	91days	
1	D.OPC.350	11.5	25.3	28	30.1	Water curing until 28 days in tank
2	D.OPC.450	16.5	34.5	37.5	38.9	
3	S.OPC.350	14.5	27.3	30.9	33.2	
4	S.OPC.450	19.5	36.8	38.9	40.6	
5	D.M10-350-1:2	22.2	30.3	31.1	33.9	
6	D.M14-350-1:2	27.8	33.2	35.2	36.2	
7	D.M16-350-1:2	28.1	34.3	36.1	37.5	
8	D.M10-450-1:2	29.2	36.1	38.3	41.1	
9	D.M14-450-1:2	34.1	40.5	41.5	42.8	
10	D.M16-450-1:2	35.2	41.1	42.1	43.5	
11	S.M10-350-1:2	32.1	38.1	39.8	41.1	60 °C oven for 24 hr
12	S.M14-350-1:2	35.5	40.4	41.6	42.9	
13	S.M16-350-1:2	36.1	41.3	42.8	44.3	
14	S.M10-450-1:2	31.8	37.9	40.9	43.2	
15	S.M14-450-1:2	35.8	41.9	43.8	45.7	
16	S.M16-450-1:2	36.8	42.5	44.9	46.2	

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

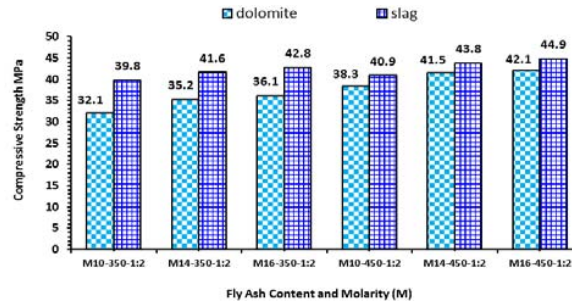


Fig. 7 Effect of local steel slag as a coarse aggregate on the compressive strength geopolymer concrete at 28 days

### 3. Effect of Local Steel Slag as a Coarse Aggregate in the Compressive Strength Geopolymer Concrete

The compressive strength of geopolymer concrete was studied at 3, 7, 28, and 90 days. From Table IX and Fig. 7, the effect of the fly ash content and local steel slag as a coarse aggregate on 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<sup>3</sup> with M10, M14 and M16 is higher than the strength of mix prepared with 350 kg/m<sup>3</sup> 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 3% strength gain was obtained when the fly ash content increased from 350 kg/m<sup>3</sup> to 450 kg/m<sup>3</sup> at 28 days, for mix containing molarity of sodium hydroxide solution M10, while keeping the ratio of sodium silicate solution constant 1:2, and the mixes containing local steel slag as a coarse aggregate. In addition, the increase in the fly ash content resulted in an increase in the compressive strength of the geopolymer concrete mixes as expected. About 5% and 4% strength gain was obtained when the fly ash content increased from 350 kg/m<sup>3</sup> to 450 kg/m<sup>3</sup> at 28 days, for mix containing molarity of sodium hydroxide solution M14 and M16, respectively. On the other hand, the using of local Steel Slag as hundred percent substitutes for coarse aggregate recorded that the compressive strength higher than about 23%, 18%, and 18% from strength of mix prepared with crashed stone as a coarse aggregate in fly ash content 350 kg/m<sup>3</sup>, and molarity M10, M14, and M16 respectively. Also, in fly ash content 450 kg/m<sup>3</sup>, the used of local Steel Slag as hundred percent substitutes for coarse aggregate recorded that the compressive strength higher than about 6%, 5%, and 6% from strength of mix prepared with crashed stone as a coarse aggregate in fly ash content 450 kg/m<sup>3</sup>, and molarity M10, M14, and M16 respectively.

### 4. Effect of Concentration of (NaOH) on Compressive Strength

The compressive strength of geopolymer concrete was studied at 3, 7, 28, and 91 days. Table VIII shows mixtures 5, 6, 7, 8, 9, and 10 with fly ash content 350 kg/m<sup>3</sup> and 450 kg/m<sup>3</sup> respectively, the above mixtures is repeated with the same components but with another type of coarse aggregate "local Steel Slag aggregate" in mixtures 11, 12, 13, 14, 15,

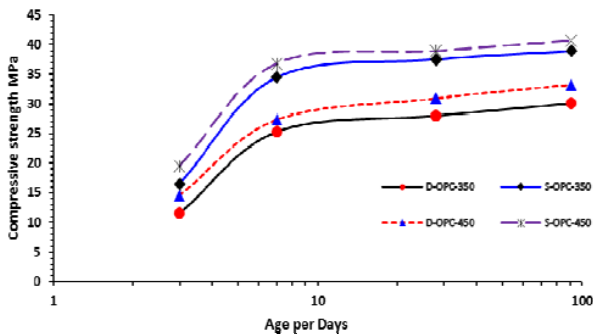


Fig. 5 Effect of cement content on the compressive strength at 3, 7, 28, and 90 days, using crashed stone and local steel slag as a coarse aggregate

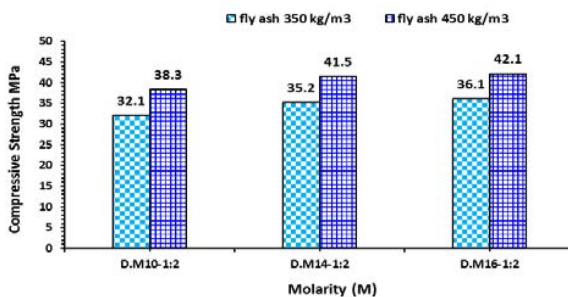


Fig. 6 Effect of fly ash content in geopolymer mixes on the compressive strength at 28 days, using crashed stone as a coarse aggregate

and 16. This type is local steel slag, to study the effect of concentration of sodium hydroxide solution on the compressive strength of concrete made from local steel slag as coarse aggregate. The measured of compressive strengths test cubes are given in Table VIII. It can be observed that the compressive strength of geopolymer concrete is increased with the increasing in molarity of NaOH upto a value of M14 and on further increase of molarity of NaOH, the compressive strength slightly increases.

The use of molarity M16 recorded that the compressive strength about 12%, and 2% higher than strength of mix prepared with molarity M10, and M14, respectively. At 28 days, with fly ash content  $350 \text{ kg/m}^3$  and crashed stone as coarse aggregates. On the other hand, the using of molarity M16, with fly ash content  $450 \text{ kg/m}^3$ , and crashed stone or local steel slag as coarse aggregates, the rate of compressive strength increase in the range about 9% and 1% for M10 and M14, respectively. The obtained results are in agreement with the published literatures [16].

#### 5. Density of Cement and Geopolymer Concrete

Variations of density of geopolymer concrete 3, 7 and 28 days. Average of density of geopolymer concrete approximately  $2200$  and  $2263 \text{ kg/m}^3$  in fly ash content  $350$  and  $450 \text{ kg/m}^3$  with crashed stone, respectively. In addition, cement concrete is approximately  $2296$  and  $2323 \text{ kg/m}^3$  in cement content  $350 \text{ kg/m}^3$  and  $450 \text{ kg/m}^3$  with crashed stone, respectively.

From the results mentioned in the above paragraph, it can be observed that the unit weight of geopolymer concrete decreased about 4% and 3% in fly ash content  $350 \text{ kg/m}^3$  and  $450 \text{ kg/m}^3$  with crashed stone, respectively from cement concrete at the same content of cement. As the same trend happen in concrete containing 100% local Steel Slag as a coarse aggregate between geopolymer concrete and cement concrete. But, the results indicated that the obtained increase in the unit weight reached about 12% when using local Steel Slag coarse aggregate, from concrete containing crashed stone as a coarse aggregate. 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 [17].

#### 6. Tensile Strength

Table IX shows the results of the splitting tensile strength for normal concrete specimens and geopolymer concrete specimens. The above experiment is being done on the concrete containing crashed stone and local steel slag as a coarse aggregate in geopolymer concrete. The splitting tensile strength of geopolymer concrete is compared with the splitting tensile strength of OPC concrete at same age. Splitting tensile strength of geopolymer concrete with molarity M14 at different contents from fly ash and coarse aggregate are presented (Table IX). It can be observed that, the splitting tensile strength markedly increased at 28 days. Using molarity

M14 with using  $450 \text{ kg/m}^3$  fly ash and 100 % local Steel Sage as coarse aggregate, increased the splitting tensile strength about 19% as compared with the same mixture but that contain crashed stone as coarse aggregate. On the other hand using M14 increased the splitting tensile strength about 23%, as compared with mix used M10. In general, Uniform dispersion and disorganized in shape of local Steel Slag is vital to the development of cement concrete and geopolymer concrete strength which effectively take advantage of the bond strength between geopolymer matrix and local Steel Slag as coarse aggregate. Generally, the splitting tensile strength of geopolymer concrete is increased compared to the splitting tensile strength of OPC concrete at same age, this result in agreement with [18].

#### 7. Flexural Strength

From table IX it can be observed from the test result the flexural strength of the geopolymer concrete is varied from 6.1 MPa to 4.3 MPa with the change of the cement content from  $350 \text{ kg/m}^3$  to  $450 \text{ kg/m}^3$  and from the comparative study, (Table IX) shown that the Flexural strength of the concrete is also increasing at replacement the crashed stone with local steel slag as coarse aggregate about 9% in cement content  $350 \text{ kg/m}^3$ . As the same trend happen in concrete containing  $450 \text{ kg/m}^3$  cement. Similarly, it can be observed from the test result that the flexural strength of the geopolymer concrete is varied from 9.1 MPa to 5.8 MPa with the change of the fly ash content from  $350 \text{ kg/m}^3$  to  $450 \text{ kg/m}^3$ , and at change of the concentration of the sodium hydroxide from M10 to M16. Generally, the flexural strength of the geopolymer concrete increases compared to OPC concrete at the same age. Similar observations were reported by investigators earlier [19].

#### 8. Static Modulus of Elasticity

Results of the static modulus of elasticity are shown in Table IX. In a similar way to the compressive strength results, the static modulus of elasticity increased with age. This improvement was rapid in the first 28 days as most of the modulus value was generally achieved in this period. The static modulus of elasticity for mixes NO: 6, 9, 12, and 15 after 28 days was about 31.5, 32.5, 33.0, 33.5 GPa at  $60^\circ\text{C}$  curing temperature for 24 hours, respectively, with that for the mixes NO: 1, 3, 2, and 4 after 28 days was about 24.2, 26.9, 28.8, 30.72 GPa, in water curing respectively. At 28 days results show that the static elastic modulus of OPC concrete containing local steel slag as coarse aggregate are around 6% to 11% more than OPC mixes containing crashed stone as coarse aggregate. On the other hand, the same trend in fly ash based-geopolymer concrete containing local steel slag was observed when compared with crashed stone as coarse aggregate, this result is in agreement with earlier studies [15], [19].

#### 9. Water Absorption and Apparent Volume of Permeable Voids

The results of water absorption of OPC concrete and geopolymer concrete for mixtures with different NaOH concentrations are presented in Table IX. The water

absorption decreases with an increase in concentration of NaOH of the mix. The results indicated that the water absorption was much affected by the water into the mixture since it increases capillary porosity of concrete. Furthermore, mixes 3, 4, 11, 12, 13, 14, 15, and 16, resulted in higher compressive strength with low water absorption and apparent volume of permeable voids than mixes 1, 2, 5, 6, 7, 8, 9, and 10, because, that the water absorption of local steel slag as

coarse aggregate lower than the crashed stone as coarse aggregate. In addition, the water absorption of Geopolymer concrete decreases because the Geopolymer concrete uses small amount of water in the mixture. OPC concrete mixes 1, 2, 3, and 4 that water cured with the lower strength than geopolymer concrete, at the same time, the OPC concrete higher water absorption and apparent volume of permeable voids than geopolymer concrete (Table IX).

TABLE IX  
MECHANICAL PROPERTIES FOR SELECTED MIXES OF GEOPOLYMER CONCRETE

Mix NO:	mix. ID	Comp. Strength Mpa	Tensile Strength Mpa	Flexural strength Mpa	Modulus of Elasticity GPa	Water Absorption %	AVPV %
		28 days	28 days	28 days	28 days	56 days	56 days
1	D-OPC-350	28	2.4	4.3	24.24	4.97	12.43
2	D-OPC-450	37.5	3.9	6.1	28.76	4.86	11.27
3	S-OPC-350	30.9	3.1	5.2	26.89	4.82	11.69
4	S-OPC-450	38.9	4.3	6.7	30.74	4.64	10.23
5	D.M10-350-1:2	32.1	3.8	5.8	30	3.99	10.35
6	D.M14-350-1:2	35.2	4.7	6.7	31.53	3.24	10.1
7	D.M16-350-1:2	36.1	5.2	6.5	29.81	3.63	9.99
8	D.M10-450-1:2	38.3	5.1	7.5	31.29	3.67	9.94
9	D.M14-450-1:2	41.5	5.7	8.4	33	2.97	9.46
10	D.M16-450-1:2	42.1	5.4	8.1	30.96	2.53	9.24
11	S.M10-350-1:2	39.8	4.3	7.6	30.82	3.94	10.05
12	S.M14-350-1:2	41.6	4.9	8.2	32.45	3.16	9.64
13	S.M16-350-1:2	42.8	4.8	8.4	30.47	2.56	9.52
14	S.M10-450-1:2	40.9	4.6	8.3	32.06	3.57	9.19
15	S.M14-450-1:2	43.8	6.1	9.1	33.46	2.83	8.98
16	S.M16-450-1:2	44.9	5.7	8.9	30.24	2.42	8.71

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

It can be seen from Table IX that the apparent volume of permeable voids of concrete with various parameters. In general, the same trend could be observed from this property with water absorption. The apparent volume of permeable voids, or closed porosity, is a percentage of pore space measured by boiling the saturated concrete. It can be seen from Table IX that the compressive strength of geopolymer concrete increase the apparent volume of permeable voids is decreased. Since, apparent volume of permeable voids was much affected by the water ratio into the mixture because it increases capillary porosity of concrete as shown in Table IX, the obtained results are in agreement with the published literatures [20].

#### 10. 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.

Sorptivity for the mixtures (1, 2, 3, and 4), mixtures (5, 6, 7, 11, 12, and 13) and mixtures (8, 9, 10, 14, 15, and 16), are shown in Figs. 8, 9 and 10, respectively, at the age of 51 days. Each set of plots shown refers to average of the three samples tested from each of the mixtures.

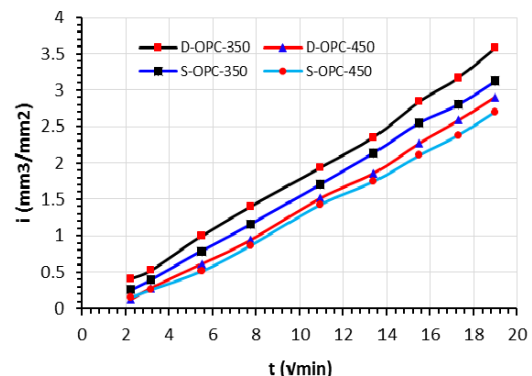


Fig. 8 Cumulative sorptivity per unit area with square root time for OPC concrete with or without electric arc furnace steel slag as coarse aggregate in cement content 350kg/m<sup>3</sup>, and 450 kg/m<sup>3</sup>

In sorptivity-time relationship, water absorption by porous materials increases as the square root of the elapsed time "t" increases. Assuming a constant supply of water at the inflow surface, the following relationship holds [21]. Typical plots of cumulative sorptivity against the square root of time are shown in Figs. 8-10.

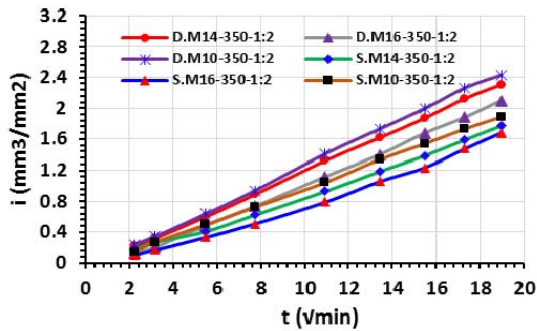


Fig. 9 Cumulative sorptivity per unit area with square root time for GPC with or without electric arc furnace steel slag as coarse aggregate in fly ash content  $350 \text{ kg/m}^3$

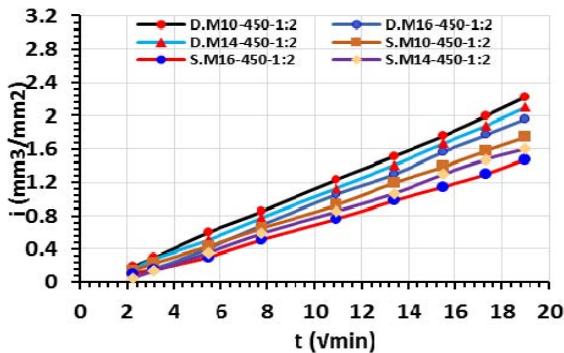


Fig. 10 Cumulative sorptivity per unit area with square root time for GPC with or without electric arc furnace steel slag as coarse aggregate in fly ash content  $450 \text{ kg/m}^3$

Figs. 8-10 represent 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 local steel slag as coarse aggregate but increase for geopolymer concrete containing crushed stone as coarse aggregate. Furthermore, the concentration of NaOH increases in geopolymer concrete the pore area was non-permeable that up to molarity M16.

#### IX. 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 CO<sub>2</sub> emission of concrete. The binder of geopolymer concrete (GPC) is different from that of ordinary Portland cement (OPC) concrete, and the compressive strength of heat-cured fly ash-based geopolymer concrete does not depend on age.
- 2- When using local Steel Slag as hundred percent substitutes for coarse aggregate recorded that the compressive strength higher than about 6% from strength of mix prepared with crushed stone as coarse aggregates in the geopolymer concrete.

- 3- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geopolymer concrete, and the higher ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete.
- 4- 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.
- 5- The flexural strength of fly ash-based geopolymer concrete is only a fraction of the compressive strength, as in the case of Portland cement concrete.

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