

Physico-Chemical and Mechanical Properties of Geopolymer Materials

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Abstract

Physico-chemical and mechanical properties of geopolymer materials (cement, mortar, and concrete) were studied. Various mixes are prepared using different liquid/solid ratios (L/S) by weight. Sodium hydroxide pellets (SH) and commercial sodium silicate liquid (SSL) are used as an activator which is dissolved in the mixing water. The hydration characteristics of the different mixes have been tested via determination of bulk density, total porosity, combined water, compressive strength, and XRD analysis at different time intervals from 1 up to 180 days in water. The results showed that the combined water content of the geopolymer materials gradually increases up to 180 days in all mixes. The bulk density increases while the total porosity decreases, as a result of the chemical reaction (geopolymerization process) with formation of new products fill the pores. The compressive strength also increases up to 180 days in all mixes. The data show that SSF1 (95% GGBFS+5 % SF) activated by (24.4% by wt. SSL, and 4 M SH), S3 (100 % GGBFS) activated by (21.7% by wt. SSL, and 4 M SH), and SMK1 (50 % GGBFS+50 % MK) activated by (31.8 % by wt. SSL, and 4 M SH) all in 95% R.H conditions are the most appropriate binding materials (geopolymer pastes) that have good different properties. GM 3 (100 % GGBFS) with a standard sand show the most appropriate mortar mix in different properties. GP Conc. 4 (100 % GGBFS) with a standard sand, and dolomite aggregate in 95% R.H showed the most appropriate concrete mix in different properties, that can be used as alternative building material to the ordinary Portland concrete.

Keywords: Artificial pozzolana, dolomite, geopolymer, and sodium silicate.

1. Introduction:

Geopolymer is a class of inorganic polymers formed by reacting silica-rich and alumina-rich solids with a high alkaline solution, which combines the properties of polymers, ceramics and cements. Nowadays, geopolymer studies are receiving noteworthy increasing attention because they may be used as a viable economical alternative to organic polymers and inorganic cements in diverse applications, such as aircraft, high-tech ceramics,

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thermal insulating foams, fire-proof building materials, protective coatings, refractory adhesives and hybrid inorganic-organic composites. This interest is due to their exceptionally high thermal and chemical stability, excellent mechanical strength, adhesive behavior and long-term durability.

Geopolymers are amorphous to semi-crystalline equivalent of certain zeolitic materials with excellent properties, such as high fire and erosion resistances, and high strength materials. Recent works have shown that the addition of moderate amount of minerals to a geopolymer can give significant improvements on the geopolymer structure and properties. The alkaline activation of materials can be defined as a chemical process that provides a rapid change of some specific structures, partial or totally amorphous, into compact cemented frameworks.

Many industrial by-products and other kinds of minerals can be used to produce the geopolymers. The geopolymerization reaction is very sensitive to different raw materials (particle size and distribution, crystallization degree), nature of alkali-activators (Sodium/potassium hydroxide, Sodium/potassium silicate, the ratio of these two), Si/Al ratios, water/ash ratios, curing conditions (temperature, moisture degree, opening or healing condition, curing time) (**Alehyen, Achouri, & Taibi, 2017**).

Geopolymer materials are such as blast furnace slag that is produced from the manufacture of pig iron. It forms when slagging agents (e.g., coke ash and limestone) are added to the iron ore to remove impurities. In the process of reducing iron ore to iron, a molten slag forms as a nonmetallic liquid (consisting primarily of silicates and aluminosilicates of calcium and other bases) that floats on top of the molten iron, slag was the first cementitious materials to be activated by alkali and due to its latent hydraulic properties(**Li Sun et al., 2010**), also silica fume (SF) that is a byproduct of the smelting process in the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000°C produces SiO₂ vapors, which oxidizes and condense in the low temperature zone to tiny particles consisting of non-crystalline silica(**Chandra et al., 2002**). Silica fume has been used as a high pozzolanic reactive cementitious material to make high-performance concrete in the severe conditions. This mineral admixture has highly been used in severe environmental conditions despite its several mixing and curing problems because of its acceptable early-age strength development (**Khater, 2013**).

Metakaolin is refined kaolin clay that is fired under carefully controlled conditions to create an amorphous aluminosilicate that is reactive in concrete. Like pozzolans such as silica fume, fly ash and blast-furnace slag, metakaolin reacts with the calcium hydroxide by-products produced during cement hydration. The particle size of metakaolin is generally smaller than cement particles, though not as fine as silica fume [**Sherif, 2017**].

Geopolymers are relatively new type of binders that have been developed and are commercially available elsewhere in the world. Geopolymers are substantially superior to Portland cement in all performance measurements. Geopolymers require 30-60% less

energy to make and release about 80% less carbon dioxide into the atmosphere, unlike Portland cement. This is because the source materials for geopolymers are by-products that have already gone through combustion in a power plant, or milling in a mine, which are processes analogous to transforming limestone into Portland cement clinker. Geopolymer can also use to make mortar, grout, concrete, and reinforced concrete [Sonafrank, 2010].

2. Materials and Method

2.1 Materials

The materials used in this investigation were ground granulated blast furnace slag (GGBFS), metakaolin (MK), silica fume (SF), sodium hydroxide pellets (SH), commercial sodium silicate liquid (SSL), local or standard sand, and dolomite aggregate. The chemical compositions of the used materials are given in Table (1).

Table (1): Chemical composition of the starting materials, (mass %)

Oxides Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	Cl	L.O.I	Total
Slag	34.10	12.40	0.77	42.30	6.50	0.90	0.35	0.26	0.08	1.50	99.08
Silica fume	92.20	2.50	2.80	0.49	0.40	0.15	0.40	0.20	0.00	2.14	101.28
Meta Kaolin	64.80	30.10	0.55	0.52	2.3	0.13	0.40	0.10	0.06	0.73	99.70

2.2. Procedure

Different mixes (paste, mortar, and concrete) are prepared as shown in Table (2.3, and 4). Sodium hydroxide pellets (SH) and commercial sodium silicate liquid (SSL) are used as an activator dissolved in the mixing water. The pastes are mixed in an automatic mixer for 2 minutes. The pastes are molded in the form of one cubic inch molds [Khater, 2013], and jolted well by the jolting table. The geopolymer pastes are cured at about 100 % relative humidity at room temperature for 1 day in the incubator. The hardened cement pastes are then removed from the molds after attaining the final setting. Curing conditions were at water and 95 % RH for different time intervals.

Table (2): Mix composition, liquid/solid (W/S) paste ratio and designations.

No.	Mix Abb.	GGBFS	SF	MK	Curing	SSL (%)	SH Conc. (M)	SH (%)	SH: SSL Ratio (Vol.)	L/S Ratio (%)
1	S 1	100	-	-	In 95% RH	24.4	2	10	1:1	28.7
2	S 2	100	-	-	In Water	24.4	2	10	1:1	28.7
3	S 3	100	-	-	In 95% RH	21.7	4	20	1:1	26.6
4	S 4	100	-	-	In 95% RH	22.3	6	30	1:1	26.3
5	S 5	100	-	-	In 95% RH	24.2	2	10	1:2	28.6
6	S 6	100	-	-	In 95% RH	24.0	2	10	2:1	28.3
7	S 7	100	-	-	In 95% RH	24.0	4	20	1.5:1	28.5
8	SMK1	50	-	50	In 95% RH	31.8	4	20	1:1	37.5
9	SMK2	33.3	-	66.6	In 95% RH	32.8	4	20	1:1	38.7
10	SSF1	95	5	-	In 95% RH	24.4	4	20	1:1	28.7
11	SSF2	90	10	-	In 95% RH	24.4	4	20	1:1	29.3

The mortar is prepared after the optimum condition in paste are taken by mixing powder with sand (local or standard sand according to EN 196-1), and liquid with sand: powder: liquid ratio 3:1:0.5 according to EN 196-1 after mixed in the automatic mixer, mortar placed in the stainless steel mold $500 \times 500 \times 500$ mm cubic shaped molds according to ASTM C150, then put the mold in the Toni Technik jolting table. Then cured in different conditions, the concrete is prepared after the optimum condition in mortar are taken by mixing powder with sand (local or standard sand according to EN 196-1) as mention before with small aggregate (Dolomite stones), and liquid with aggregate:sand:powder: liquid ratio 3:2:1:0.5 according to ISO 1920 after mixed in concrete mixer, concrete placed in the stainless steel mold $700 \times 700 \times 700$ mm cubic shaped molds, then put the mold in the Toni Technik jolting table. Also curing condition was as mention.

Table (3): Mix composition, liquid /solid (W/S) mortar ratio and designations.

No.	Mix Abb.	GGBFS (%)	liquid : Powder : Sand	Sand Type	Curing	SSL (%)	SH Conc. (M)	SH (%)	SH : SSL Ratio	L/S Ratio (%)
1	GM1	100	0.5 : 1 : 3	Local	In 95% RH	10.5	2	10	1:1	12.5
2	GM2	100	0.5 : 1 : 3	Local	In Water	10.5	2	10	1:1	12.5
3	GM3	100	0.5 : 1 : 3	Stand.	In Water	10.5	4	20	1:1	12.5
4	GM4	100	0.5 : 1 : 3	Local	In Water	10.5	4	20	1:1	12.5
5	GM5	100	0.5 : 1 : 3	Local	In 95% RH	10.5	4	20	1:1	12.5

Table (4): Mix composition, liquid /solid (W/S) concrete ratio and designations.

No.	Mix Abb.	GGBFS (%)	Liquid : Powder : Sand : Aggregate	Sand Type	Curing	SSL (%)	SH Conc. (M)	SH (%)	SH : SSL Ratio	L/S Ratio (%)
1	GP Conc1	100	0.5:1:2:3	Local	In Water	6.5	4	20	1:1	7.7
2	GP Conc2	100	0.5:1:2:3	Stand.	In Water	6.5	4	20	1:1	7.7
3	GP Conc3	100	0.5:1:2:3	Local	In 95% RH	6.5	4	20	1:1	7.7
4	GP Conc4	100	0.5:1:2:3	Stand.	In 95% RH	6.5	4	20	1:1	7.7

2.3. Methods of investigation

The hydration characteristics of the different geopolymer mixes are investigated via:

1. Determination of bulk density, total porosity, and combined water content.
2. Determination of water consistency, and setting time (initial, and final).
3. Compressive strength measurements using compression and bending test plant ToniPRAX according to EN-ISO 4012 with a load measuring range from 3 to 300 KN.
4. X-ray diffraction analysis to identify the hydration products formed at different ages of the different mixes using ARL XTRA X-ray diffractometer.

3. Results and Discussion:

3.1. Combined water content (W_n %)

The results of chemically combined water contents (W_n) for all paste mixes cured in water and 95% RH up to 180 days are represented in Tables (5). The W_n content can be adopted as a criterion to evaluate the relative amount of hydration products and the relative hydration degrees between different samples with the same kind of hydration products. It is clear that the combined water content of the alkali-activated GBFS pastes (S1-SSF2) gradually increases up to 180 days in water and 95% RH. as shown in Table (5). This may be due to the continuous hydration and accumulation of hydrated products, which are deposited in the available open pores [Darweesh, 2005, El-Didamony, 2008].

The W_n content of mix S1 at the age of 2 days in H₂O is 4.88 %, but at mix S4 at the same age reaches 7.63 %, indicating that the degree of hydrolytic destruction of alkali activated GBFS increases with the content of Na₂O. Table (5) indicates that the influence of

increasing alkalinity on the hydration of GBFS increases with age. At the age of 180 days, Wn contents of the mixes S1, and S4 are 7.13 %, and 9.00 %, respectively, i.e., as the hydration time increases, the amount of hydration products increases. Hence, the chemically combined water content increases. Which may be mainly due to the highest hydraulic properties of GBFS with increasing the alkaline concentration. So, S4 shows the highest value of the chemically combined water of all mixes due to the highest concentration of the activator. In 95% R.H S2 showed higher Wn% than S1 in water curing conditions in all times, this may explain in 95% R.H reaction occurs better and more amount of products formed, also the combined water content of the alkali activated GBFS pastes gradually increases up to 180 days in all mixes as shown in Table (5).

Table (5): Chemically combined water content (Wn %) for all paste mixes cured up to 180 days cured in water and 95% RH.

Days	2 d	7 d	28 d	90 d	180 d
Mix	Wn %				
S 1	4.88	5.61	6.94	6.99	7.13
S 2	6.27	7.61	8.83	9.21	9.30
S 3	4.26	6.31	7.51	8.00	8.70
S 4	7.63	7.78	7.92	8.20	9.00
S5	4.51	5.32	6.42	7.55	7.60
S 6	5.21	6.31	7.20	7.90	8.50
S 7	6.00	6.50	7.20	8.10	8.50
SMK 1	6.23	7.55	8.21	9.31	9.70
SMK 2	6.50	7.33	7.98	8.32	8.50
SSF 1	5.96	6.25	6.92	7.50	8.20
SSF 2	6.51	7.30	7.50	8.20	8.50

3.2.Compressive strength (kg/cm²)

The compressive strength of the hardened geopolymer(pastes, mortar, and concrete) cured in water and 95% R.H are shown in tables (6-8). The compressive strength of all mixes increases with curing time in different curing conditions. However, Mix SSF1 shows the highest values of compressive strength as paste at most of curing ages of hydration. As the amount of alkali activator increases up to 4 M, the compressive strength increases [Darweesh, 2006]. It is clear that the values of the compressive strength are related to the formation of more hydration products, which may be due to the acceleration of the activation process. Further increase in Na₂O content (than 4 M) results in a decrease of the compressive strength. One plausible reason is that increasing of Na₂O content in the activating solution may result in a reduced level of long-range structural ordering products [Duxson et al., 2007].

By a comparison S1 in 95% R.H showed higher compressive strength than S2 in water curing conditions at the same concentration of activator, this may have explained by leaching of activator in water and decrease of its concentration unlike in 95 RH which is

better, as shown in Table (6)[Darweesh, 2006]. Adding silica fume to GBFS in Mixes SSF1, and SSF2 shows that silica fume addition up to 5 % greatly enhances the geopolymerization process with the formation of a well-refined and compact matrix, where silica fume represents an enrichment source of amorphous silica and enhancing geopolymerization [Ho, 1997]. However, the further increase of SF content to 10 % in mix SSF2 leads to a decrease in the mechanical characteristics of the reaction product as shown in Table (6).

Table (6): Compressive strength of all paste mixes cured up to 180 days in water and 95% RH.

Days Mix	2 d	7 d	28 d	90 d	180 d
	Compressive strength (kg/cm ²)				
S 1	243.44	390.40	632.80	669.60	714.00
S 2	186.64	325.60	417.12	561.60	590.00
S 3	547.86	785.69	800.05	932.50	990.00
S 4	575.27	655.44	727.85	789.25	830.00
S 5	275.93	385.60	526.35	537.84	575.00
S 6	365.60	572.90	670.20	779.60	850.00
S 7	317.00	398.00	555.32	645.50	730.00
SMK 1	361.52	588.80	689.60	893.20	940.50
SMK 2	237.68	381.60	506.16	651.00	728.00
SSF 1	567.20	763.20	949.60	1037.00	1126.00
SSF 2	396.90	611.00	628.00	722.00	835.00

Geopolymer mortar exhibit the same way as paste, compressive strength of all mortar mixes increases with curing time in different curing conditions. GM 5 showed the higher compressive strength of all mortar mixes this may be due to the higher activator concentration. By a comparison using standard sand with various grain size according to EN 196 as mix GM 3 was better than Local sand (natural siliceous sand) as fine aggregate with size 0.1 to 2 mm as mix GM 4 in the same conditions.

Table (7): Compressive strength of all mortar mixes cured up to 180 days in water and 95% RH.

Days Mix	2 d	7 d	28 d	90 d	180 d
	Compressive strength(kg/cm ²)				
GM1	445.00	660.30	664.00	754.00	830.00
GM2	421.00	590.15	649.00	683.00	790.00
GM3	452.00	671.00	876.00	988.00	1035.00
GM4	443.00	669.00	704.00	855.00	910.00
GM5	472.00	720.00	890.00	1022.00	1085.00

Concrete is prepared according to the optimum condition in mortar, compressive strength of all concrete mixes increases with curing time in different curing conditions. GP concr 4 shows the highest compressive strength. Using a small aggregate (Dolomite stones) gives a good strength as concrete.

Table (8): Compressive strength of all concrete mixes cured up to 90 days in water and 95% RH.

Days Mix	7 d	28 d	90 d
	Compressive strength(kg/cm²)		
GP Concr 1	445.00	630.50	710.00
GP Concr 2	480.00	696.00	745.80
GP Concr 3	510.00	687.00	830.00
GP Concr 4	532.00	700.00	868.00

3.3.Bulk density(dp gm/cm³)

The bulk density of the hardened activated geopolymer(paste, mortar, and concrete) cured in water and R.Hare represented in Tables (9-11). It is clear that the bulk density increases with curing time in all mixes. The bulk density of alkali-activated GBFS increases with curing time due to the continuous activation and formation of hydration products which may deposit in the open pores that increase the bulk density of the activated slag. The increase of the alkali activator enhances the bulk density of the investigated pastes. The alkali activator enhances the production formation of higher concentration of $[\text{SiO}_4]^{-4}$. which increases the rate of hydration and formation of more C-S-H [Heikal et al., 2014]. As the amount of the alkali activator content increases, the bulk density accordingly increases. S4 shows the highest value of bulk density is in good agreement with its compressive strength. Also the same thing occurs in mortar and concrete. There is a direct relationship between bulk density and compressive strength.

Table (9): Bulk density of all paste mixes cured up to 180 days in water and 95% RH.

Days Mix	2 d	7 d	28 d	90 d	180 d
	Bulk density				
S 1	2.133	2.210	2.215	2.230	2.233
S 2	2.065	2.069	2.076	2.077	2.094
S 3	2.206	2.350	2.370	2.430	2.550
S 4	2.230	2.260	2.280	2.290	2.292
S 5	2.123	2.152	2.166	2.169	2.174
S 6	2.162	2.170	2.180	2.182	2.190
S 7	2.040	2.095	2.102	2.113	2.135
SMK 1	2.075	2.099	2.156	2.165	2.176
SMK 2	2.061	2.121	2.151	2.161	2.173
SSF 1	2.171	2.201	2.211	2.231	2.252
SSF 2	2.074	2.122	2.135	2.144	2.155

Table (10): Bulk density of all mortar mixes cured up to 180 days in water and 95% RH.

Days Mix	2 d	7 d	28 d	90 d	180 d
	Bulk density				
GM1	2.223	2.280	2.290	2.292	2.299
GM2	2.098	2.280	2.290	2.292	2.296
GM3	2.207	2.292	2.340	2.355	2.368
GM4	2.190	2.290	2.328	2.343	2.360
GM5	2.228	2.292	2.310	2.385	2.390

Table (11): Bulk density of all concrete mixes cured up to 90 days in water and 95% RH.

Days Mix	7 d	28 d	90 d
	Bulk density		
GP Conc1	2.350	2.440	2.500
GP Conc2	2.380	2.460	2.530
GP Conc3	2.390	2.480	2.540
GP Conc4	2.240	2.500	2.570

3.4.Total porosity (%)

The total porosity of geopolymer pastes for all mixes cured in water and 95% RH are shown in Table (12). As the alkaline activation of GBFS increases, more hydration products are formed, which precipitate in some of the available open pores leading to decrease the total porosity. The addition of 6 M of NaOH the highest concentration of all mixes (mix S4) gives the lowest values of total porosity. Mix S5 shows the highest value of total porosity at 180 days this may be due to it contain ratio of higher amount of sodium silicate liquid than sodium hydroxide. The total porosity values are in a good agreement with compressive strength values, such that as the total porosity decreases the compressive strength increases. Also the same thing occurs in mortar and concrete. Using small stones of dolomite as a coarse aggregate plays a good role in decreasing the total porosity, and as a result increases the bulk density with increasing the compressive strength. There is a reverse relationship between total porosity and compressive strength.

Table (12): The total porosity of all mixes cured up to 180 days in water, and 95% RH. %.

Days Mix	2 d	7 d	28 d	90 d	180 d
	Total porosity				
S 1	28.95	27.72	25.52	25.09	24.33
S 2	28.01	26.41	25.01	23.86	23.85
S 3	32.48	29.60	26.97	25.56	25.37
S 4	25.17	22.90	22.43	20.36	17.87
S 5	30.91	29.49	27.67	25.33	24.75
S 6	29.85	27.88	26.08	24.26	23.29
S 7	27.12	26.97	25.89	24.12	22.96
SMK 1	28.74	26.67	26.43	24.08	23.05
SMK 2	27.71	26.46	25.83	24.35	23.56
SSF 1	31.97	28.39	26.55	25.39	23.52
SSF 2	26.95	26.37	25.94	24.37	23.18

3.5. Phase composition

XRD patterns of geopolymer pastes samples are shown in Figs (1- 4). It can be seen that the peak represents C-S-H phase at 3.02 \AA changes in the period of curing time between 2 to 28 days, suggesting that a poor crystalline C-S-H gel may be produced in the pastes. Indeed, once the GBFS powder is mixed with the alkaline solution, geopolymer gel and C-S-H gels could be formed after setting and hardening. The geopolymer paste exhibits an increase in the mechanical properties as represented in Table (6). For all XRD diagrams, broad and diffuse peaks are shown, implying amorphous or short-ordering structure phases which generally present in the alkali-activated GBFS. In the alkali activated GBFS, the presence of the strong peak at $d = 3.02 \text{ \AA}$ is attributed to C-S-H phases, which are composed of calcium silicate hydrate. The compressive strength is in a good agreement with XRD analysis.

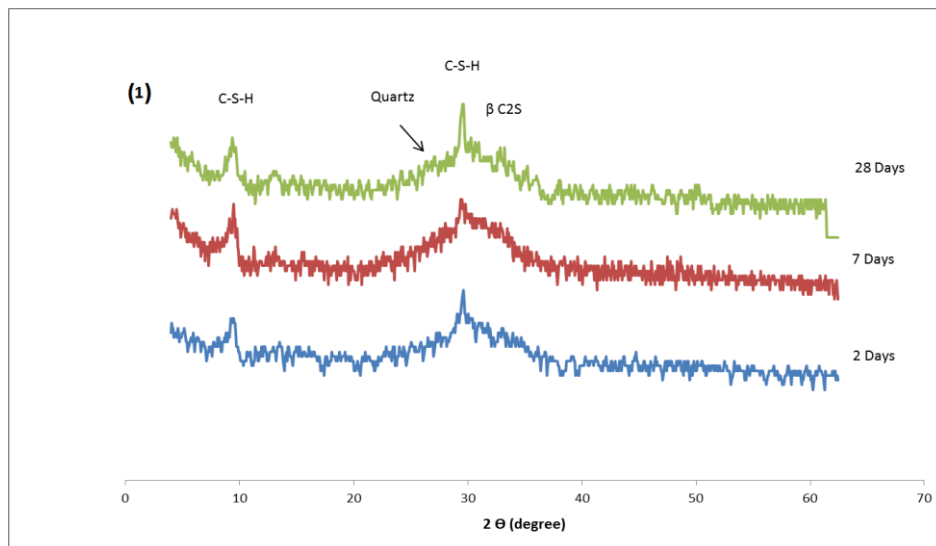


Figure (1): X-ray diffraction patterns for mix 100 % GBFS S 1 which shows the presence of C-S-H (Calcium silicate hydrate), Q (Quartz), and $\beta \text{ C}_2\text{S}$ (Di calcium silicate) phases formed during the hydration reaction.

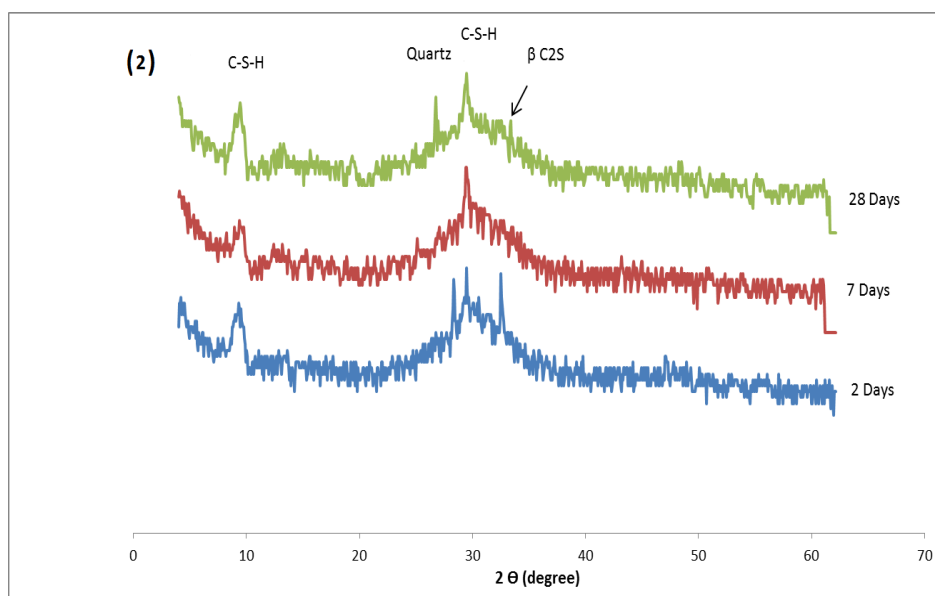


Figure (2): X-ray diffraction patterns for mix 100 % GBFS S 3 which shows the presence of C-S-H (Calcium silicate hydrate), Q (Quartz), and β C₂S (Di calcium silicate) phases formed during the hydration reaction.

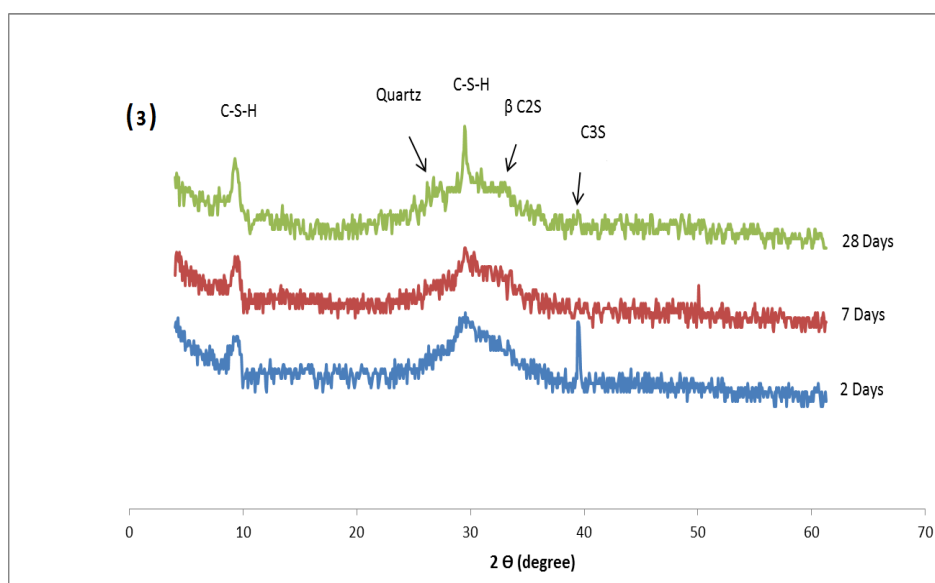


Figure (3): X-ray diffraction patterns for mix 100 % GBFS S 4 which shows the presence of C-S-H (Calcium silicate hydrate), Q (Quartz), C₃S and β C₂S (Di calcium silicate) phases formed during the hydration reaction.

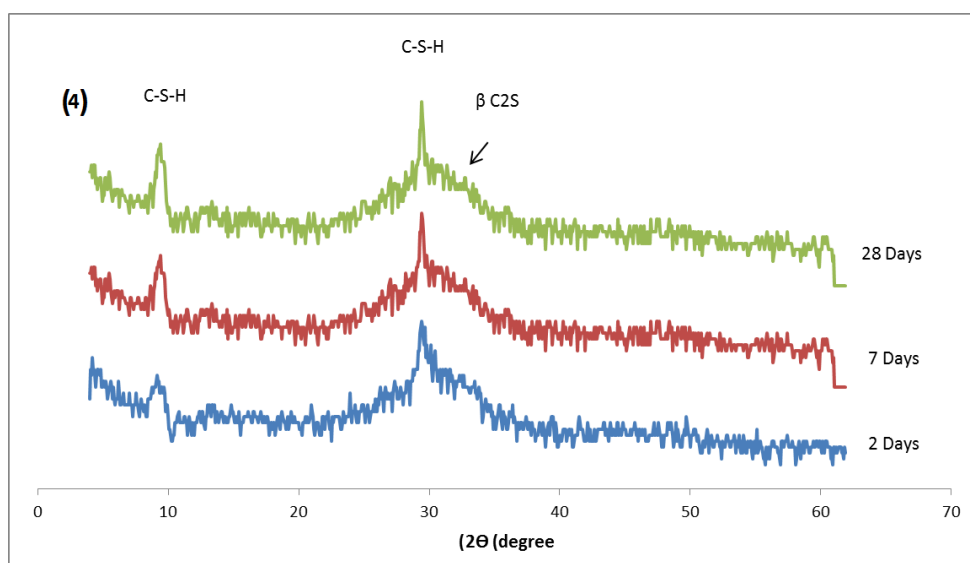


Figure (4): X-ray diffraction patterns of mix (SS 2), which shows the presence of C-S-H (Calcium silicate hydrate), and β C₂S (Di calcium silicate) phases formed during the hydration reaction.

4. Conclusions

- The combined water content of the geopolymer materials gradually increases up to 180 days in all mixes. The bulk density increases while the total porosity decreases, as a result of the chemical reaction (geopolymerization process) with formation of new products fill the pores. The compressive strength also increases in all mixes.
- The data shows that SSF1 (95 % GGBFS+5 % SF) activated by (24.4 % by wt. SSL, and 4 M SH), S3 (100 % GGBFS) activated by (21.7% by wt. SSL, and 4 M SH), and SMK1 (50 % GGBFS+50 % MK) activated by (31.8 % by wt. SSL, and 4 M SH) all in 95% R.H conditions are the most appropriate binding materials (geopolymer paste) that have good different properties.
- Silica fume addition up to 5 % greatly enhances the geopolymerization process with the formation of a well-refined and compact matrix, as silica fume represents an enrichment source of amorphous silica and enhancing geopolymerization. While the increase of SF content to 10 % in SS1 leads to the decrease in the mechanical characteristics of the reaction product.
- GM 3 (100 % GGBFS) with a standard sand show the most appropriate mortar mix in different property. GP Concr. 4 (100 % GGBFS) with a standard sand, and dolomite aggregate in 95% R.H show the most appropriate concrete mix in different properties, that can be used as alternative building material to the ordinary Portland concrete.

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الملخص باللغة العربية

دراسة على الخواص الفيزيوكيميائية والميكانيكية للمواد الجيوبوليمرية

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تم دراسة الخواص الفيزيائية والكيميائية والميكانيكية لمواد الجيوبوليمر (الاسمنت والمونة والخرسانة). وتم تحضير عدد من المخاليط بنسب مختلفة من تلك المواد وإضافة هيدروكسيد الصوديوم وبيسيليكا الصوديوم كمادة منشطة للتفاعل حيث تم إضافتهم على ماء الخلط بتركيزات مختلفة ودراسة خواص كل خليط بعد عملية التأخر في الماء بعد فترات زمنية مختلفة. وقياس الكثافة الظاهرية، المسامية الكلية، ماء الخلط، مقاومة الضغط الميكانيكي، الماء المتحد كيميائي أو دراسة التركيب الدقيق باستخدام حيود الأشعة السينية. ويمكن تلخيص أهم النتائج التي حصلنا عليها في مايلي:

- تشير النتائج إلى أن الخليط (95% GGBFS + 5% SF) SSF1 المنشط بواسطة (24.4% بالوزن SSL + 4M SH) والخليط (100% GGBFS) S3 المنشط بواسطة (21.7% بالوزن 4SSL + 4M SH) والخليط (50% GGBFS + 50% MK) SMK1 المنشط بواسطة (31.8% بالوزن 4M SH + SSL) في 95% RH رطوبة هي الخلطات الأكثر ملائمة التي لها خصائص مختلفة جيدة.
- إن إضافة غبار السيليكا فائق النعومة بنسبة تصل إلى 5% يعزز إلى حد كبير عملية بلورة الجيوبوليمر تكوين مصفوفة متقنة وصغيرة الحجم، حيثي مثل غبار السيليكا فائق النعومة مصدر التنشيط السيليكا غير المتبلورة وتعزيز الجيوبوليمر. فحينئذ زيادة محتوى SF إلى 10% فيؤدي إلى انخفاض في الخصائص الميكانيكية لمنتج التفاعل.
- (100% GGBFS) GM 3 خليط باستخدام رمل قياسي والمزيج الأكثر ملائمة في خصائص مختلفة. والخليط (100% GGBFS) GP Concr. 4 باستخدام الرمل القياسي وركام الدلوميت صغير الحجم في ظروف معالجة 95% RH رطوبة أنسب خليط من الخرسانة في كل الخصائص المختلفة، والتي يمكن استخدامها كمادة بناء بديلة للخرسانة العادية.