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Influence of Composition Parameters, Curing Conditions and Salt Solutions on Geopolymer Concrete Properties

K. M. Elsayed, *M. H. Makhlouf* and M. K. Elkady

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Abstract— **The growing demand for environmentally friendly construction has been the driving force behind the production of sustainable and cost-effective construction materials. Portland cement (PC), which is not considered an environmentally friendly material, is an important ingredient in concrete. In contrast to Portland cement, geopolymers are gaining increased interest as low-CO2 emission binders.**

This research consists of two basic stages, the first stage investigates the effects of many parameters on the properties of geopolymer concrete based on fly ash, in particular the compressive strength, tensile strength, and flexural strength .The parameters included were fly ash content, degree of solution molarity, alkaline liquid ratio to fly ash content, curing conditions, fine aggregate to coarse aggregate ratio.

Second stage of the research concerned with the durability of geo-polymer concrete developed using fly ash class-F. As a guide for assessing the durability of geo-polymer concrete, the efficiency of ordinary Portland cement (OPC) concrete is also discussed. The influence of salt solutions of different concentrations through various periods of wetting – drying cycles on the weight loss, water absorption, and geo-polymer concrete has been investigated for its compressive strength.

According to the first stage results, the best parameters which gave the highest geo-polymer concrete's mechanical properties, were: fly ash content of 400 kg/m3, 16 M degree of molarity, curing time of 3 days in oven, the ratio of alkaline liquid to the content of fly ash equals 0.5 and ratio of fine aggregate to coarse aggregate equals to 1:2, where the compressive strength reached its highest value (387 Kg/cm2).

The results of second stage revealed that geopolymer concrete is less affected than cement concrete with respect to compressive strength and more affected in weight loss and water absorption. Geopolymer concrete showed an increase in water absorption compared to OPC concrete, after 9 weeks of wetting – drying cycles in salt solutions, by about 176% &184% for 5% & 10% solutions concentration, respectively. Also, more weight loss for geopolymer concrete specimens was revealed compared to OPC concrete by about 33% & 30% for 5% & 10% solutions concentration, respectively. However, the geopolymer concrete (GPC) showed less reduction in compressive strength due to the exposure to salt solutions (wet – dry cycles) than OPC. For both solution concentrations (5% & 10%), the average reductions in GPC compressive strength were 18%& 25%, respectively, while the corresponding reductions in OPC were 25% & 34%.

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Khaled Mohamed Elsayed, Professor of Properties and Strength of Materials, Department of Civil Engineering, Benha Faculty of Engineering, Benha University, Egypt (e-mail: khelsayed@hotmail.com).

Mohamed Hussien ali Makhlouf, Assistant Prof., Department of Civil Engineering, Benha Faculty of Engineering, Benha University, Egypt (e-mail: mohamedmakhlouf83@yahoo.com).

Corresponding Author: *Mostafa Khairy Elkady, Demonstrator, Department of Civil Engineering, Benha Faculty of Engineering, Benha University, Egypt (e-mail: mostafaelqady3@gmail.com).*

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I. INTRODUCTION

Global warming is caused by the release of greenhouse gases, such as CO_2, from human activities to the atmosphere. CO_2 contributes nearly 65% to global warming to greenhouse gases (McCaffrey [1]). Around 7% of all CO_2 emissions are accounted for by the cement industry, where the output of one ton of Portland cement releases approximately one ton of CO_2 into the atmosphere (McCaffrey [1], Davidovits [2]). In this regard, the geo-polymer technology proposed by Davidovits shows great promise as an alternative binder to OPC for the concrete industry. Geo-polymer technology could reduce the emission of CO_2 into the atmosphere caused by the cement industry by about 80 percent in terms of reducing global warming. Researchers have recently been very involved to develop cement less concrete (geopolymer concrete) in order to reduce carbon dioxide emissions (CO_2).

In 1978, the theoretical basis for geopolymerization as a major reaction mechanism for cement less concrete was established for the first time by the French researcher Davidovits, who used kaolinite (Al_2 Si_2 O_2 (OH)) and alkaline activators. Many scholars have subsequently studied this topic [3, 4].

Geo-polymer is an inorganic compound of alumina-silicate synthesized from materials of geological origin synthesized from materials of geological origin or derived materials rich in silicon and aluminum, such as fly ash rice husk ash, etc. [5].

An significant technique for making concrete more environmentally friendly is the consumption of fly ash in the manufacture of geo-polymer concrete [18]. For this purpose, in order to better use this industrial waste, fly ash has been chosen as a base material for this study. Concrete containing alkali-aluminosilicate gel was shown to have high compressive strengths and fire resistance and resistance to chemical attacks [6, 7, 14] as the binder.

Starting content, activating agent type and concentration are the most critical parameters affecting the properties of the alkali activated end product [8, 9]. Previous research has shown that the amount of vitreous silica and alumina present in the starting material plays a significant role in the activation reactions and the properties of the reaction product [6, 10 & 19].

Palomo et al, [11] found that a GPC with a compressive strength between 35 and 40 MPa was formed by various fly ash samples enabled with Na OH 8-12 M curing at 85 ° C for 24 h.

Songpiriyakij et al, [12] suggested that 15.9 in fly ash-based geo-polymer was the optimum SiO_2/Al_2O_3 ratio to obtain the maximum compressive capacity.

The mechanical characteristics of geopolymer concrete (GPC) based on fly ash were investigated by Ramujee & Potharaju [17]. Compressive strength and splitting tensile strength values of GPC specimens of low, medium and higher grades were experimentally calculated compared to control mixes prepared by ordinary Portland cement mixes (OPC). In order to analyze the relationship between the compressive strength and the splitting tensile strength, regression model analysis was performed and it was found that GPC's mechanical behavior is close to that of concrete (OPC).

A research on geo-polymers formed by mixing fly ash, kaolinite, sodium silica solution, Na OH and water was conducted by Swanepoel and Strydom [13]. The compressive strength was influenced by both the curing time and the curing temperature, and the optimum strength prevailed when the specimens were cured for duration of 48 h at 60 ^{o}C. The chemical components of geo-polymer concrete vary from those of OPC concrete, where geo-polymers are formed instead of calcium silicate hydrate (C-S-H) gel from geo-polymeric aluminosilicate hydrate (A-S-H) gel. Therefore, studying the diffusion-reaction of geo-polymer concrete is of special importance.

The Impact of silica fume on the durability characteristics of GPC based on fly ash has been investigated by immersing the cubes in solutions of 2% sulphuric acid and 5% sodium chloride [16]. Visually, the resistance of samples to chemical attack was measured, assessing changes in weight and percentage losses in compressive strength at different time intervals [20].

Service conditions [15] do not generally reflect continuous immersion of test specimens. In operation, concretes, especially those near the coasts or those used in piping systems, are typically subjected to environmental impacts such as wetting-drying and heating-cooling.

It is found that marine conditions are very violent, as sea water consists mainly of sodium chloride and sodium sulphate. Actually, in conjunction with the presence of water and salts, heating-cooling cycles reflect many deterioration scenarios, such as freezing and thawing and chemical attack. Moreover, heating-cooling and wetting-drying cycles are the conditions for certain oxidation processes, such as crystallization pressure and thermal pressures. Therefore, it is important to determine the deterioration processes in this situation in order to be able to forecast the behavior of a concrete subjected to wet-dry and heat-cool conditions during its service life.

II. MATERIALS PROPERTIES

Fly ash, coarse and fine aggregates, water, and alkaline liquid (sodium hydroxide and silicate of sodium) have been used in manufacturing geo-polymer concrete (GPC) in this research.

2.1. Fine aggregate

In the concrete mix, natural silica sand was used as a fine aggregate. It was clean and almost free from impurities. Sieve analysis of the fine aggregate was carried out in the laboratory as shown in Fig (1). In order to eliminate any particle larger than .475 cm, the sand was first sewn into a .475 cm sieve. The fineness modulus of the used sand has been found to be 3.00. In the table, the properties of the sand used are given (1).

TABLE (1)
CHARACTERISTICS OF FINE AGGREGATE.

Property	Test Result
Specific gravity	2.65
Volumetric weight (kg/m^3)	1660
Voids ratio	35%
Fineness modulus	3.00
Clay, silt and fine dust (by weight)	1.4%

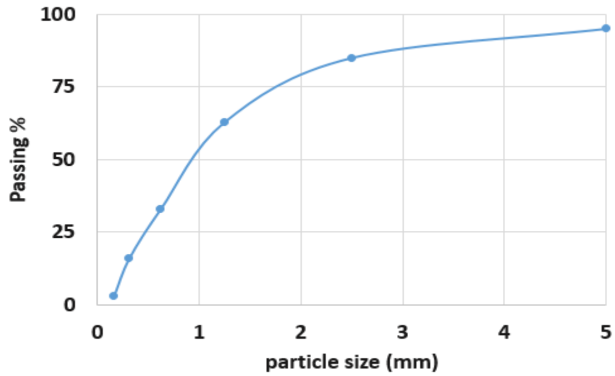

Fig (1): Sieve analysis for fine aggregate

2.2. Coarse aggregate

Crushed graded hard Dolomite (locally available) was used in the concrete mix throughout the experimental study. Dolomite has maximum size of 3/4" (1.9 cm). General shape was angular and sub-angular; the surface texture was rough, uniform and free from any undesired impurities. The physical characteristics of the crushed dolomite, these are listed in the Table (2).

TABLE (2)
COARSE AGGREGATE CHARACTERISTICS.

Property	**Test Result**
Type	Crushed
Specific gravity	2.63
Volumetric weight (kg/m3)	1500
Total water absorption	1.6%
Fineness modulus	6.90

2.3. Fly ash

Sika Company in Egypt produced fly ash Type F used in this research. Fly ash is generally used in the powder form of spherical particles as a concrete admixture; fly ash characteristics are listed in Table (3).

TABLE (3)
FLY ASH CHARACTERISTICS.

Presentation	**Fine-split dry powder**
Colour	Light grey colour
Bulk Weight	≈ 0.90 ton/m^3
Specific density	≈ 2.30 ton/m^3
Size of particle	90% < 45 micron
Particle shape	Spherical

2.4. Alkaline Liquid

The most popular alkaline liquid used in geo-polymerization is a mixture of sodium hydroxide (Na OH) or potassium.

Alkaline liquid plays an essential part in the polymerization process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. The alkaline solutions used to prepare the GPC were sodium hydroxide and sodium silicate.

2.5. Water

Clean potable fresh water free from impurities was used for mixing and curing the OPC concrete mix which used as a control mix for GPC mixes. The water was free from impurities, organic matter, silt, oil, sugar, acidic material.

2.6. Cement

Ordinary Portland cement was provided from Suez-factory and used in this experimental work for the preparation of the OPC concrete specimens. The cement has a uniform color and free from any hard lumps. The usual chemical and physical properties are in compliance with the Egyptian Standard Specification ES4756-1:2011. Table (4) presents the properties of the used Portland cement.

TABLE (4)
PROPERTIES OF ORDINARY PORTLAND CEMENT.

Test Description	ES4756-1:2011 Specification Limits	Test Results
Fineness of cement percentage (retained on the standard 0.09 mm sieve by weight)	≤ 10%	2 %
Soundness of cement (Le Chatelier test)	≤ 10 mm	3.5 mm
% water to give a paste of standard consistency, w/c %	---	26 %
Setting Time (Vicat test): Initial Final	 ≥ 45 min. ≤ 10 hr.	Hr. : Min. 1 : 30 7 : 00
Compressive strength of mortar 7x7 cm cubes after 3 days after 7 days	 ≥ 160kg/cm^2 ≥ 240kg/cm^2	 215 kg/cm^2 290 kg/ cm^2

III. SPECIMENS PREPARATION

For first stage

The first stage concerned with evaluating the influence of the mix proportion parameters on the main mechanical properties of GPC. Eleven geopolymer concrete mixes were prepared. The experimental program includes the determination of basic properties of the different geopolymer concretes. The

parameters investigated were fly ash content, degree of molarity solution, ratio of alkaline liquid to fly ash content, curing conditions, ratio of fine aggregate to coarse aggregate as shown in Table (5).

From each mixture, three different types of specimens were prepared: cubes (10 x 10 x 10 cm), cylinders (10 cm diameter, 20 cm high) and beams (10 x 10 x 50 cm).

For second stage

The second stage aims to evaluate the durability of geopolymer concrete in comparison with OPC concrete. This stage includes eighteen geopolymer concrete mixes and, also, eighteen OPC concrete mixes. All the specimens were cubes of 7 cm. The specimens were exposed to three different salt solutions; magnesium sulphate ($Mg\ SO_4$), sodium sulphate ($Na_2\ SO_4$) and sodium chloride (Na Cl). The salt solutions were prepared with two concentrations (5% & 10%). All solutions were made by dissolving the salt solids in water then the salt solution was diluted by additional water according to the required concentration. The solutions used for specimens immersion, were replaced every three weeks to refresh it. The specimens were immersed for three periods (3, 6 & 9 weeks).

For each period, the specimens immersed for 6 days then they were extracted and dried in oven (110 °C) during 24 hours, and then re-immersed in the salt solution. The wetting – drying cycles help to accelerate the degradation of concrete specimens under the effect of salt solutions. Table (6) presents the different mix groups of this stage. For each mix, three typical cubic specimens were used to study the effect of every exposure case. The OPC concrete specimens are used in this stage for comparison. The OPC concrete had the same grade (compressive strength) as the geopolymer concrete.

3.1. Preparation of geopolymer specimens

The solids of sodium hydroxide (Na OH) were immersed in water for a day until they were fully dissolved. The mass of Na OH solids in the solution ranged according to the molar concentration of the solution, M. A fraction of the Na OH solution was the mass of Na OH solids and the main component was water. The sodium silicate solution and the sodium hydroxide solution were mixed together for at least half an hour to prepare the alkaline solvent.

TABLE (5)
PROPORTIONS OF GEOPOLYMER MIXES AND THEIR MECHANICAL PROPERTIES

Group	**Code**	**Parameters**						**Compressive strength kg/cm²**	**Splitting tensile strength kg/cm²**	**Flexural strength kg/cm²**
		Variable	**Fly ash content kg**	**Degree of molarity**	**Ratio of alkaline liquid**	**Curing conditions**	**Ratio of fine aggregate to coarse aggregate**			
	F1		400					320	33.3	60.3
G1	F2	Fly ash content	500	14	0.6	2 d. in oven + 5 d. in Air	1 : 2	304	32.8	61
	F3		600					226	29.9	53.2
	M1			12				308	31.7	57.7
G2	M2	Degree of molarity	500	14	0.6	2 d. in oven + 5 d. in Air	1 : 2	304	32.8	61.9
	M3			16				341	33.9	63.1
	A1				0.5			380	33.1	69.5
G3	A2	Ratio of alkaline liquid	500	14	0.4	2 d. in oven + 5 d. in Air	1 : 2	313	31.4	64.3
	A3				0.6			304	32.8	61.9
	C1					1 d. in oven + 6 d. in Air		269	30.6	60.2
G4	C2	Curing condition				2 d. in oven + 5 d. in Air		304	32.8	61.9
	C3		500	14	0.6	3 d. in oven + 4 d. in Air	1 : 2	297	32.8	62.1
	R1						1 : 1.5	341	30.5	56.4
G5	R2	Ratio of fine aggregate to coarse aggregate	500	14	0.6	2 d. in oven + 5 d. in Air	1 : 1.7	311	32.2	62.2
	R3						1 : 2	304	32.8	61.9

TABLE (6)
PROPORTIONS OF GEOPOLYMER MIXES AND HARDENED PROPERTIES OF MIXTURES.

Group / solution	Code	Cementitious material Type	Concentration of the solution %	No of periods	Weight loss %	Absorption %	f_{cu} (Kg/cm^2)
A/ Na_2SO_4	ACI 1	OPC Concrete	5	3	1.73	.96	301
	ACI 2		5	6	1.68	1.35	269
	ACI 3		5	9	2.14	1.53	260
	ACII 1		10	3	2.24	.93	286
	ACII 2		10	6	2.28	1.38	252
	ACII 3		10	9	2.7	1.46	228
	AGI 1	Geopolymer Concrete	5	3	2.05	2.01	312
	AGI 2		5	6	2.09	2.94	290
	AGI 3		5	9	2.92	3.5	276
	AGII 1		10	3	2.3	2.46	301
	AGII 2		10	6	2.42	2.91	275
	AGII 3		10	9	3.46	3.39	255
B/ NaCl	BCI 1	OPC Concrete	5	3	1.91	.97	285
	BCI 2		5	6	2.05	1.35	263
	BCI 3		5	9	2.46	2.09	261
	BCII 1		10	3	2.06	1.15	281
	BCII 2		10	6	2.17	1.51	261
	BCII 3		10	9	2.93	2.16	252
	BGI 1	Geopolymer Concrete	5	3	2.34	2.58	366
	BGI 2		5	6	2.16	2.95	350
	BGI 3		5	9	3.5	3.25	279
	BGII 1		10	3	2.43	2.68	345
	BGII 2		10	6	2.64	3.17	300
	BGII 3		10	9	3.65	3.34	266
C/ $MgSo_4$	CCI 1	OPC Concrete	5	3	1.9	.95	275
	CCI 2		5	6	2.16	1.25	271
	CCI 3		5	9	2.69	1.57	256
	CCII 1		10	3	2.11	.89	272
	CCII 2		10	6	2.27	1.25	268
	CCII 3		10	9	3.44	1.33	223
	CGI 1	Geopolymer Concrete	5	3	2.12	2.44	298
	CGI 2		5	6	2.31	2.64	287
	CGI 3		5	9	3.38	3.04	267
	CGII 1		10	3	2.32	2.48	286
	CGII 2		10	6	2.4	2.93	271
	CGII 3		10	9	4.49	3.13	232

In a small pan mixer, the fly ash and alkaline liquid were first mixed for about 4 minutes to form binder material, then the aggregates were applied to the binder material and the mixing continued for another 4 minutes, obtaining fresh geopolymer concrete as shown in Figs. (2-4). The consistency of geopolymer concrete mixes was estimated by flow test T500, as shown in Figs. (5-6). The fresh concrete was cast into the molds directly after mixing, into three layers for cylindrical specimens, cube specimens and two layers for prism specimens. For the compaction of the specimens, 60 to 80 manual strokes were provided to each layer using a rodding bar with a diameter of 1.6 cm and a length of 60 cm, as shown in Fig (7). The specimens were heat-cured at 60 °C for 24 hours 48 hours and 72 hours. The specimens of second stage were immersed in different salt solutions, as shown in Figs. (8 & 9), and then wet- dry cycles were applied.

3.2. Preparation of OPC concrete specimens

Before placing, the specimen molds were tightly assembled and checked for dimensional accuracy and well cleaned. A 120-liter capacity mixer was used with a speed of about 50 revolutions per minute. In the following series, the concrete contents of the mixer drum were added: coarse aggregate, sand and cement. The dry components were mixed for one minute without water, then water was added and the process proceeded for another three minutes to ensure proper mixing. The forms were painted with a thin layer of oil before casting, so that the specimens can be easily removed from the mould after 24 hours.

Mix components were coarse aggregate (1060 Kg/m^3), fine aggregate (663 Kg/m^3), cement content (470 Kg/m^3), and water content (210 Kg /m^3).

3.3. Durability evaluation of geopolymer concrete

The durability of geopolymer concrete was evaluated in comparison with the OPC concrete by exposing the concrete specimens to different solutions of different concentrations, and under different exposure periods as mentioned before. At the end of each period (3, 6 & 9 weeks), the weight loss, compressive strength and water absorption were determined.


Fig (2): Mixer pan.


Fig (3): Adding fine aggregate


Fig (4): Fresh geopolymer concrete


Fig (5): Flow test (T500)


Fig (6): Measuring diameter, flow test (T500)


Fig (7): Compacting geopolymer


Fig (8): Adding Solutions.


Fig (9): Immersion in solutions

IV. RESULTS AND DISCUSSIONS

The results of compressive strength, tensile strength, and flexural strength for all parameters of stage one is shown in Table (5). Also, the results of the second stage which includes the weight loss, water absorption and compressive strength for both cement concrete and geopolymer concrete, are presented in Table (6). To reveal the impact of the parameters considered in this study, comparisons were carried out between the effects of different mixes.

4.1.1 Effect of Alkaline Liquid-to-Fly Ash ratio

The used ratios of alkaline liquid-to-fly ash content were 0.4, 0.5 and 0.6. The effect of this parameter could be observed by comparing the mechanical properties of mixes A1, A2 and A3. The compressive strength, splitting tensile strength and flexural strength for mixes with different ratios content at 7 days age are shown in Figs. (10-12).

The obtained results of compressive, splitting tensile and flexural strengths revealed that the optimum ratio of alkaline liquid to fly ash was 0.5, where increasing the ratio of alkaline ratio of alkaline liquid to fly ash content from 0.4 to 0.5 enhances all the determined strengths. However, increasing the ratio from 0.5 to 0.6 decreases the strengths. It seems that alkaline liquid to fly ash ratio of 0.5 produces the best geopolymerization process which led to better bond between molecules.

4.1.2. Curing time

The influence of this parameter was observed by studying the behavior of three mixes (C1, C2 & C3), which correspond to three different times of curing, first group (C1) was cured for 1 day in oven then 6 days in Air, second group (C2) was cured for 2 days in oven then 5 days in Air and third group (C3) was cured for 3 days in oven then 4 days in Air. The specimens were cured in oven under temperature of 60 °C.

The obtained results of compressive, splitting tensile and flexural strengths revealed that the optimum curing duration time was 2 days in oven then 5 days in air as shown in Figs. (13-15).

Increasing the curing time improves the polymerization process resulting in higher compressive strength, tensile strength and flexural strength. The rate of strength increasing was rapid up to 48 hours of curing time. This result indicates that longer curing time over 2 days did not improve significantly the strength of geopolymer concrete as shown in Figs. (13-15).

4.1.3. Fly ash content

A study of the hardened properties of mixtures F1, F2 and F3 corresponding to three different fly ash contents (400, 500 and 600 kg/m3) may be used to observe the effect of this parameter.

The obtained results of revealed that the optimum fly ash content was ranged from 400 to 500 kg/m^3 as shown in Figs (16-17). It seems this range produce the best geopolymerization process which led to better bond between molecules.

As shown in Fig (16), increasing the fly ash content from 500 to 600 kg/m^3 leads to decrease the compressive strength, splitting tensile strength and flexural strength by 26%, 9% and 14%, respectively. This may be caused due to decreasing the workability of fresh geopolymer concrete when higher fly ash content was used, which lead to reduce the efficiency of compacting process.

4.1.4. Degree of molarity

It was possible to observe the effect of this parameter by comparing the mechanical properties of the mixtures M1, M2 and M3, corresponding to three different degrees of molarity 12, 14 and 16, it was noticed that increasing degree of molarity produce significant increase in all mechanical properties of geopolymer concrete as shown in Figs(19-21). Increasing molarity from 12 to 16 led to increase the compressive strength, splitting tensile strength and flexural strength by 11%, 7% and 10% respectively. It seems that increasing the degree of molarity lead to increase the flow ability and homogeneity of the concrete mixes.

4.1.5. Fine aggregate to coarse aggregate ratio

An analysis of the behavior of three mixes (R1, R2 & R3) corresponding to three different combinations of the fine aggregate to coarse aggregate ratio may be used to observe the effect of this parameter. The three mixes had ratio of fine aggregate to coarse aggregate 1:1.5, 1:1.7 and 1:2, respectively. Increasing the proportion of coarse aggregates in the mixture leads to decrease compressive strength by about 11% as shown in Fig (22), this may be caused due to increase the amount of aggregates and thus the lack of uniformity of the mixture and the presence of voids. However, increasing the proportion of coarse aggregates in the mixture leads to increase both of the splitting tensile strength and flexural strength by about 6.9% and 9.7%, respectively, as shown in Figs (23 & 24).

4.2. Effect of some salt solutions on the durability of geopolymer concrete

4.2.1. Water absorption

The effects of the different chemical solutions used in this study of both geopolymer and cement concrete are shown in Figs (25 & 26), for solutions concentrations 5% and 10%, respectively. Geopolymer concrete showed an increase in water absorption ratio (water absorption to water absorption control) comparing with OPC concrete after 9 weeks by about 176% & 184% for 5% & 10% solutions concentration, respectively. Also, it was noticed that sodium chloride (Na Cl) solution has aggressive effect on the cement concrete at all periods (3, 6 & 9 weeks), for both concentrations (5% and 10% solutions). Figs. (25-26) show also that sodium chloride (Na Cl) solution has a great effect on geopolymer concrete for the first six weeks but after that we notice that at 9 weeks solution of sodium sulphate (Na_2 SO_4) showed very slight effect on geopolymer concrete for 5% & 10% concentrations, respectively, compared to the OPC mixes.

4.2.2. Weight loss

The weight loss results of both GPC and OPC concrete specimens exposed to the different used chemical solutions are shown in figs 27 & 28 for 5% and 10% solution concentrations, respectively.

Generally, it is noticed that the specimens' weight remains, almost constant during the first and second periods (3 & 6 weeks) then the weight loss increased significantly at the last period (9 weeks). This can be attributed to, (i) the inclusion of the chemical particles that penetrate the concrete within the solution, which resulting an increase in concrete weight during the early ages, and (ii) the expansion of several elements inside the concrete during early ages which cause later harmful effects due to cracks formation. Also, it was noticed that the magnesium sulphate Mg SO_4 have the most effect on the both concretes. For different chemical solutions of 5% concentration, the weight losses of geopolymer concrete specimens after 9 weeks of immersion were ranged from 2.9 to 3.6%, as shown in Fig. (27), while the range of weight loss for OPC concrete specimens was from 2.1 to 2.8 %. For 10% solution concentration, the weight loss of geopolymer concrete specimens after 9 weeks was from 3.4 to 4.5%, while the corresponding range for OPC concrete was from 2.7 to 3.4%, as shown in Fig. (28).

It is evident that the immersion of tested specimens in the used salt solutions for 9 weeks led to more weight loss for geopolymer concrete specimens than OPC concrete, by about 33% and 30%, for the 5% and 10% concentrations, respectively.

4.2.3. Compressive strength

The percentage of compressive strength of both geopolymer and OPC concrete with respect to the control mix, for all specimens exposed to chemical solutions of 5% and 10% concentrations are presented in Figs. 29 and 30.

As expected, increasing the chemical solution concentrations (from 5% to 10%) and the period of immersion (till 9 weeks) lead to decrease the compressive strength of both concrete types. The type of chemical solution was effective, also, on the compressive strength reduction, where magnesium sulphates solution was the more aggressive one, especially at 3 & 6 week periods.

The compressive strength of GPC specimens was reduced to 69% and 60% after 9 weeks of immersion in magnesium sulphates solution of 5% and 10% concentrations, respectively, and the corresponding values for OPC concrete were 67% and 58%.

Immersing the geopolymer concrete specimens in sodium chloride solution of 5% and 10% for 9 weeks led to reduce the compressive strength to 72% and 69%, respectively, and the corresponding values for OPC concrete were 68% and 66%.

V. CONCLUSIONS

Throughout this research, geopolymer has been used as an alternative binder to replace Portland cement concrete. The main mechanical properties of geopolymer concrete were studied under various mix parameters. Also, the durability characteristics of geopolymer concrete were investigated under various salt solutions attacks in comparison with OPC concrete of similar grade.

The following conclusions can be drawn based on the results and discussions reported in this paper:

1- The highest compressive strength of geopolymer concrete (387 Kg/cm^2), was achieved when 500 Kg/m^3 fly ash content was used, 14 M degree of molarity, 0.6 alkaline liquid to fly ash content ratio, 1:2 fine aggregate to coarse aggregate ratio and the specimens were cured for 3 days in oven.

2- Immersion of the tested specimens in the used chemical solutions for 9 weeks leads to more weight loss for geopolymer concrete specimens than OPC concrete specimens, by 33% and 30%, for 5% and 10% concentrations, respectively.

3- The most affecting salt solutions on both geopolymer concrete and OPC concrete was the magnesium sulfate solution where the compressive strength decreased after 9 weeks of immersion and drying cycles in this solution at a concentration of 10% to 67% and 58% of the compressive strength of the control mixture for both geopolymer concrete and OPC concretes, respectively.

4-

eopolymer concrete showed an increase in water absorption after 9 weeks by about 176% & 184% for 5% & 10% solution concentrations, respectively, in comparison with OPC concrete.

5-

eopolymer concrete specimens had more weight loss than OPC concrete by about 33% & 30% for 5% & 10% solutions concentration, respectively.

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Title Arabic:

تأثير معاملات التركيب وظروف المعالجة ومحاليل الملح على خواص الخرسانة الجيوبوليمرية

Arabic Abstract:

يعتبر الطلب المتزايد على البناء الصديق للبيئة القوة الدافعة لتطوير مواد بناء مستدامة واقتصادية. المكون الأساسي للخرسانة هو الأسمنت البورتلاندي، والذي لا يعتبر من المواد الصديقة للبيئة. تكتسب الجيوبوليمرات اهتمامًا متزايدًا كمواد رابطة ذات انبعاثات منخفضة لثاني أكسيد الكربون مقارنة بالأسمنت البورتلاندي . يتكون هذا البحث من مرحلتين أساسيتين، المرحلة الأولى تبحث في تأثيرات عدة معاملات على خواص الخرسانة الجيوبوليمرية القائمة على الرماد المتطاير، وخاصة مقاومة الضغط، ومقاومة الشد، ومقاومة الانحناء، والمعايير المدرجة هي محتوى الرماد المتطاير، ودرجة محلول المولارية، نسبة السائل القلوي إلى محتوى الرماد المتطاير، ظروف المعالجة، نسبة الركام الناعم إلى الركام الخشن في تقييم الخصائص الجيوبوليمرية. تهتم المرحلة الثانية من البحث بتحمليه الخرسانة الجيوبوليمرية المصنعة باستخدام الرماد المتطاير فئة F. كما تم فحص أداء الأسمنت البورتلاندي العادي كمرجع لتقييم تحمليه الخرسانة الجيوبوليمرية. تمت دراسة تأثير المحاليل الملحية بتركيزات مختلفة خلال فترات مختلفة من دورات البلل والجفاف على فقدان الوزن وامتصاص الماء ومقاومة الضغط للخرسانة الجيوبوليمرية. وفقًا لنتائج المرحلة الأولى، فإن أفضل المعاملات، والتي أعطت أعلى الخصائص الميكانيكية للخرسانة الجيوبوليمرية، كانت محتوى الرماد المتطاير 400 كجم / م 3، ودرجة المولارية 16 جزئي، ووقت المعالجة 3 أيام في الفرن، ونسبة السائل القلوي للرماد المتطاير 0.5، ونسبة الركام الناعم إلى الركام الخشن 1: 2، حيث وصلت مقاومة الضغط إلى أعلى قيمة لها (387 كجم / م2) .أظهرت نتائج المرحلة الثانية أن الخرسانة الجيوبوليمرية أقل تأثراً من الخرسانة الأسمنتية فيما يتعلق بمقاومة الضغط وأكثر تأثراً بفقدان الوزن وامتصاص الماء. حيث أظهرت الخرسانة الجيوبوليمرية زيادة في نسبه الامتصاص مقارنة بالخرسانة الاسمنتيه بعد 9 أسابيع من البلل والجفاف في محاليل الملح بحوالي 176٪ و 184٪ لتركيز 5٪ و 10٪ على التوالي. أيضا، أظهرت زيادة في فقدان الوزن لعينات الخرسانة الجيوبوليمرية بالمقارنة بالخرسانة الاسمنتيه بحوالي 33٪ و 30٪ لتركيز 5٪ و 10٪ محاليل على التوالي. مع ذلك، أظهرت الخرسانة الجيوبوليمرية انخفاضًا أقل في مقاومة الانضغاط بسبب التعرض لمحاليل الملح (دورات رطبة - جافة) بالمقارنة بالخرسانه الاسمنتيه لتركيزات المحلول 5٪ و 10٪ ، حيث كان متوسط النقصان في مقاومة الضغط للخرسانه الجيوبوليمريه 18% و 25 ٪ على التوالي، بينما كانت قيم النقصان المناظرة في الخرسانه الاسمنتيه 25% و34٪.