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Mechanical properties and durability performance of Zeolite and Red-Mud geopolymer concrete

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الملخص

يتعرض هذا البحث بالدراسة المعملية لإختبار تأثير مادتى الزيوليت و خبث الألومنيوم كبديل كلى للأسمنت (خرسانه جيوبوليميريه) على كل من الخواص الميكانيكية للخرسانة المتصلده و كذلك سلوكها و تحملها مع الزمن. وقد استخدم كل من هيدروكسيد الصوديوم و هيدروكسيد البوتاسيوم كمحاليل قلويه بنسب تركيز (8-12-16) و كذلك معامل تركيز قلوى بين كل من صوديوم ميتا سيليكات/هيدروكسيد بنسبة ثابته تساوى 1، و قد تم استخدام هذه المحاليل القويه لتعويض تفاعلات الاماهه الناتجه من تفاعل الأسمنت مع المياه فى كل من حالتى الاحلال بالمواد السابقة الذكر وقد تم دراسة بعض الخواص الميكانيكيه للخلطات المختلفه من الخرسانه لمعرفة مدى تأثير هذه المواد، حيث وجد تفاوت فى تأثير هذه المواد على بعض الخواص الميكانيكيه للخرسانه و كذلك سلوكها مع الزمن وتحملها لدرجات الحراره المختلفة. و نتيجة للتجارب المعملية وجد ان كل من الزيوليت و خبث الألومنيوم لهم تأثير ايجابى مقبول على كل من اجهاد الضغط, الشد غير المباشر وكذلك فى اختبارات التحمل مع الزمن.

ABSTRACT

Potassium and Sodium based alkaline activators with sodium Meta silicate (Na_2SiO_3) were used for different mix proportions. The parameters in this study were the NaOH or KOH solution with (8 M, 12 M and 16 M) concentration. One Na_2SiO_3/NaOH, KOH ratio equal 1 were inspected. The present study aims to investigate the durability behaviour of zeolite/red mud geopolymer concrete mixtures such as rapid chloride permeability and porosity. The development of mixtures and their fresh and mechanical properties were also investigated and presented. Mechanical properties such as compressive strength and splitting tensile strength were determined for each mixtures. In addition the water absorption and density were also measured. The microstructure of the samples was also investigated using DTA test. The results showed that the studied parameters significantly affected the properties of the produced geopolymer mortars.

1 INTRODUCTION

Portland cement is the most common cement for concrete and is used extensively in the construction industry. However, Portland cement production is an energy intensive process, depletes a large amount of natural resource, and releases a large amount of greenhouse gas. The use of supplementary materials to partially replace Portland cement and other form of cementing materials should be emphasized to reduce Portland cement consumption. Geopolymer binder is another form of cementing materials compared with the common technology based on Portland cement. [1]. In 1978, Davidovits created the name ‘‘geopolymers’’ meaning the mineral polymers resulting from geochemistry or geosynthesis. The geopolymer chemistry concept was invented in 1979 [3]. Geopolymer is considered as the third generation cement after lime and ordinary Portland cement. The term ‘‘geopolymer’’ is generically used to describe an amorphous alkali aluminosilicate which is also commonly used for to as ‘‘inorganic polymers’’, ‘‘alkali-activated cements’’, ‘‘geocements’’, ‘‘alkali-bonded ceramics’’, ‘‘hydroceramics’’ etc [4].

Geopolymerization is a reaction that chemically integrates minerals involving silico–aluminates sources. Source of alumina in and silica acts as a source of precursor that readily dissolved in the alkaline solution, and synthesized by alkaline and/or silicate activation which lends itself to the process of geopolymerization [3].

This process releases water that is normally consumed during dissolution. The water, expelled from geopolymer during the reaction provides workability to the mixture during handling. This is in contrast to the chemical reaction of water in Portland cement mixture during the hydration process [4]. Also, [5] stated that, Geopolymerization is based on alumino-silica chain. It is a polymeric reaction that takes place between certain amount of alumina and silica in the presence of a strong alkaline solution (i.e., NaOH, KOH, etc.). Geopolymerization is often referred as alkali activation, transforms the amorphous ingredients of materials into a composite that have strong binding property.

Geo-polymerization process, although not fully understood, may be divided into three main phases; namely dissolution of Si and Al species found in the raw materials through the effect of hydroxide ions followed by condensation of precursor ions into monomers and finally polymerization of monomers into three dimensional polymeric structures. These three steps can either take place simultaneously or concurrently with each other [6].

Also, water is produced through the polymerization process as discontinuous a nono-pores in the paste. Water plays no role in the chemical reaction; it merely provides workability and initial reaction medium to the geopolymer [6]. The high rise in temperatures is due to the separation of the sodium hydroxide molecules into Na+ (sodium) and the OH- (hydroxide) ions. The rules of safety for these alkaline materials can be divided into two categories: Corrosive products which have some hostile properties and irritant products which are friendlier to work with [7]. The objective of this work was to evaluate the conditions of synthesis for geopolymerization (sodium hydroxide concentration, sodium silicate, time, and curing temperature) from natural zeolitic material and red mud in order to obtain binder material similar to Portland cement with attractive mechanical properties in concrete industry.

2 EXPERIMENTAL PROGRAMME

2.1 Materials

2.1.1 Zeolite

Zeolite was obtained with specific gravity was 2.15 g/cm^3, volumetric weight was 1.08 g/cm^3, specific surface area was 6150 cm^2/g and the soundness was 1 mm. The particle size distribution of Zeolite is shown in Fig. 1. It is off-white in colour and substantially lighter than Portland cement. The chemical composition of Zeolite is shown in Table 1; while its physical properties are given in Table 2.

TABLE 1
Chemical composition of constituent materials

Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO
Zeolite	0.66	0.02	12.14	64.79	0.08	0.55	Nil	3.21	3.6
Red-Mud	0.65	2.27	56.8	23.6	0.45	1.18	0.8	0.61	6.18
Oxides	**TiO_2**	**MnO**	**Fe_2O3**	**ZnO**	**ZrO_2**	**BaO**	**CuO**	**L.O.I***	
Zeolite	0.44	Nil	4.06	Nil	Nil	Nil	Nil	10.1	
Red-Mud	2.29	0.06	2.99	0.14	0.12	0.72	0.11	0.79	

2.1.2 Red-Mud (Aluminum slag)

Red-Mud (Water – Cooled aluminum slag) was obtained with specific gravity is 2.65 g/cm3, volumetric weight is 1.18 g/cm3, specific surface area is 5200 cm2/gm and the soundness was 1.12 mm. The particle size distribution of Red-Mud also shown in Fig. 1. It is dark-grey in colour. The chemical composition of Red-Mud is shown in Table 1; while its physical properties are given in Table 2.

2.1.3 Ordinary Portland cement (OPC) & Fly ash (FA)

Ordinary Portland cement (CEM - 42.5 N) was used. The specific gravity was 3.13 g/cm3, specific surface area was 3000 cm2/gm .Fly ash (FA) was obtained according to ASTM: C618-12a, FA is divided into two distinct categories i.e., low-calcium FA (Class F, CaO < 10%) and high calcium FA (Class C, CaO > 10%). In this study low-calcium FA was used. The chemical composition of OPC and FA shown in Tables 2,

TABLE 2
Chemical composition of OPC and FLY ASH

Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO
OPC	0.29	1.24	5.48	20.29	0.17	0.45	63.11
Fly ash	0.43	1.1	27.28	54.72	1.12	1	5.31
Oxides	**TiO_2**	**MnO**	**Fe_2O3**	**SO_3**	**Cl**	**CuO**	**L.O.I***
OPC	0.27	0.08	2.85	2.49	NIL	0.02	3.39
Fly ash	1.82	0.1	5.15	1.01	0.01	0.01	6.8

2.1.4 Fine aggregate (Sand)

Natural siliceous sand has been used as fine aggregate with a specific gravity of 2.54 gm/cm3, fineness modulus of 2.60 and volumetric weight was 1.81 g/cm3

2.1.5 Coarse aggregate

Conventional crushed limestone aggregate was used for comparison purpose. The other coarse aggregates, cruhed granite and normal gravel used in this study were collected from the local quarry with maximum nominal size of 10 mm.

2.1.6 Activator materials/Solution

The alkaline activator used was sodium silicate (Na2SiO3), sodium hydroxide (NaOH) and potassium hydroxide (KOH) solution.

Sodium meta-silicate (Na2SiO3.9H2O) solution (Na = 16.17%, O = 67.55%, H = 6.38% and Si = 9.88% by mass). Density 2.4 g/cm3 and melting point 1.088 0C. It is colourless crystals and molecular weight (M.W) 284.2 g/mole with 98% purity. Sodium meta-silicate also known as high specific gravity glass water.

Sodium hydroxide (NaOH) was in flakes form as shown in Fig. 3 with 96% purity, density 2.13 g/cm3, melting point 318 0C and molecular weight (M.W) 40 g/mole.

Potassium hydroxide (KOH) was in flakes form with 85% purity, density 2.12 g/cm3, melting point 360 0C and molecular weight (M.W) 56.11 g/mole.

2.2 Specimen preparation and curing

2.2.1 Material preparation

Zeolite and Red-Mud (Aluminum slag) as raw materials obtaining a particle size that pass a # 200 ASTM sieve (75 µm) of Zeolite and Red-Mud by grinding using Retsch grinder. The particle size distribution of Zeolite and Red-Mud is shown in Fig. 1.

2.2.2 Activator Solution

A combination of sodium meta-silicate (Glass water) and sodium hydroxide or potassium hydroxide solution was used as an alkaline activator. The parameters involved in this study were the NaOH or KOH solution molarity and the [Na2SiO3/NaOH or Na2SiO3/KOH] ratios.

Three NaOH and KOH concentrations (8, 12, and 16 molarity (M)) were investigated. The Na2SiO3/NaOH or KOH ratio was varied between 1 and 2.5 with 0.5 as step.

2.2.3 MIX PROPORTION OF GEOPOLYMER CONCRETE

The mix design for ordinary Portland cement concrete (OPC-Concrete) or low calcium fly ash concrete (LCFA-Concrete) was based on the method recommended by the ACI committee 211.

The geopolymer concrete mixtures were originally designed using a calculation developed by Monita [8] and Partha [9], and also some other researches; by assuming some parameters such as aggregate content, alkaline/binder ratio and sodium/sodium hydroxide ratio. The calculation was used to obtain binder (Zeolite or Red-Mud), aggregate, solid sodium hydroxide, sodium silicate, and water quantities. They [8] and [9] also stated that, the density of geopolymer concrete is almost equal to that of OPC concrete (2400 kg/m^3), mass of combined aggregates occupy 75–77 % by mass in geopolymer concretes. In the present mix design of geopolymer concrete, combined aggregates were taken as 77% by mass of the entire mixture. To obtain maximum strength NaOH/KOH concentration was taken as 8M, 12M and 16M. Taking into consideration the workability, the ratio of sodium silicate to sodium hydroxide solution was kept 2.

A different mixtures design porportion are presented in Table 5 – Phase 1, 2. The resulting mixture proportion produced concrete with compressive strength of 35±3 MPa. The mixing procedures were similar to that specified for the OPC concrete by the ASTM standards C-305.

TABLE 5
Mix proportion of different geopolymer concrete mixtures
Phase 1 with NaOH as alkaline activator

Mix. Designation	Coarse agg. 7 mm.	Coarse agg. 10 mm.	F. agg. Sand	Zeolite (kg/m^3)	Red-Mud (kg/m^3)	OPC (kg/m^3)	LCFA (kg/m^3)	NaOH Solution (kg/m^3) 8 M	NaOH Solution (kg/m^3) 12 M	NaOH Solution (kg/m^3) 16 M	Na_2SiO_3 Solution (kg/m^3)
Mix. 1 - Ls	647	554	647	--	--	408	--	--	--	--	--
Mix. 2 - Ls	647	554	647	--	--	285	123	--	--	--	--
Na-Gl-8Z	647	554	647	408	--	--	--	48	--	--	96
Na-Gl-12Z	647	554	647	408	--	--	--	--	48	--	96
Na-Gl-16Z	647	554	647	408	--	--	--	--	--	48	96
Na-Gl-8R	647	554	647	--	408	--	--	48	--	--	96
Na-Gl-12R	647	554	647	--	408	--	--	--	48	--	96
Na-Gl-16R	647	554	647	--	408	--	--	--	--	48	96
Na-Gr-8Z	647	554	647	408	--	--	--	48	--	--	96
Na-Gr-12Z	647	554	647	408	--	--	--	--	48	--	96
Na-Gr-16Z	647	554	647	408	--	--	--	--	--	48	96
Na-Gr-8R	647	554	647	--	408	--	--	48	--	--	96
Na-Gr-12R	647	554	647	--	408	--	--	--	48	--	96
Na-Gr-16R	647	554	647	--	408	--	--	--	--	48	96

*e.g.: (Na-Gr-12 Z) refers to Geopolymer concrete using zeolite material as binder with 12 mole of NaOH and Granite (Gr) as coarse aggregate.

Phase 2 with KOH as alkaline activator

Mix. Designation	Coarse agg. 7 mm.	Coarse agg. 10 mm.	F. agg. Sand	Zeolite (kg/m^3)	Red-Mud (kg/m^3)	OPC (kg/m^3)	LCFA (kg/m^3)	KOH Solution (kg/m^3) 8 M	12 M	16 M	Na_2SiO_3 Solution (kg/m^3)
K-Gl-8Z	647	554	647	408	--	--	--	48	--	--	96
K-Gl-12Z	647	554	647	408	--	--	--	--	48	--	96
K-Gl-16Z	647	554	647	408	--	--	--	--	--	48	96
K-Gl-8R	647	554	647	--	408	--	--	48	--	--	96
K-Gl-12R	647	554	647	--	408	--	--	--	48	--	96
K-Gl-16R	647	554	647	--	408	--	--	--	--	48	96
K-Gr-8Z	647	554	647	408	--	--	--	48	--	--	96
K-Gr-12Z	647	554	647	408	--	--	--	--	48	--	96
K-Gr-16Z	647	554	647	408	--	--	--	--	--	48	96
K-Gr-8R	647	554	647	--	408	--	--	48	--	--	96
K-Gr-12R	647	554	647	--	408	--	--	--	48	--	96
K-Gr-16R	647	554	647	--	408	--	--	--	--	48	96

2.2.4 Curing procedure

The standard curing used for OPC/LCFA concrete specimens was applied. The curing was 24 hours at room temperature before demoulded and followed by water Immersion curing until testing. The fresh concrete geopolymer mixtures have cured using high temperature ambience to accelerate the geopolymerisation process and hardening of the concrete. According to previous studies [10, 11], all cast samples of zeolite and red-mud geopolymer concrete mixtures were molded and then covered with plastic sheet to prevent water evaporation causing surface cracking during heating. All covered zeolite and red-mud geopolymer concrete samples were left at room temperature for 24 hours then cured in the oven at 100^{O} C for 72 hours.

3 RESULTS AND DISCUSSION

3.1 Mechanical properties

3.1.1 Compressive strength

Compressive strength tests of all specimens were evaluated by using universal hydraulic testing machine (2000 KN capacity). Compressive test was carried out to evaluate the strength development of the specimens. The samples were tested at age 7 and 28 days. Three specimens were tested for each mixture. The compressive strength was taken as a ratio of ultimate load and cross-sectional area of the specimen. The final result was the average of triplicate specimens. Table 7 shows compressive strength values at age of 7 and 28 days for different mixtures.

TABLE 7
Compressive strength of different geopolymer concrete mixtures

	Mean Compressive Strength (Mpa) - 7, 28 days				
	7 day	28 day		7 day	28 day
Mix. 1 - Ls	29	37			
Mix. 2 - Ls	33	39			
Na-Gl-8Z	26	32	K-Gl-8Z	25	29
Na-Gl-12Z	28	31	K-Gl-12Z	23	28
Na-Gl-16Z	26	29	K-Gl-16Z	25	28
Na-Gl-8R	28	33	K-Gl-8R	26	31
Na-Gl-12R	28	31	K-Gl-12R	24	30
Na-Gl-16R	27	30	K-Gl-16R	23	29
Na-Gr-8Z	31	34	K-Gr-8Z	26	31
Na-Gr-12Z	28	33	K-Gr-12Z	24	30
Na-Gr-16Z	27	31	K-Gr-16Z	21	27
Na-Gr-8R	29	35	K-Gr-8R	25	32
Na-Gr-12R	28	33	K-Gr-12R	21	27
Na-Gr-16R	26	32	K-Gr-16R	24	29

Table 6 shows the compressive strength developed between 7 and 28 days. For example, the 7-day compressive strengths of 26, 28 and 26 MPa were obtained for Na-Gl-8Z, Na-Gl-12Z and Na-Gl-16Z, respectively, and these values were 82%, 89% and 90% of the 28-day strength, as also shown in Table 7. Most of the geopolymer concrete (GC) specimens achieved 85-90% of the 28-day strength at 7 days for oven dry curing while normal OPC concrete and LCFA concret specimens achieved 77-80 % of the 28-day at 7 days.

Generally, the NaOH solution molarity has a higher effect on compressive strength more than KOH solution molarity. Also, NaOH with 8 M has the highest effect on compressive strength especially with Red-Mud mixtures. Also, different geopolymer mixtures with crushed granite showed a higher compressive strength values than others mixtures with crushed gravel.

3.1.2 Splitting tensile strength

Brazilian/Splitting tensile tests of all specimens were evaluated by using universal hydraulic testing machine (2000 KN capacity). The samples were tested at age 7 and 28 days. Three specimens were tested for each mixture. The specimens were loaded by compressive force along the length of the cylinders. Tensile strength was calculated by dividing the maximum load (2P) sustained with geometrical factors (πDL). The final result was the average of triplicate specimens. Fig. 13 and Fig. 14 presents a comparison between age 7-days and 28-days splitting tensile strength values for two phases. Fig. 13 and Fig. 14 showed the splitting tensile strength developed between 7 and 28 days. For example, the 7-day splitting tensile strengths of 2.1, 2.4 and 2.2 MPa were obtained for Na-Gl-8Z, Na-Gl-12Z and Na-Gl-16Z, respectively, and these values were 78%, 92% and 85% of the 28-day strength. Most of the geopolymer concrete (GC) specimens achieved 73-92% of the 28-day strength at 7 days for oven dry curing while normal OPC concrete and LCFA concret specimens achieved 82-90 % of the 28-day at 7 days.

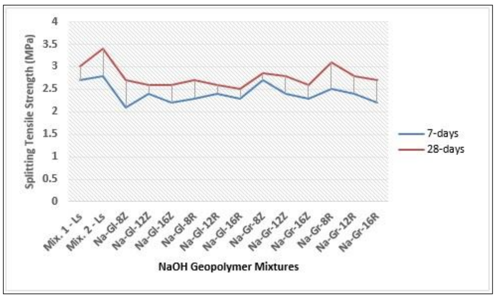

Fig. 13: Effect of the NaOH molarity in splitting tensile strength

Generally, as compressive strength as, the NaOH solution molarity has a higher effect on compressive strength more than KOH solution molarity. Also, NaOH with 8 M has the highest effect on splitting tensile strength especially with Red-Mud mixtures.

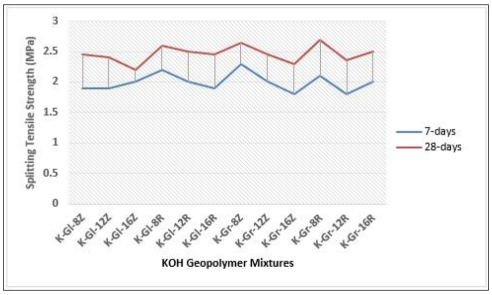

Fig. 14: Effect of the KOH molarity in splitting tensile strength

3.1.3 Density

The density of the various concrete mixtures specimens was determined before the cubes were crushed. Thus, the densities of the three cubes were obtained and the average was taken as the density of the specific mix design. The density was determined using following:

$$\rho = \frac{m}{v} \quad \text{Eq. No. (1)}$$

Where is the density (kg/m^3), m the mass of the concrete cube in kg and V is the volume of the cube in m3. The volume of the cubes was measured with a Vernier caliper to the nearest mm. According to Table 8, the density of the geopolymer concrete varied from 2248 kg/m^3 to 2294 kg/m^3, while density of control concrete varied from 2250 kg/m^3 to 2410 kg/m^3 depending on the constituents in the mixtures. The aggregate content had the largest influence on the density of geopolymer concrete, especially type of coarse aggregate content (Gravel/Granite) which increased the density.

TABLE 8
Density (kg/m^3) of different geopolymer concrete mixtures

	Density kg/m^3				Density kg/m^3		
	28 - day	60 - day	90 - day		28 - day	60 - day	90 - day
Mix. 1 - Ls	2250	2276	2312				
Mix. 2 - Ls	2370	2395	2410				
Na-Gl-8Z	2248	2254	2261	K-Gl-8Z	2213	2216	2224
Na-Gl-12Z	2267	2285	2294	K-Gl-12Z	2231	2247	2257
Na-Gl-16Z	2259	2251	2262	K-Gl-16Z	2220	2213	2225
Na-Gl-8R	2252	2274	2287	K-Gl-8R	2213	2234	2250
Na-Gl-12R	2264	2285	2291	K-Gl-12R	2226	2241	2254
Na-Gl-16R	2259	2267	2277	K-Gl-16R	2221	2231	2240
Na-Gr-8Z	2251	2259	2269	K-Gr-8Z	2212	2222	2232
Na-Gr-12Z	2272	2279	2288	K-Gr-12Z	2231	2243	2251
Na-Gr-16Z	2261	2268	2279	K-Gr-16Z	2224	2234	2242
Na-Gr-8R	2262	2271	2291	K-Gr-8R	2226	2237	2254
Na-Gr-12R	2273	2279	2287	K-Gr-12R	2234	2244	2250
Na-Gr-16R	2275	2283	2291	K-Gr-16R	2237	2248	2254

Also, its showed that, the density of Zeolite/Red-Mud geopolymer concrete with different coarse aggregate types is lower than OPC concrete. This might be attributable to the specific gravity of the raw materials used to produce Zeolite/Red-Mud geopolymer concrete. The specific gravity of the Zeolite/Red-Mud is 2.15/2.65 gm/cm3 which is lower than that of Portland cement with a specific gravity of 3.13 gm/cm^3. The density of different geopolymer concrete tended to increase over time as shown in Fig. 15 and Fig. 16. This suggests that the reaction process is not complete at 28 days. Overall an increase in density of 1.03% is observed between 28 and 90 days. Generally, the NaOH solution molarity has a higher effect on density more than KOH solution molarity. Also, NaOH with 8, 12 M has the highest effect on density especially with Red-Mud mixtures.

3.1.5 DTA Analysis of different geopolymer concrete mixtures

Differential Thermal Analyzer (DTA) allows you to know quickly sample thermal properties such as transition temperature, melting point, reaction temperature and distinction between heat absorption and generation.

In order to know the thermal stability of geopolymer concrete specimens, DTA studies were made Fig. 24. At higher temperatures the curves become complex and differ from each other. This may be due to varying extent of polymerizations. The structural transition from amorphous to crystalline of geopolymers synthesized at low to mild

temperatures in concentrated slurries also implies that the synthesis temperature and aging are critical in determining the structure of the reaction products.
Curing of geopolymer concrete up to 100 ^{0}C decrease the compressive strength. It is possible that higher temperature causes excessive loss of moisture and subsequent cracks in the specimen, which produce void thereby resulting in the loss of weight and strength.

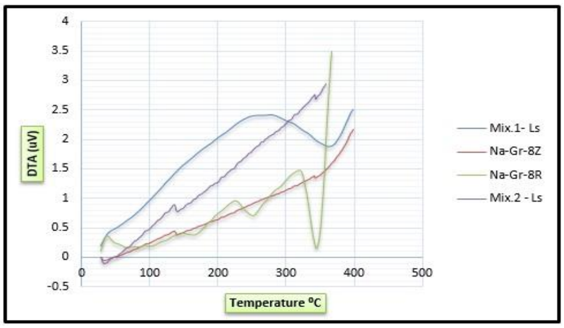

Fig. 24: DTA for the best geopolymer mixtures

3.2 Durability properties

Durability tests will include the water absorption test, the porosity test and Rapid Chloride Permeability Test.

3.2.1 Water absorption

The water absorption is one of parameters of concrete cover quality. Water absorption determination was carried out according to ASTM C-642. Three specimens were cut into slices with maximum thickness of 50 mm and 100 mm diameter for each concrete mix. Water absorption values were measured by drying the specimens until constant mass was achieved, immersed them in water and measured the increase in mass as a percentage of dry mass. The water absorption was calculated by equation:

$$Water\ absorption = \left(\frac{Ms - Md}{Md}\right)x100 \quad \text{Eq. No. (1)}$$

Where Ms = the mass of the specimen after immersion in SSD condition (g), Md = mass of oven dried sample (g).
Fig. 26, 27 and Also, Table 6 showed values of water absorption (%) developed between 28 days, 60 days and 90 days.

TABLE 8
Water absorption (%) of different geopolymer concrete mixtures

	Water Absorption (%)				Water Absorption (%)		
	28 - day	60 - day	90 - day		28 - day	60 - day	90 - day
Mix. 1 - Ls	4.48	4.16	3.82	Mix. 1 - Ls	4.48	4.16	3.82
Mix. 2 - Ls	4.07	4.73	4.57	Mix. 2 - Ls	4.07	4.73	4.57
Na-Gl-8Z	4.97	4.63	4.45	K-Gl-8Z	5.06	4.71	4.53
Na-Gl-12Z	4.87	4.64	4.24	K-Gl-12Z	4.96	4.72	4.32
Na-Gl-16Z	5.33	5.16	5.06	K-Gl-16Z	5.42	5.25	5.14
Na-Gl-8R	4.41	4.20	3.88	K-Gl-8R	4.49	4.27	3.95
Na-Gl-12R	4.66	4.54	4.25	K-Gl-12R	4.74	4.61	4.32
Na-Gl-16R	5.12	4.75	4.36	K-Gl-16R	4.60	4.83	4.44
Na-Gr-8Z	3.86	3.88	3.53	K-Gr-8Z	3.93	3.95	3.59
Na-Gr-12Z	4.09	3.80	3.43	K-Gr-12Z	4.16	3.60	3.49
Na-Gr-16Z	3.96	3.47	3.08	K-Gr-16Z	4.03	3.53	3.13
Na-Gr-8R	4.67	4.33	3.90	K-Gr-8R	4.75	4.41	3.97
Na-Gr-12R	4.44	4.12	3.67	K-Gr-12R	4.52	4.19	4.10
Na-Gr-16R	4.20	4.00	3.66	K-Gr-16R	4.28	4.07	3.72

Due to low water absorption of geopolymer concrete, the concrete can be classified generally as an 'excellent' concrete according to [8] who stated that, concrete can be

classified as an 'excellent' concrete if water absorption (%) was lower than 5% and classified as "good' concrete if water absorption (%) was between (5-6)%.
A continuous reaction of geopolymerization process slowly refills the concrete pores with aluminosilicates producing denser pores. Therefore a change in concrete porosity could affect the water absorption of the concrete.
Furthermore, Na/K-Gl-16Z at 28 days had the highest water absorption (5.53-5.42%) compared to other geopolymer mixes. It seems that the high sodium hydroxide amount in the system had an adverse impact for porosity.
Generally, water absorption (%) of different geopolymer mixtures decreased to 90 days and can be classified as an 'excellent' concrete. Water absorption (%) decreases with an increase of the compressive strength according to test age. Otherwise, Water absorption (%) increases with an increase of the sodium hydroxide molarity and constant sodium silicate modulus. The fact that pore development is more affected by mixture composition such as aggregates, alkaline solution binder type than strength evolution. The geopolymer concrete performs unlimited pore refinement by aluminosilicates, unlike the OPC that has a continuous hydration process. Also, Different Red-mud geopolymer concrte mixtures showed an ability to resist water absorption than zeolite geopolymer concrte mixtures.

3.2.2 Porosity

The effective porosity or apparent volumetric proportion of void test (AVPV) was undertaken in accordance with ASTM C-642. The porosity test can be used to identify the possibility of micro-cracks on Zeolite/Red-Mud geopolymer concrete specimens. Three sets of cylinder specimens, 100 mm diameter x 50 mm long, were tested 28, 60 and 90 after casting.
The procedure was drying the specimen in an oven at temperature of 100^0 C until constant mass and record this mass of the specimen (A) in grams then, boil the specimen in water for 5 hours. Store the specimen in water at a temperature of approximately 21^0 C for not less than 48 hours.

The effective porosity of the specimen is calculated as follows:
Effective porosity (%) = (B-A)/V x 100
Where A = mass of oven dried sample in air, B = saturated mass of the surface dry sample in air after immersion, V = bulk volume of the sample.
The Apparent Volume of Permeable Voids (AVPV) or porosity of the OPC or LCFA concrete and different geopolymer concrete mixtures are shown in Table 9

TABLE 9
Porosity (%) of different geopolymer concrete mixtures

	Porosity (%)				Porosity (%)		
	28 - day	60 - day	90 - day		28 - day	60 - day	90 - day
Mix. 1 - Ls	10.13	9.62	8.35	Mix. 1 - Ls	10.13	9.62	8.35
Mix. 2 - Ls	11.39	10.89	9.87	Mix. 2 - Ls	11.39	10.89	9.87
Na-Gl-8Z	12.41	10.63	9.62	K-Gl-8Z	12.16	11.14	10.13
Na-Gl-12Z	11.14	10.89	9.37	K-Gl-12Z	11.39	10.89	9.62
Na-Gl-16Z	12.15	12.15	11.14	K-Gl-16Z	12.15	12.66	10.63
Na-Gl-8R	10.13	9.87	8.61	K-Gl-8R	10.13	9.62	8.61
Na-Gl-12R	10.63	10.63	9.37	K-Gl-12R	11.14	10.38	9.62
Na-Gl-16R	11.65	11.14	9.62	K-Gl-16R	11.65	10.89	9.62
Na-Gr-8Z	8.86	9.11	7.85	K-Gr-8Z	9.11	9.37	7.59
Na-Gr-12Z	9.37	8.86	7.59	K-Gr-12Z	9.37	8.61	7.85
Na-Gr-16Z	9.11	8.10	6.84	K-Gr-16Z	9.37	8.35	7.09
Na-Gr-8R	10.63	10.13	8.61	K-Gr-8R	10.63	9.87	8.86
Na-Gr-12R	10.13	9.62	8.10	K-Gr-12R	10.13	9.62	8.86
Na-Gr-16R	9.62	9.37	8.10	K-Gr-16R	9.87	9.11	7.09

In general, the AVPV of the different geopolymer concrete mixtures followed a similar as shown by the water absorption. The OPC or LCFA concretes have AVPV varied in the range of 8.35-11.39 % and can be classified as ‘Good or low porosity’ to 'Medium porosity' According to Technical Report No.54, while the geopolymer concrete indicate lower AVPV values in the range of 6.84-12.16%. Also, the geopolymer can be classified as ‘Good or low porosity’ to 'Medium porosity' According to Technical Report [12] and a relation between water absorption and AVPV, as the water absorption increases the AVPV also increases correspondingly.

4 CONCLUSION

Based on the experimental results the following conclusions could be drawn:

1. The OPC, LCFA mixtures show higher workability than geopolymer binder in concrete refering to the higher viscosity of the liquids used in geopolymer production
2. Increasing the NaOH, KOH and Na2SiO3 molarity in zeolite or red-mud mixtures geopolymer concrete decreases the workability.
3. Zeolite and Red-Mud can be classified as an acceptable geopolymer material according to results which shown.
4. Materials of geological origin which are rich in aluminum silicate are good materials for geopolymer concrete.
5. Showed positive effect on the geopolymerization process and the compressive strength was found much higher as compared to the concrete made from OPC.
6. A strong chemical bonding between the geopolymer gel and aggregate was observed under SEM.
7. A chemical reaction between aggregate and alkali, or mechanical interlocking between the geopolymer gel and coarse surface of the aggregate could be a reason for the high compressive strength and splitting tensile strength.
8. Concrete cured in low temperature or ambient temperature might have coarser microstructure with high porosity gel. An increase of silicate content or alkaline molarity could increase the reactivity, providing a denser microstructure in the microstructure.

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