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## Effect of Alkali Concentration on Physico -Chemical and Mechanical Properties of Slag Based Geopolymer Cement.

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### Abstract

In this article we studied the effects of sodium hydroxide pellets (SH) and sodium silicate liquid (SSL) as an activator on the physico chemical and mechanical Properties of ground granulated blast furnace slag (GGBFS) geopolymer pastes. Various mixes are prepared using different liquid/solid ratios (L/S) by weight. The hydration characteristics of the various mixes have been tested through determination of total porosity, compressive strength, bulk density, chemically combined water, and XRD analysis at different time intervals from 2 days up to 90 days under relative humidity 100%. The results elucidated that as the quantity of alkali activator increases up to (15% SSL, and 15% SH), the compressive strength increases up to 90 days. The combined water content of all mixes increases up to 90 days. Also the bulk density raises and the total porosity minimizes, this is due to the addition of the pozzolanic materials. All mixes showed good stability of its compressive strength values in 5 % MgSO<sub>4</sub> solution. The data showed that mix S6 (100% GGBFS) activated by (15% SSL, and 15% SH) is the most appropriate binding material (geopolymer cement) that has good properties so it can be used as alternative binding materials to the ordinary Portland cement.

**Keywords:** geopolymer cement, sodium silicate, slag, mechanical properties, and sulphate resistance.

### 1. Introduction:

Cement and concrete are widely used in building and construction material in the world. Ordinary Portland cement (OPC) is traditionally applied as the essential binder to produce concrete. Unfortunate, manufacturing of Portland cement consumes

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huge amounts of energy and raw materials and emits a lot of CO<sub>2</sub> which responsible for global warming. In 2020, the annually cement output is predicted to be 5.9 billion tons, and about 4.8 billion tons of CO<sub>2</sub> production [22]. Hence there is a need to find alternative material which may be used in place of cement or may be used to partially replace cement, with a positive effect on the durability and strength of the concrete and thus reducing the CO<sub>2</sub> emission. Researchers have pointed some pozzolanic materials which can be used to partially replace OPC cement and contribute to development of strength of the concrete and durability. Such as Fly ash (FA), Ground granulated blast furnace slag (GGBS), Metakaolin (MK) and SF which can be used for partial replacement of OPC cement in concrete production[6]. Alkali-activated cements (Geopolymer cements) are proportionally unprecedented group of binding materials, which were first developed by Joseph Davidovits in 1978 [26]. Now a days, alkali activated binders or geopolymer cement get to be an alternative to traditional concrete, and can give comparable performance to OPC cements, with the added advantages of low carbon-dioxide emissions, high compressive strength, rapid setting and hardening, fire resistance, resistance to sulphate reaction, low shrinkage, low thermal conductivity, and remarkable durability [1,27]. Available literatures on geopolymer cement are summarized and discussed. Puertas et al.(2000) concluded that the activator concentration and the slag content showed significant impact on strength development [9]. Prakash R. Vora et al.(2012) performed experimental work in which they casted 20 geopolymer concrete mixes and evaluated the effect of various parameters in its compressive strength in order to enhance its overall performance. The results showed increase in compressive strength with increases in curing temperature, rest period, concentration of NaOH and decreases with increase in the ratio of water to geopolymer solids [24].

GGBFS is commonly used as the most important binding material in concrete field due to it has elevated percentage of SiO<sub>2</sub>, CaO, and Al<sub>2</sub>O<sub>3</sub> in an amorphous phase. So GGBFS has pozzolanic and binding features in the alkaline medium. Slag also was the first cementitious materials to be alkali activated and because it has latent hydraulic properties, slag (GGBS) become the most proper materials for alkali activated cements. Several researches suggested that sodium hydroxide and sodium silicate based activators are the most suitable considering the mechanical properties of GGBFS and FA geopolymers. Studies on the mechanical properties and

microstructure of GGBFS mixed with some admixtures like flay ash, and silica fume are ongoing. In the production of geopolymers, especially when sodium silicate is added, high concentrations of silicate are used to form stronger ion-pair. This will give rise in further long chain silicate oligomers beside Al–O–Si complexes. The purpose from sodium silicate addition was to improve the geopolymer precursors formation on mineral-solution contact [16]. The principal products produced as a result of alkali activation of GGBFS are CASH and CSH gels which are also resulted from OPC hydration process. Due to GGBFS has a glassy phase material, it is, therefore, easier to be alkali activated [29,31]. In this paper, fresh and hardened properties of geopolymer cement prepared from slag activated with different ratios of sodium hydroxide and sodium silicate liquid under ambient condition were emphasised. Hopefully one day in the near future this new binder will replace ordinary Portland cement in ordinary concrete and become a geopolymer concrete which is a sustainable building material that is better than ordinary concrete in multiple areas.

## 2. Materials and Method

### 2.1. Materials and specimens

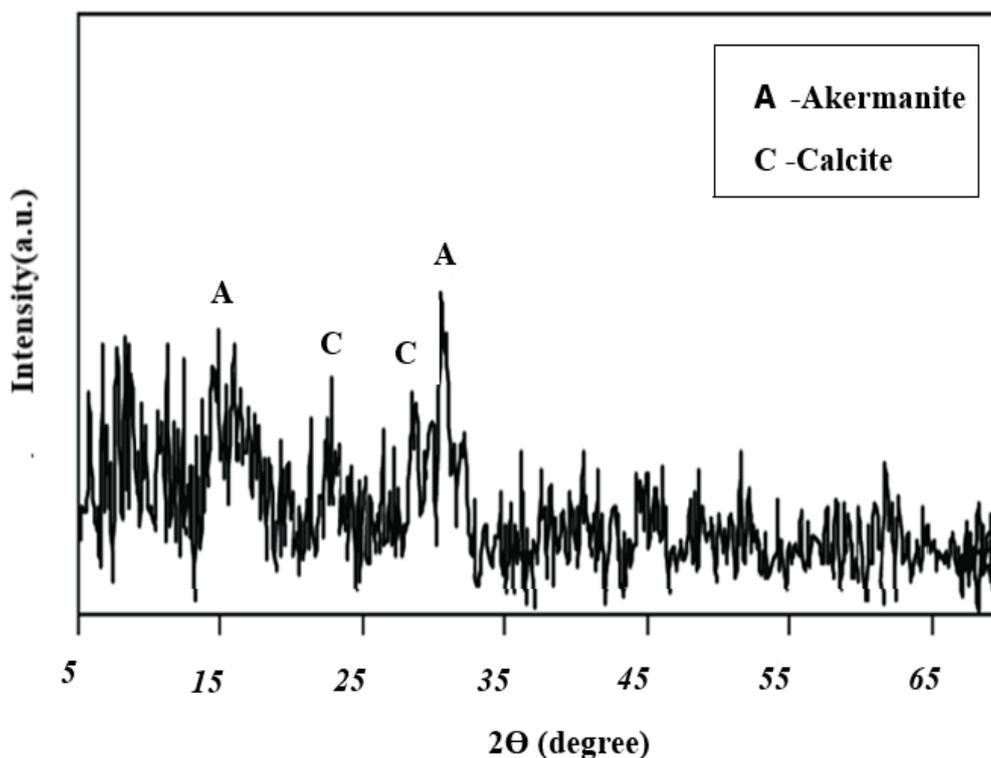
The materials used in this investigation were ground granulated blast furnace slag (GGBFS) was obtained from the Egypt iron & steel of Helwan company, Sodium hydroxide pellets (SH) pure lab chemicals (96%) is obtained from EL Nasr pharmaceutical Chemicals Company, Qalyubiya, Egypt, and sodium silicate liquid (SSL) is given from Silica Egypt Company, Burg Al-Arab, Alexandria, Egypt; Analysis of SSL according to ES574/2007 is given in Table (2). The chemical composition of the used material (GGBFS) are given in Table (1). The XRD pattern is also shown in Figure (1).

**Table (1):** Chemical oxides composition of the used material, (mass %)

Oxides	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Cl <sup>-</sup>	L.O.I	Total
Slag	34.10	12.40	42.30	0.77	0.90	6.50	35.0	26.0	0.08	1.50	99.16

**Table (2):** Chemical analysis of sodium silicate liquid.

Oxides	SiO <sub>2</sub>	Na <sub>2</sub> O	H <sub>2</sub> O	Total
Content %	32.8	11.7	55.5	100.0



**Fig.1.** x-ray pattern of GGBFS.

## 2.2. Procedure

Different mixes of slag based geopolymer cement were prepared as shown in Table (3). First the alkali activator (AA) is prepared by mixing sodium silicate liquid (SSL) and sodium hydroxide pellets (SH) then stirred them till SH fully dissolved, initially the temperature of the mixture was quite high then left few minutes to reach to room temperature before the proceeding. Then by the addition of each dry mix with the different mixing ratio to the alkali activator solution and mixing them on a smooth and non absorbent surface for about 5 minutes. The pastes were molded in the form of one cubic inch molds. The geopolymer pastes were cured under relative humidity 100% at room temperature for one day in the incubator. The hardened pastes were then removed from the molds after attaining the final setting. Then after 28 days some cubes were immersed in 5% MgSO<sub>4</sub> solution for different time intervals up to 90

days to study the durability of geopolymers against magnesium sulfate attack especially that contain GGBFS is a topic needing more investigations because the researches in this field are limited [33].

**Table (3):** Mixes composition, water/solid (W/S) ratio and there designations.

NO.	Mixes	GGBFS	SSL (%)	SH (%)	W/S Ratio
1	S1	100	10	5	0.53
2	S2	100	10	10	0.52
3	S3	100	10	15	0.48
4	S4	100	15	5	0.45
5	S5	100	15	10	0.43
6	S6	100	15	15	0.41

### 3. Results and Discussion:

#### Hydration characteristics

The hydration products formation begin actually once the water is mixed within the GGBFS mixes. They are determined for mixes (S 1–6) cured up to 90 days. Standard consistency of water, initial and final setting times are investigated in addition, compressive strength, bulk density, combined water, total porosity, and phase composition of hydration products are investigated by XRD analysis at different time periods [23].

##### 3.1.1. Standard water of consistency

The quantity of mixing water needed for reaching to standard consistency (W/S) was determined by using Vicat Needle as described in ASTM; C-191, 2013 [13,15,28], are presented in Table (4). It can be showed that the quantity of mixing water demanded for standard consistency of geopolymer cement little decreases as the amount of alkali activator increases, however it can be showed that the amount of mixing water required for standard consistency for GGBFS mixes slightly increases than that is required for OPC. This is may be due to the higher fineness of the raw

materials, also more the specific surface area is higher, more the water demand increases; this is due to the increase in the surface of contact between water and the grains of cement, which increases the absorption of water and increases the setting time values [5,11].

### 3.1.2. Setting times

The initial and final setting times of geopolymer cement required for the different mixes (S 1-6) are shown in Table (4). It is obvious that both the initial and final setting times minimize with increasing the amount of alkali activator, and decreasing liquid to solid ratio(W/S), This can be assigned to increase the alkaline activator accelerate the activation process and enhance the production of higher concentration of  $[\text{SiO}_4]^{4-}$  which increases the rate of hydration and leads to reduce setting times of GGBFS mixes [17,20]. However it should be noted that the composition of slag varies depending on the raw materials used by the metallurgical industry to produce metals. These differences in raw materials lead to differences in how different slag responds to the alkali activation [25]. compared to the cement concrete, geopolymer concrete has lower workability due to the short setting time of geopolymer concrete. The concrete mixes with good workability bring many attributes together in balance and results in a quality product with long service life. Geopolymer concrete prone to harden before delivered to the construction site located far away from the batching plant. This obstacle cause more difficulties if the construction site is not located at the same site as the batching plant. To deal with this problem, the setting time of the geopolymer concrete need to be increased. In this paper as a result of higher fineness, high specific surface area, CaO content in GGBFS, and low hydraulic activity of the used GGBFS material the\_GGBFS mixes needed more water which in turn increased the workability of GGBFS pastes and increased the setting time values than usual results in literature as shown in table.

**Table (4):** The water of consistency and setting times of GGBFS mixes (S 1-6).

Mixture	SSL% : SH%	W/S	Initial setting	Final setting	Reference
100% GGBFS	1:1	0.35	150	390	[21]
100% GGBFS	1:2	0.34	100	370	[21]
S1	10:5	0.53	375	395	This work
S2	10:10	0.52	360	378	This work
S3	10:15	0.48	255	270	This work
S4	15:5	0.45	195	208	This work
S5	15:10	0.43	180	190	This work
S6	15:15	0.41	150	155	This work

### 3.1. Compressive strength

The compressive strength of hardened alkali-activated GGBFS cured under relative humidity 100% up to 90 days are shown in Table (5). With increasing curing time, the compressive strength of all mixes increases. However mix S6 appears the highest rate of compressive strength at most of whole curing ages of hydration process. The compressive strength enhances as the amount or the concentration of alkali activator increases. This can be attributed to that increasing of the concentration of alkali activator increases the alkalinity of the solution, which enhancing the dissolution and reaction rates. Also it is pointed that the compressive strength values are related to the formation of more hydration products, which may be due to acceleration of activation process [12,25].

**Table (5):** Compressive strength (MPa) for all mixes cured up to 90 days under relative humidity 100%.

Mix \ Days	2	7	28	56	90
S1	22.56	30.31	47.56	51.98	56.39
S2	25.99	34.42	52.36	53.93	60.61
S3	27.95	37.26	54.92	62.76	69.23
S4	30.89	38.44	57.86	66.68	70.61
S5	33.34	40.31	59.82	68.45	73.55
S6	44.13	47.56	63.75	70.61	76.49

### 3.2. Chemically Combined water content (W<sub>n</sub> %)

Chemically combined water contents (W<sub>n</sub>%) is the part of water stilled in the dry sample after removing of the free water, i.e., it is the amount of water combined in the structure of the dry hydrated product. About 1 g of the dried specimen (at 100 ° C) is weighed in a silica crucible then ignited at 950 ° C for 1hr in an adjusted muffle furnace, cooled in a desiccator then weighed (w<sub>3</sub>). The chemically combined water (W<sub>n</sub>%) is calculated according to the following equation:

$$W_n \% = [(w_2 - w_3) / (w_3 - w_1)] \times 100$$

Where: (w<sub>1</sub>) is the weight of the empty crucible, (w<sub>2</sub>) is the weight of the crucible with 1g of the sample before ignition, and (w<sub>3</sub>) is the weight of the crucible with 1g of the sample after ignition [11]. W<sub>n</sub>% for all mixes cured under relative humidity 100% up to 90 days are represented in Table (6). Based on the results of the present investigation, the content of combined water of the alkali activated GGBFS

mixes increases progressively from 2 days up to 90 days. This is due to the sustainable hydration and assemblage of the hydration products, which precipitated in the affordable open pores. The  $W_n$  content of alkali activated GGBFS is also found to be increases with increases alkali content. Increase of the alkali content promote the hydration of alkali activated GGBFS[30].  $W_n$  values are in a good agreement with compressive strength values, such that as the  $W_n$  increase the compressive strength also increase. The amount of hydration products usually increase as the time of hydration increases, so the increase in  $W_n$  content, is essentially resulted from the superior hydraulic properties of GGBFS with the enhancement of alkali activators content. So mix S6 shows the higher value of the chemically combined water of all GGBFS mixes due to the higher concentration of the alkali activator.

**Table (6):** Chemically combined water content (%) for all mixes cured up to 90 days under relative humidity 100%.

Days Mix	Days				
	2	7	28	56	90
S1	5.11	5.59	6.96	7.87	8.84
S2	5.18	5.82	7.83	8.92	9.43
S3	5.24	5.91	7.99	9.35	9.81
S4	5.41	5.99	8.09	9.56	9.93
S5	6.02	6.24	8.89	9.88	10.68
S6	6.65	7.11	9.68	10.34	11.34

### 3.3. Bulk density

The bulk density of all mixes cured under relative humidity 100% up to 90 days are represented in Table (7). Based on the results of the present investigation, the bulk density gradually increases with curing age from 2 days up to 90 days. The increasing of the bulk density values of alkali activated GGBFS with curing age progress can be mainly due to the sustainable activations and production of the hydration products. Then these hydrated products are deposited in the available opened pores which enhances the bulk density of the activated GGBFS pastes. It is pointed that the increase of the alkali activators ratio elevates the bulk density of the examined pastes. This is due to the alkali activators promotes the formation of higher concentration of  $[\text{SiO}_4]^{4-}$  which accelerates the rate of hydration and formation of more CSH [14].

**Table (7):** Bulk density ( $\text{g/cm}^3$ ) for all mixes cured up to 90 days under relative humidity 100%.

Mix \ Days	2	7	28	56	90
S1	2.44	2.63	2.72	2.78	2.85
S2	2.53	2.68	2.79	2.81	2.89
S3	2.58	2.71	2.82	2.88	2.91
S4	2.59	2.75	2.86	2.94	2.98
S5	2.62	2.79	2.91	2.96	3.04
S6	2.82	2.89	2.96	2.99	3.15

### 3.4. Total porosity

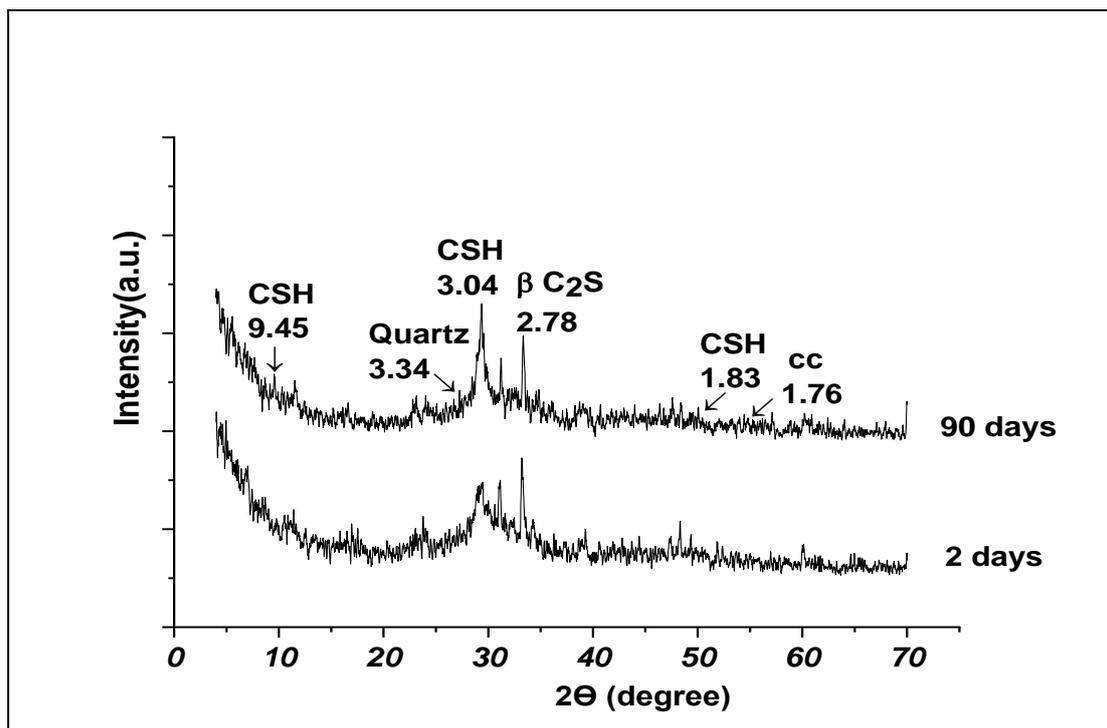
The total porosity for all mixes cured under relative humidity 100% up to 90 days are represented in Table (8). As the alkali content of GGBFS increases, further hydration products are produced, which deposited in any affordable open pores resulting in a decrease in the total porosity which explain the gradually decrease in the total porosity, and increase in the bulk density with hydration age up to 90 day [18]. Mix S6 gives the lower porosity, actually because of the increase of the concentration of NaOH which quickness the activation rate of GGBFS resulting in more hydration products, and leads to increase in the compressive strength.

**Table (8):** Total porosity (%) for all mixes cured up to 90 days under relative humidity 100%.

Mix \ Days	2	7	28	56	90
S1	36.54	34.63	30.46	29.81	28.11
S2	36.21	33.81	29.31	27.63	26.01
S3	35.52	32.05	28.11	26.51	25.06
S4	33.78	31.02	27.06	25.81	24.21
S5	32.21	30.11	26.25	24.31	21.91
S6	29.23	27.21	24.06	23.63	20.11

### 3.5. Phase composition

The results of XRD patterns of mixes (S3), and (S6) cured under relative humidity 100% up to 90 days are represented in Figures (2), and (3) respectively. It can be shown that the peak elucidates CSH phase at  $3.04 \text{ \AA}$  varies in the period 2 to 90 days of curing time, which indicate that poor crystalline CSH gel may be produced in the pastes. After setting and hardening, CSH gel and geopolymer gel could form when GGBFS powder is mixed with the alkaline solution. The mechanical properties of geopolymer pastes have been enhanced as shown in Table (5). For all XRD patterns, diffuse and broad peaks are appeared around  $d = 2.78 - 3.34 \text{ \AA}$ , which implying amorphous structure phases generally exhibited in alkali-activated GGBFS. The presence of the strong peak at  $d = 3.04 \text{ \AA}$  in alkali activated GGBFS is attributed to CSH phases. It is clear that compressive strength is in a good harmony with XRD analysis.



**Fig.2.** XRD patterns of mix (S3) cured up to 90 days under relative humidity 100%.

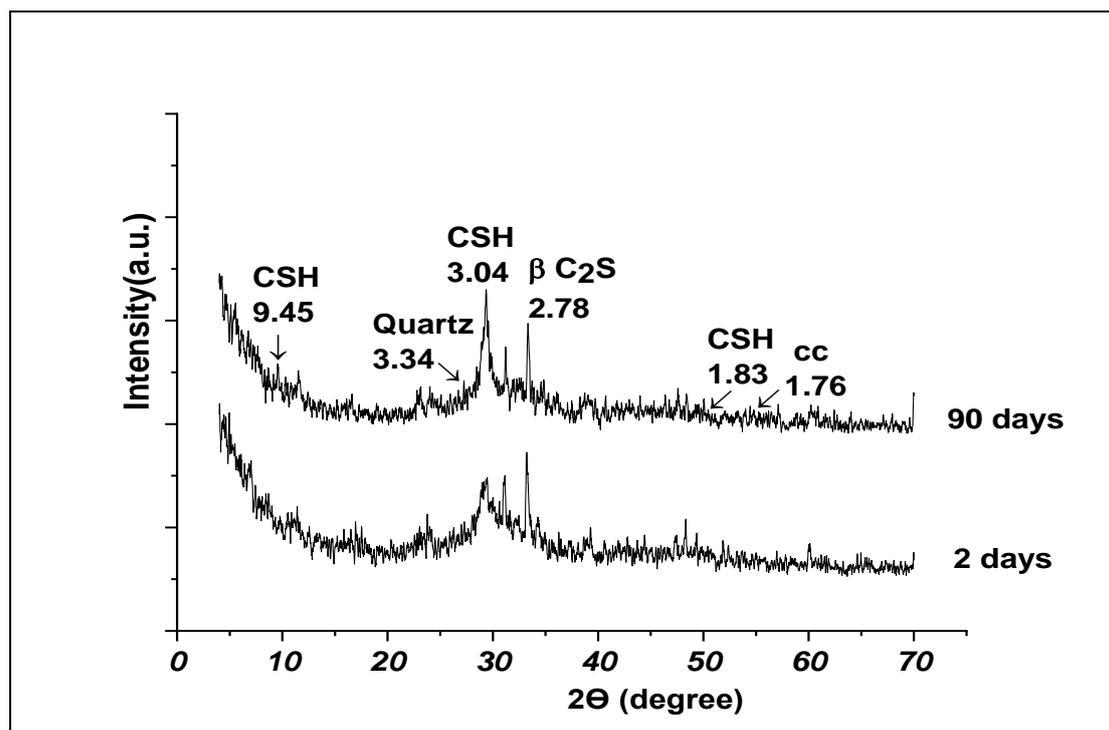


Fig.3. XRD patterns of mix (S6) cured up to 90 days under relative humidity 100%.

### 3.6. Resistance to magnesium sulphate solution

Buildings (concretes) which subjected to seawater can damage as a result of the chemical effect of seawater constituents on the hydration products of cement. The seawater chemical attack on concrete constituents is the reactions between sulphates, or chlorides, which are known as strong aggressive ions with hydration products of cement, due to certain products of cement can enter into deleterious reactions with  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  ions, which causing  $\text{Ca}(\text{OH})_2$  dissolution, then formation of chloroaluminate and sulphoaluminate, which resulting in expansion, softening, and cracking of concrete. Ground granulated blast furnace slag cement (GGBFS) is utilized in most of countries due to its characteristic attribute of improving chloride and sulphate resistance [19,32]. Some researchers studied the characteristics of GGBFS when mixed with different amounts of  $\text{Na}_2\text{O}$  and  $\text{SiO}_2$ . They detected that as the hydration time increases the formation of hydration products increase, and the combined water of slag increase. Also, the increase of  $\text{Na}_2\text{O}$  content result in formation of a denser microstructure, which leads to elevated compressive strength rates [8].

Various investigations reported that the effect of slag content on the sulphate resistance of the concrete with sufficient quantity of slag is mainly because of the minimization of  $\text{C}_3\text{A}$  with the rise of slag amount in cement. Also, the increase of slag

amount in concrete decreases the  $\text{Ca}(\text{OH})_2$  formed by the reaction with it to produce further amounts of calcium silicate hydrates, and CSH gel, then these hydration products can fill up the affordable pores, and resulting in the production of more compact body. So many researchers reported that blended cement paste can resist chloride and sulphate attack [10,19]. The effect of 5%  $\text{MgSO}_4$  solution on the physico-chemical and mechanical properties of the different mixes was studied, and all results showed high stability of its compressive strength values in 5 %  $\text{MgSO}_4$  solution. This is mainly due to a good pozzolanic activity of alkali-activated GGBFS which shows superior resistance to acids attack up to 90 days. Dipping of alkali activated GGBFS pastes in 5%  $\text{MgSO}_4$  solution optimizes the GGBFS pastes activation.

### 3.6.1. Compressive strength

The compressive strength of all mixes dipped in 5%  $\text{MgSO}_4$  solution up to 90 days was studied. The results cleared that the compressive strength of GGBFS samples increases as curing time increase as shown in Table (9). All mixes exhibit good stability of its compressive strength in 5 %  $\text{MgSO}_4$  solution. This is due to the high pozzolanic activity of alkali-activated GGBFS which exhibit high resistance to sulphate attack, this is due to GGBFS does not contain  $\text{C}_3\text{A}$ , so its addition in concrete dilutes the total amount of  $\text{C}_3\text{A}$  in the system. Also it reduces concrete permeability, making it harder for sulfates to penetrate into concrete [19,31]. When the GGBFS is compared to the OPC, it is clear that the strength of alkali activated slag increases up to 90 days, which is due to the additional formation of hydration products, without formation of ettringite which causes deterioration in concrete as occurred with OPC. It is pointed that as the alkali activator contents increase the resistance towards sulphate attack also increases. This essentially resulting from the decrease in the total porosity which retards the interpenetration of sulphate ions into the matrix, this may be because the alkali activated GGBFS has no free lime content in its matrix. So mix S6 has the highest compressive strength values at most of all hydration curing ages [15].

**Table (9):** Compressive strength (MPa) for all mixes cured up to 90 days in 5% MgSO<sub>4</sub> solution.

Mix \ Days	2	7	28	56	90
S1	47.95	49.22	59.82	64.53	67.86
S2	52.96	55.21	63.74	68.16	70.12
S3	55.31	56.87	65.99	69.53	71.11
S4	58.35	59.33	67.56	71.59	74.04
S5	60.61	61.29	68.94	73.06	76.49
S6	64.53	66.19	72.08	74.63	79.44

### 3.6.2. Combined water content (W<sub>n</sub> %)

Chemically combined water contents (W<sub>n</sub>) for all mixes dipped in 5 % MgSO<sub>4</sub> solution up to 90 days are represented in Table (10). Based on the results of the present investigation, the content of combined water of all GGBFS mixes increases progressively up to 90 days. This is due to the sustainable hydration and assemblage of the hydrated products, which precipitated in the affordable pores [7]. The W<sub>n</sub> content of alkali activated GGBFS is also found to be increases with increases alkali content. Increase of the alkali content promote the hydration of alkali activated GGBFS. The amount of hydration products usually increase as the time of hydration increases, so the increase in W<sub>n</sub> content, is essentially result from the superior hydraulic properties of GGBFS with the enhancement of alkali concentration [2,8].

**Table (10):** Chemically combined water content (%) for all mixes cured up to 90 days in 5% MgSO<sub>4</sub> solution.

Mix \ Days	2	7	28	56	90
S1	6.96	7.02	7.82	8.11	8.23
S2	7.84	7.92	8.21	8.58	8.75
S3	8.01	8.27	9.05	9.63	9.94
S4	8.12	8.38	9.21	9.94	10.23
S5	8.91	8.96	9.66	10.31	10.65
S6	9.75	9.81	10.85	11.23	11.84

### 3.6.3. Bulk density

The bulk density for all mixes dipped in 5 % MgSO<sub>4</sub> solution from 2 days up to 90 days are shown in Table (11). Based on the results of the present investigation, the bulk density gradually increases with curing age up to 90 days. Increasing of the bulk density values of all GGBFS mixes with curing age progress can be mainly due to the sustainable activations and formation of more hydration products, then these hydration products are deposited in the available opened pores which enhances the bulk density of the activated GGBFS. It is pointed that the increase of the alkali activators ratio elevates the bulk density of the examined pastes. This is due to the alkali activators promotes the formation of higher concentration of [SiO<sub>4</sub>]<sup>4-</sup> which accelerates the rate of hydration and formation of more CSH [3,7].

**Table (11):** Bulk density ( $\text{g/cm}^3$ ) for all mixes cured up to 90 days in 5%  $\text{MgSO}_4$  solution.

Mix \ Days	2	7	28	56	90
S1	2.72	2.78	2.83	2.88	2.96
S2	2.79	2.81	2.89	2.94	2.98
S3	2.82	2.87	2.91	2.96	2.99
S4	2.86	2.88	2.94	2.98	3.01
S5	2.92	2.96	2.99	3.08	3.21
S6	2.96	2.98	3.06	3.11	3.36

#### 3.6.4. Total porosity

The total porosity for all mixes dipped in 5 %  $\text{MgSO}_4$  solution up to 90 days are shown in Table (12). As the alkali content of GGBFS increases, further hydration products are produced, which deposited in any affordable open pores resulting in a decrease in the total porosity which explain the gradually decrease in the total porosity with hydration age up to 90 day. Also in the aggressive solution the increase of alkali activated contents increases the resistance towards sulphate attack solution as indicated by the stability of the compressive strength values as shown in Table (9). This is primarily due to a decrease in total porosity, which prevents sulphate ions from penetrating the matrix [4]. Mixture S6 has the lowest porosity, actually because of the

increase in the concentration of NaOH, which quickness the activation rate of GGBFS, resulting in further hydration products.

**Table (12):** Total porosity (%) for all mixes cured up to 90 days in 5% MgSO<sub>4</sub> solution.

Mix \ Days	2	7	28	56	90
S1	30.44	30.12	28.23	27.11	26.51
S2	29.31	28.91	27.55	26.01	25.11
S3	28.11	27.81	25.63	24.81	23.44
S4	27.06	26.31	23.51	21.48	20.31
S5	26.24	25.71	22.06	20.61	19.11
S6	24.03	23.81	20.54	18.68	17.08

### 3.6.5. Phase composition

The results of XRD patterns of GGBFS samples (S3), and (S6) dipped in 5 % MgSO<sub>4</sub> solution up to 90 days are represented in Figures (4), and (5) respectively. It can be shown that the peak elucidates CSH phase at 3.04 Å varies in the period 2 to 90 days of curing time, which indicate that poor crystalline CSH gel may be formed in the pastes. The XRD patterns of GGBFS hardened pastes appeared no ettringite formed, but gypsum (CaSO<sub>4</sub>) was appeared. The formation of gypsum can be explained by diffusion of magnesium sulphate close to the surface regions which result in the deformity of CSH through of calcium and displacing by Mg<sup>2+</sup> ions to form MSH. Also free calcium may be interact with SO<sub>4</sub><sup>2-</sup> ions in order to form

gypsum. Furthermore, CSH is the basic hydration product of slag. This CSH may be locking more  $Al_2O_3$ , which limiting the distortion caused by aggressive  $SO_4^{2-}$  ions. Also, NaOH causes ettringite to decompose into its components, then releases  $SO_4^{2-}$  ions into the pore solution [19].

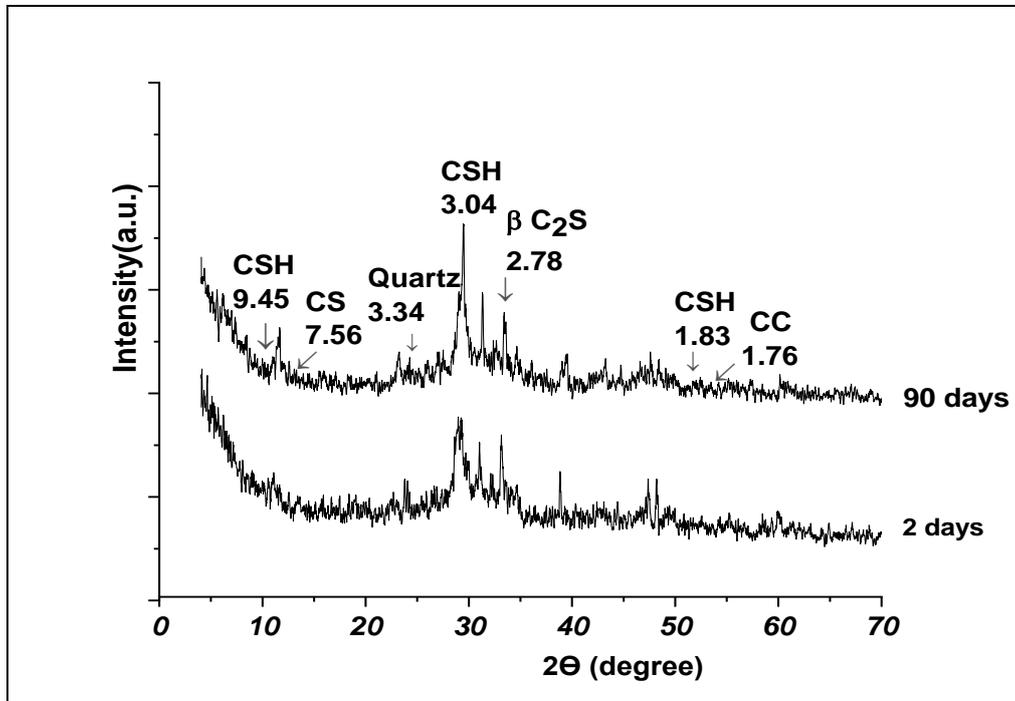


Fig.4. XRD patterns of mix (S3) cured up to 90 days in 5%  $MgSO_4$  solution.

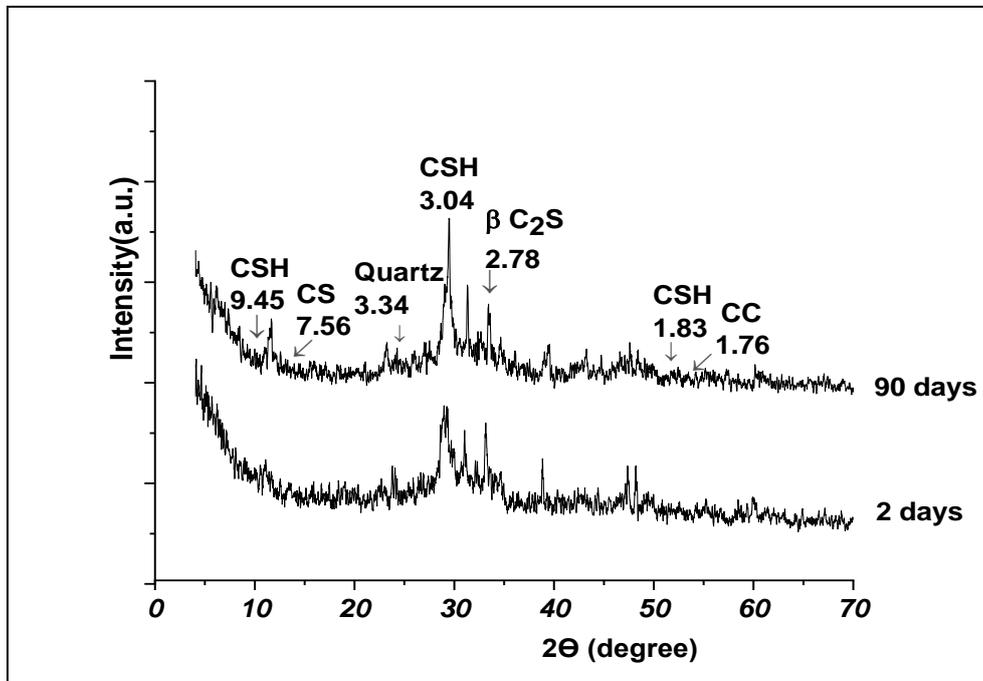


Fig.5. XRD patterns of mix (S6) cured up to 90 days in 5%  $MgSO_4$  solution.

#### 4. Conclusions

- All mixes exhibit high stability of its compressive strength values in 5 %  $\text{MgSO}_4$  solution. This is mainly due to a good pozzolanic activity of alkali-activated GGBFS which shows superior resistance to acids attack up to 90 days. Dipping of alkali activated GGBFS pastes in 5%  $\text{MgSO}_4$  solution optimizes the GGBFS pastes activation.
- The amount of water combined with the alkali activated GGBFS pastes gradually increases up to 90 days. This is resulting from the sustainable formation of hydration products that have deposited in the available open pores.
- The bulk density of alkali activated GGBFS enhances as the curing time increase this is can attributed to the continuous activation and formation of hydrated products. These hydrated products are deposited in the open pores, which explains why the bulk density of the activated slag increased.
- X-ray diffraction patterns for different mixes showed the presence of CSH phase that formed during the hydration reaction, which is mainly responsible for the good distinct strength of GGBFS.
- The data showed that mix S6 is the most appropriate binding materials (geopolymer cement) that have a good distinct properties which enhance its using as alternative binding material to the ordinary Portland cement.

#### References

- [1] A.M. Mustafa Al Bakri, H. Kamarudin, M. Bnhussain, I. K. Nizar, and W. I. W. Mastura, Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement- A Review, *J. Chem. Inf. Model* 53: (2013) 1689-1699.
- [2] A. Sarhan, E. A. Kishar, and S. A. Hamed, Uses of EAFS in production of blended cements, *J. Sci. Res. Sci.* 37: (2020) 111–124.
- [3] A. Rizk, E. A. Kishar, D. Ahmed, and M. Kohail, Preparation and Characterization of Low Cost Geopolymer Cement, *J. Sci. Res. Sci.* 36: (2019) 36–48.
- [4] M. Abdullah, E. A. Kishar, S. A. Sayed, Preparation and Characterization of Geopolymer Cement, *J. Sci. Res. Sci.* 33: (2016) 537–551.
- [5] B. Vlastimil and R. Novotn, Cement Kiln By-Pass Dust : An Effective Alkaline Activator for Pozzolanic Materials, *Materials* 11: (2018), <http://doi:10.3390/ma11091770>.
- [6] C. Li, H. Sun, and L. Li, A review: The comparison between alkali-activated slag (Si + Ca) and metakaolin (Si + Al) cements, *Cem. Concr. Res* 40: (2010) 1341-

1349.

- [7] D. Tripathi, R. Kumar, P. K. Mehta, and A. Singh, Silica fume mixed concrete in acidic environment, *Mater. Today Proc* 27: (2020) 1001-1005.
- [8] D. Bondar, C. J. Lynsdale, N. B. Milestone, and N. Hassani, Sulfate Resistance of Alkali Activated Pozzolans, *Int. J. Concr. Struct. Mater* 9: (2015) 145-158.
- [9] F. Puertas, S. Martinez-Ramirez, S. Alonso, & T. Vazquez, Alkali-activated fly ash/slag cements: Strength behaviour and hydration products, *Cement and Concrete Research* 30: (2000) 1625–1632.
- [10] G. F. Huseien and K. W. Shah, Durability and life cycle evaluation of self-compacting concrete containing fly ash as GBFS replacement with alkali activation, *Construction and Building Materials* 235: (2020) 117458-117472.
- [11] I. Aiad, A. M. El-Sabbagh, A. I. Adawy, S. H. Shafek, & S. A. Abo-EL-Enein, Effect of some prepared super plasticizers (acetone based) on physico-chemical and mechanical properties of oil well cement pastes, *Bulletin of Faculty of Science, Zagazig University* 38: (2020) 1-17.
- [12] J. Singh and S. P. Singh, Geopolymerization of solid waste of non-ferrous metallurgy – A review, *J. Environ. Manage* 251: (2019) 109571-109579.
- [13] K. Ali, Azizi, Z. Man, & H. Ullah, "Effects of Parameters on the Setting Time of Fly Ash Based Geopolymers Using Taguchi Method", *Procedia Engineering*, 148: (2016), <https://doi.org/10.1016/j.proeng.2016.06.624>.
- [14] K. Elie et al., Dependence of the geopolymerization process and end-products to the nature of solid precursors: Challenge of the sustainability, *J. Clean. Prod* 278: (2021) 123587-123598.
- [15] M. Heikal, M. Y. Nassar, G. El-sayed, and S. M. Ibrahim, Physico-chemical, mechanical, microstructure and durability characteristics of alkali activated Egyptian slag, *Construction and Building Materials* 69: (2014) 16-72.
- [16] M. J. McCarthy and T. D. Dyer 2019 in 5th (ed) *Pozzolanas and pozzolanic materials* (Elsevier Ltd) p 363.
- [17] M. Ahdaya and A. Imqam, Investigating geopolymer cement performance in presence of water based drilling fluid, *J. Pet. Sci. Eng* 176: (2019) 934-942.
- [18] M. S. Muniz-Villarreal et al., The effect of temperature on the geopolymerization process of a metakaolin-based geopolymer, *Mater. Lett* 65: (2011) 995-998.
- [19] M. A. El, S. A. El, M. Heikal, and H. El Didamony, Hydration and durability of sulphate-resisting and slag cement blends in Caron 's Lake water, *Construction and Building Materials* 35: (2005) 1592-1600.
- [20] M. Dineshkumar, and C. Umarani, "Effect of alkali activator on the standard consistency and setting times of fly ash and GGBS-based sustainable geopolymer pastes", *Advances in Civil Engineering*, 10: (2020), <https://doi.org/10.1155/2020/2593207>.
- [21] M. Dineshkumar & C. Umarani, Effect of alkali activator on the standard consistency and setting times of fly ash and GGBS-based sustainable geopolymer pastes, *Advances in Civil Engineering* 2020: (2020) 1155-1165.

- [22] N. B. Singh and B. Middendorf, Geopolymers as an alternative to Portland cement: An overview, *Constr. Build. Mater* 237: (2020) 117455-117469.
- [23] N. Dave, A. Kumar, A. Srivastava, and S. K. Kaushik, Setting time and standard consistency of quaternary binders : The influence of cementitious material addition and mixing, *Int. J. Sustain. Built Environ* 6: (2017) 30-36.
- [24] P. R., Vora, and U. V. Dave, Parametric studies on compressive strength of geopolymer concrete. *Procedia Engineering* 51: (2013) 210-219.
- [25] P. Awoyera and A. Adesina, Case Studies in Construction Materials A critical review on application of alkali activated slag as a sustainable composite binder, *Case Stud. Constr. Mater* 11: (2019) e00268-e00282.
- [26] S. V. Maruti, R. krishna, and M. Mounesh, Properties of Geopolymer Cement Mortar and Blocks with Calcium Carbonate, *Mater. Today Proc* 24: (2020) 1518-1524.
- [27] S. Salehi, M. J. Khattak, A. H. Bwala, and F. S. Karbalaei, Characterization, morphology and shear bond strength analysis of geopolymers: Implications for oil and gas well cementing applications, *J. Nat. Gas Sci. Eng* 38: (2017) 323-332.
- [28] S. Samantasinghar, and S. P. Singh, "Fresh and hardened properties of fly ash–slag blended geopolymer paste and mortar", *International Journal of Concrete Structures and Materials*, 13: (2019), <https://doi.org/10.1186/s40069-019-0360-1>.
- [29] S. Mesgari, A. Akbarnezhad, and J. Z. Xiao, Recycled geopolymer aggregates as coarse aggregates for Portland cement concrete and geopolymer concrete: Effects on mechanical properties, *Constr. Build. Mater* 236: (2020) 117571-117580.
- [30] S. Pilehvar, A. M. Szczotok, M. Carmona, R. Pamies, and A. L. Kjoniksen, The effect of microencapsulated phase change materials on the rheology of geopolymer and Portland cement mortars, *J. Am. Ceram. Soc* 103: (2020) 5852-5869.
- [31] T. Phoo-ngernkham, A. Maegawa, N. Mishima, S. Hatanaka, and P. Chindaprasirt, Effects of sodium hydroxide and sodium silicate solutions on compressive and shear bond strengths of FA – GBFS geopolymer, *Constr. Build. Mater* 91: (2015) 1-8.
- [32] T. Lingyu, H. Dongpo, Z. Jianing, and W. Hongguang, Durability of geopolymers and geopolymer concretes: A review, *Rev. Adv. Mater. Sci.* 60: (2021) 1–14.
- [33] Z. Benghazi, Zeghichi, L., & Hamdane, A. study of alkali-activated pozzolana/slag cement , based on local material, 21: (2009), <https://www.researchgate.net/publication/267944488>.

### الملخص باللغة العربية

تأثير تركيز القلوي علي الخواص الفيزيوكيميائية و الميكانيكية للاسمنت الجيوبوليمر المعتمد علي خبث الفرن العالي

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تم في هذا البحث دراسة تأثير تركيز القلوي علي الخواص الفيزيوكيميائية و الميكانيكية للعجائن المحضرة من حبيبات خبث الفرن العالي لتحضير اسمنت جيوبوليمري ومقاومتها لاملاح الكبريتات. تم تحضير اكثر من خليط من تلك المواد وتم اضافة هيدروكسيد الصوديوم وسيليكات الصوديوم كمادة منشطة للتفاعل حيث تمت اضافتهم علي ماء الخلط بتركيزات مختلفة وتم دراسة خواص كل خليط بعد عملية التآدرت في الماء بعد فترات زمنية مختلفة تصل الي 90 يوم, ثم تم نقع بعضها في محلول كبريتات الماغنسيوم بتركيز 5% بعد تركها تحت تأثير الرطوبة لمدة 28 يوم وتم دراسة تأثير املاح كبريتات الماغنسيوم علي الخلطات المختلفة وذلك بقياس مقاومة الضغط الميكانيكي, المسامية, الكثافة, الماء المتحد كيميائياً ودراسة التركيب باستخدام حيود الاشعة السينية.

#### ويمكن تلخيص اهم النتائج فيما يلي :

- أظهرت جميع المخاليط ازدياد تدريجي في مقاومة الضغط حتى 90 يوم كما اظهرت ايضا مقاومة عالية بعد نقعها في محلول كبريتات الماغنسيوم تركيز 5% ويرجع ذلك للمحتوى القلوي المرتفع للبورولانا الصناعي مما تسبب في نشاط التفاعل وزيادة الضغط الميكانيكي.
- انخفضت المسامية الكلية تدريجيا حتي 90 يوم وذلك بسبب تكوين مركب سيليكات الكالسيوم الهيدراتية (CSH) والجيوبوليمر جيل مع زيادة تركيز المنشط والتي تملئ الفراغات الموجودة بالمكعب مما يسبب تقليل المسامية.
- ازدادت الكثافة الظاهرية تدريجيا حتي 90 يوم وذلك بسبب تكوين مركب سيليكات الكالسيوم الهيدراتية (CSH) والجيوبوليمر جيل مع زيادة تركيز المنشط وزيادة سرعة التفاعل.
- وجد انه باستخدام حيود الاشعة السينية يظهر تكوين مركب سيليكات الكالسيوم الهيدراتية (CSH) والجيوبوليمر جيل المسئولين عن زياده مقاومة الضغط في دراسة التركيب للمخاليط .
- اعطي الخليط S6 افضل النتائج الذي يحتوي علي (خبث 100%) في وجود منشط بتركيز (هيدروكسيد صوديوم 15% + سيليكات صوديوم 15%).