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## Effect of sulphate, chloride and elevated temperature on the properties of Egyptian slag binder

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### Abstract:

The present research aims to explain the physico-chemical and mechanical characteristics of alkali activated slag geopolymer binder (AASGB). Commercial sodium hydroxide (SH) and sodium silicate liquid (SSL) are utilized as an alkaline activator at different temperature namely 25°C and 65°C. The hydration characteristics and physico-mechanical properties are illustrated through the determination of combined water contents (W<sub>n</sub>), combined slag, total porosity (TP), compressive strength (CS), bulk density (BD) and XRD analysis as spectroscopic tools upto 180 days. The durability of the AASGB against aggressive ions (sulphate and chloride ions) as well as effect of elevated temperatures upto 1000°C are studied. The activated binders are immersed under 5% MgSO<sub>4</sub> and/or 5% MgCl<sub>2</sub> solutions upto 12 months. The data showed that the higher concentration of SH (1mol/kg) at 65°C exhibited the highest resistance to elevated temperature upto 1000°C as well as given a high resistance against sulphate and chloride attack.

**Keywords:** Alkali Activated Slag Geopolymer Binder (AASGB), Fire resistance, Sulphate and Chloride Attack, Compressive strength.

### 1. Introduction:

The manufacture of the Portland cement (PC) raises global greenhouse gas pollution during calcination of clinker in hydrocarbon-heated furnaces. To decrease CO<sub>2</sub> emissions and save energy, large quantities of industrial wastes such as FA, GBFS and SF were used to manufacture of alkali-activated binders.

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Geopolymer or alkali binders are materials characterized by networks of inorganic molecules or chains. These binders have technical and ecological characteristics as compared with portland cement (PC), where the commercial usage of geopolymer concrete has increased in recent years [1]. The production of geopolymers request 30-60% less energy and released 80% lower carbon dioxide (CO<sub>2</sub>) into the atmosphere as compared with the Portland cement production [2].

Geopolymer is a class of an inorganic polymer binders formed by reacting alumina-rich and silica-rich solids in a high alkaline solution. The geopolymers could generate by using several industrial by-products. Geopolymerization depends on components, particle size, degree of crystallisation and distribution, kind of alkali-activators, pH, ratio of Si/Al, water/binder ratio, healing states (temperature, degree of moisture, healing or opening state) [3]. Geopolymerization proceeded in various steps, the first step of alkaline activation involved the disintegration of aluminate (AlO<sub>4</sub>) and silicate (SiO<sub>4</sub>) starting materials that are activated by alkali, resulting geopolymer gel as final yield. Hydrolysis occurred in the second step, the bond breaks to allow AlO<sub>4</sub> and SiO<sub>4</sub> tetrahedral units to react with each other so that, the polymeric geopolymer precursors produced. A poly-condensation occurred in the final level, where the geopolymer gel solidified and shaped three-dimensional alumino-silicate network [4].

Geopolymer used in various applications as fire-resistant, sealants, concrete, ceramics, etc. Geopolymers are environmentally sustainable because of their excellent functional, durability to elevated temperature and their smaller carbon footprint than PC. Qureshi and Ghosh [5] examined an improvement in compressive strength (CS) by raising the alkaline content to 10.41 %. Further raising in the alkaline material reduces the CS. Li et al., [6] showed the mechanical characteristic and the microstructure of the AAS exposed to temperature at 400-800°C. He demonstrated that the decrease in the CS by 23.9% to 35% at 400 °C. After exposure at 800 °C, another decrease in CS was observed to 87.0 % relative to the reference blend.

Sulphate and chloride ions enter in the deleterious reactions of cement causes the disintegration of CH, sedimentation of sulfoaluminates, gypsum and chloroaluminates causing the expansion and softening of concrete [7,8]. The existence of magnesium ions (Mg<sup>2+</sup>) as MgSO<sub>4</sub> and/or MgCl<sub>2</sub> share in a deformation of C-S-H

by dissolution of  $\text{Ca}^{2+}$  ions to produce CH and Mg-S-H, which followed by a decline in the CS [9-13].

The durability of AAS pastes and concretes demonstrated by [14-19], they showed that the AASGB is more durable binders in sulphate and acid resistant.

This study aims to explain the effect of various alkaline concentrations and cure at elevated thermally treated temperature on the hydration characteristics of GBFS geopolymer. The resistance of the activated binders to sulphat, chloride attack as well as elevated temperatures are also investigated.

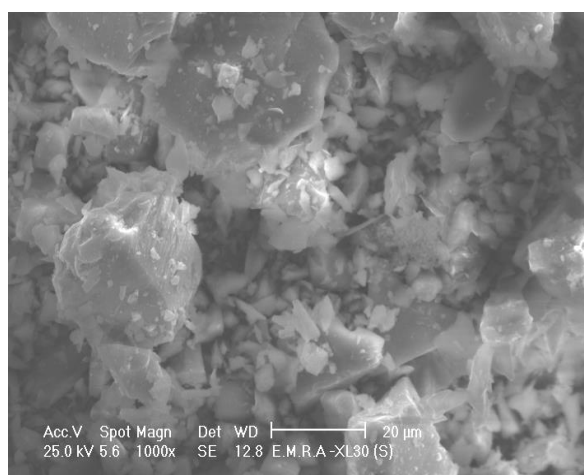
## 2. Materials and experimental procedures:

### 2.1. Materials:

The utilized materials are granulated blast furnace slag (GBFS), SSL and SH. GBFS is stocked from Iron and Steel Company, Helwan, Egypt. The surface area determined from Blaine test of GBFS was  $3570 \text{ cm}^2$ . The SEM of GBFS is given in Fig. (1). Chemical analysis of GBFS is present in Table (1)

**Table 1:** Chemical analysis of GBFS

slag	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	CaO	MgO	$\text{SO}_3$	$\text{K}_2\text{O}$	$\text{Na}_2\text{O}$	L.O.I	Total
oxide	43.21	9.97	0.59	35.96	5.43	1.37	0.67	0.79	1.98	99.97



**Figure 1:** SEM of GBFS

## 2.2. Procedure:

Various mixes are prepared as represented in Table (2). SSL and SH used as an alkaline activator in geopolymerization process, which dissolved in the mixing water as given in table (2). The binders are mixed in rotary mixer for 2 minutes. The prepared binders are molded in to 0.5x0.5x0.5 inch stainless steel cubic moulds. In order to prepare a better compaction of the pastes the mould vibrated, to take out any air bubbles, then stored in 100% RH after moulding at 25°C and 65°C for 3 days, then demoulded and then keep under water up to 180 days. For elevated thermally treated temperature, or firing resistance, the specimens cured at 28 days then dried at 100°C for one day, and then exposed to various elevated temperatures at (200°C upto 1000°C) in an electric furnace at two hours, and then after thermally treated temperature cooled in off-closed furnace to reach room temperature.

For aggressive attack, the specimens are stored under water for 28 days (zero month), then subjected to 5% MgSO<sub>4</sub> or 5% MgCl<sub>2</sub> solution. The specimens are tested at 1,3,6 and 9 months.

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

Mix No	GBFS	SSL, mol/kg	SH, mol/kg	W/S ratio	cured temperatures
S1	100	0.75	0.5	28	25°C
S2	100	0.75	0.5	28	65°C
S3	100	0.75	1.0	13	25°C
S4	100	0.75	1.0	13	65°C

## 2.3. Methods of investigation:

The binders are stopped using stopping solutions (1:1 acetone – methanol mixture), then dried at 70°C for one hour [20]. The physico-chemical and mechanical properties of geopolymer mixes are tested by determination; the compressive strength (CS) according to ASTM specification [21] by using 600kN capacity SEIDNER Riedinger compression-machine; combined water (Wn) and combined slag (CG) can

be measured according to [7,22]. Bulk density and total porosity (TP) was calculated before the determination of CS [22]. Determination of total sulphate and chloride contents was determined according to [23]. XRD method used to determination the phase compositions of the formed hydrates. XRD technique is carried out on certain cement pastes to indicate the hydration products.

### **3. Results and discussion:**

#### **3.1. Hydration characteristic of slag geopolymer:**

##### **3.1.1. Compressive strength:**

Figure (2) showed the CS of the activated mixes cured upto 180 days at 25°C and 65°C. The results showed that the CS gradually increased with the time period for all hardened mixes, due to higher reactivity of AASGB and formation of successive amounts of calcium silicate hydrates (CSH), calcium aluminium (CAH) and sodium-aluminum-silicate gel (N,C) ASH through the activation process. These products precipitated in open pores, and creation of the compact-body. The data showed that the CS values improved with the increasing of the Na<sub>2</sub>O content and heat-treated temperatures to 65°C. Mix S4 give the highest CS values at all curing period. The accumulation and precipitation of the large amount of (N,C) ASH gel improved the CS of AASGB binders [22,24]. Mix S4, which activated and thermally cured at 65°C, has the highest CS values than other mixes. Mix S2 showed the resanable value of compressive strength of mix S3, especially at 3-28 days, then the CS of mix S3 increased upto 180 days due to the increasing of the alkaline activation with 1 mol/kg of Na<sub>2</sub>O.

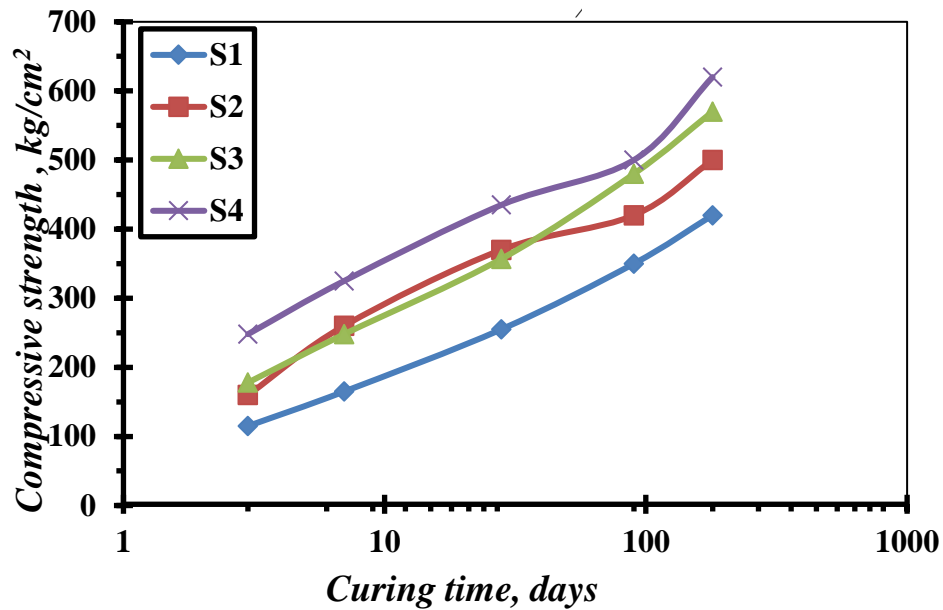
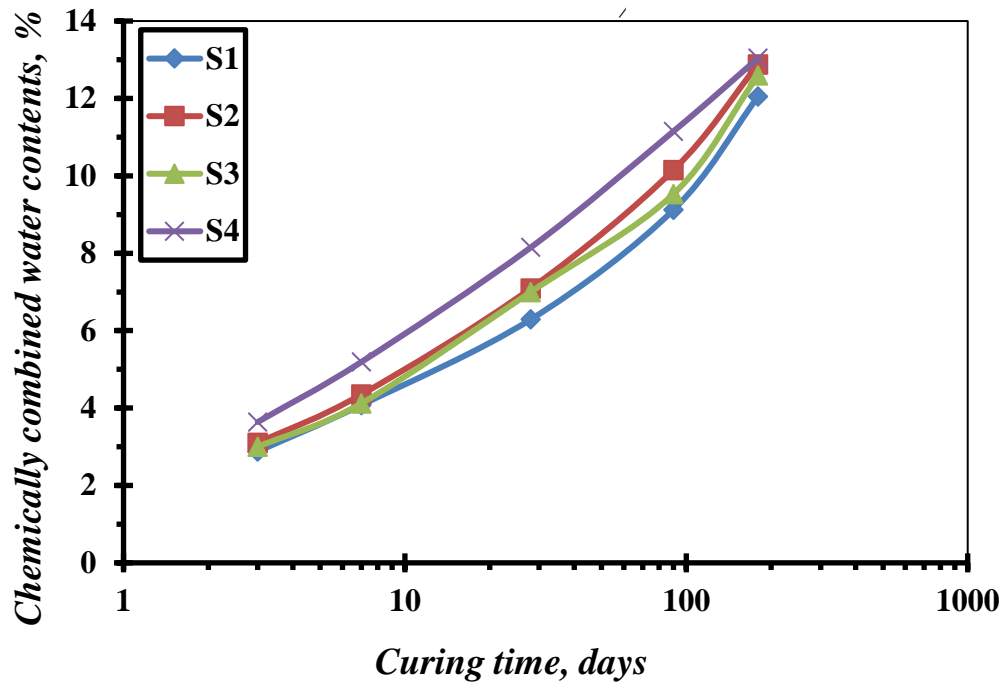


Fig. 2: Compressive strength (CS) of activated GBFS at 180 days.

### 3.1.2. Chemically combined water contents:

The chemically combined water ( $W_n$ ) of activated mixes cured upto 180 days at 25°C and 65°C is graphically described in Fig. (3). The  $W_n$  content of all mixes improved with increasing the alkaline activation, hydration time, and thermally treated temperature to 180 days. This is due to the progress of geopolymer processes that is producing the geopolymerized products which precipitated in the empty vacant pores within the binder matrix. The results also observed that the  $W_n$  contents of AASGB enhanced as  $Na_2O$  content increased from 0.5 to 1 mol/kg as seen in mixes S2 and S4. Increasing alkaline activator concentration increased the rate of dissolution of GBFS, then increasing the production of CSH, CAH, (N,C)SAH geopolymer gel. The alkaline activator ( $Na_2O:SiO_2$ ) facilitated the liberation of  $Ca^{2+}$ ,  $Si^{4+}$  and  $Al^{3+}$  from GGBS grains, thereby enhancing GGBS hydrolytic degradation to produce more alkali-activated gel products [25,22]. The data also revealed that the S2 and S4 mixes cured at 65 °C explained an improvement in the values of  $W_n$  relative to those of mixes cured at 25 °C, due to geopolymerization reactions, synergetic activity of alkali concentration and higher curing temperature at 65 °C.

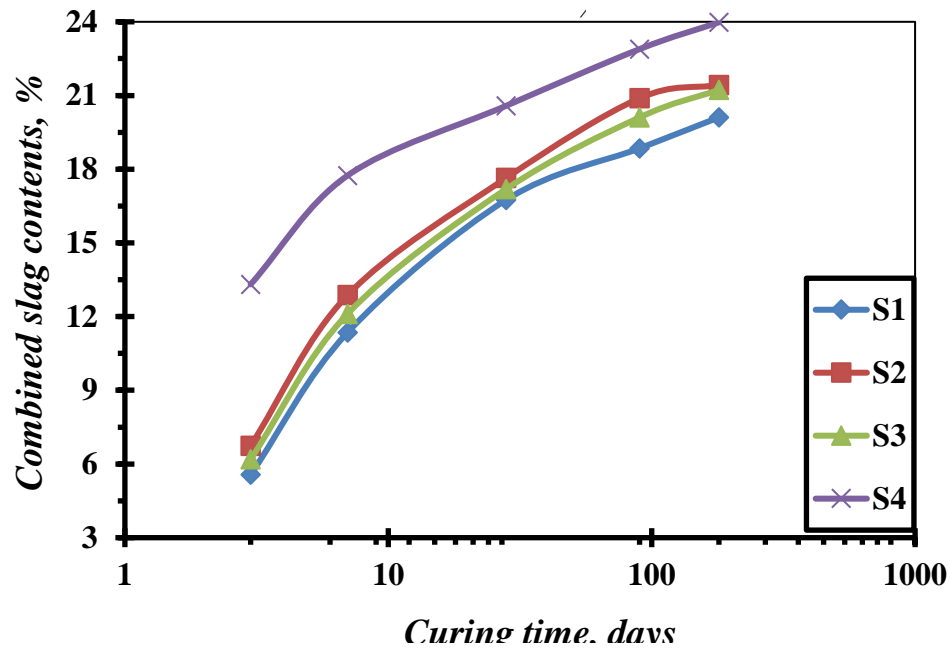


**Fig. 3:** Chemically combined water contents ( $W_n$ ) of alkaline activated GBFS cured up to 180 days.

### 3.1.3. Combined slag contents:

The combined slag content (CG) of AASGB cured up to 180 days at 25°C and 65°C was plotted in Fig. (4). The data revealed that the combined slag content increased with the ages-period for all mixes, this is attributable to the production of excessive amount of CSH, CAH in addition to (N,C) ASH geopolymer gel. Increasing of Na<sub>2</sub>O alkali activated contents from 0.5 to 1 mol/kg binder resulting an increasing of alkali-activated products. The combined slag of AASGB improved with the alkali-activated content. The dissolved species of GGBS increased by increasing the XNa<sub>2</sub>O:SiO<sub>2</sub> content so a sharp increase in the combined slag observed. The combined slag of the mixes cured at 65°C were higher than the mixes cured at 25°C. Mixes S2 and S4 at 65°C represented the highest combined slag values than other mixes.





**Fig. (4):** Combined slag contents of alkali activated binder cured upto 180 days

#### 3.1.4. Bulk density and total porosity:

Figure (5, A and B) shows the variation of bulk density (BD) and total porosity (TP) of the AAGSB cured at 180-days. The data showed that the values of the BD improved wherever the TP decreased with treatment temperatures and ages, this is accredited to the increase in the excessive of geopolymeric products with the alkaline activation contents. The addition of a chemical activator ( $\text{XNa}_2\text{O}:\text{SiO}_2$ ) improved the concentration of  $[\text{SiO}_4]^{4-}$  and  $\text{AlO}_4^{5-}$ , that is intensified the production of AAGB [26]. As the curing temperature increased to  $65^\circ\text{C}$ , the TP decreased as shown in the samples (S2 and S4). This is related to the formation of the (N,C) ASH gel which permit the formation of matrix structure with lower TP. Mix S4 gives lower values of TP. It can be concluded that physico-mechanical properties, namely CS and BD, are in good agreement with each other and represented in an increasing trend, while TP displayed a decreasing trend from 3-180 days.

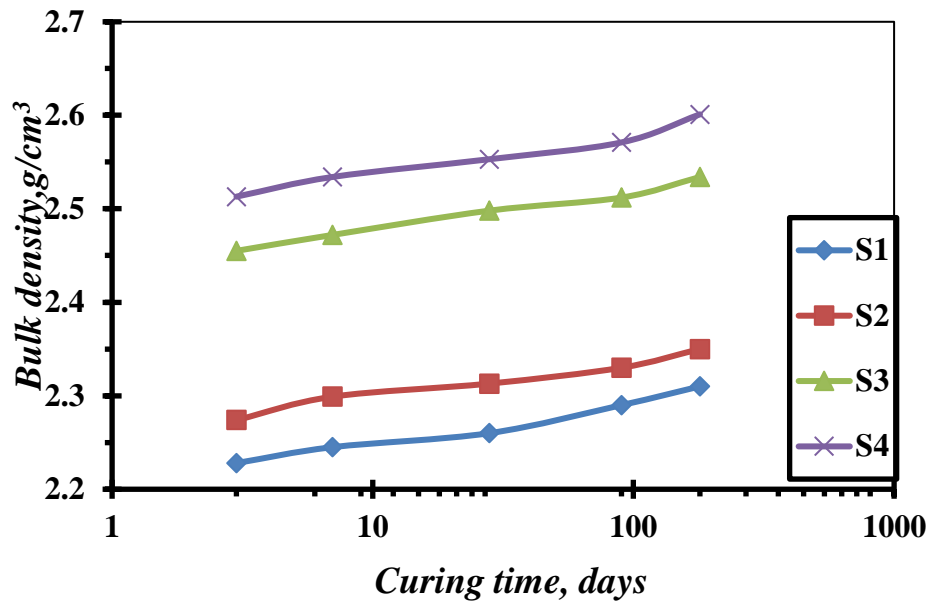


Fig. 5, A: Bulk density of alkaline activated GBFS upto 180 days.

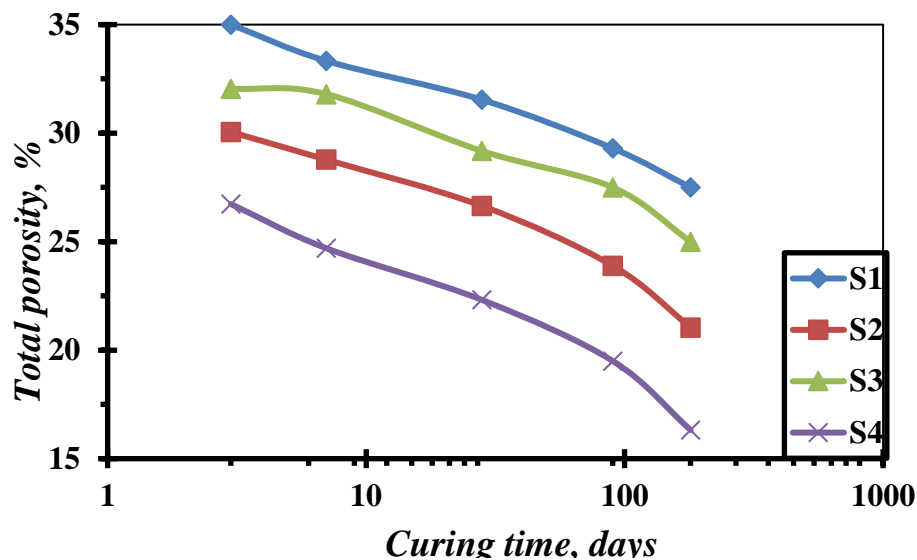
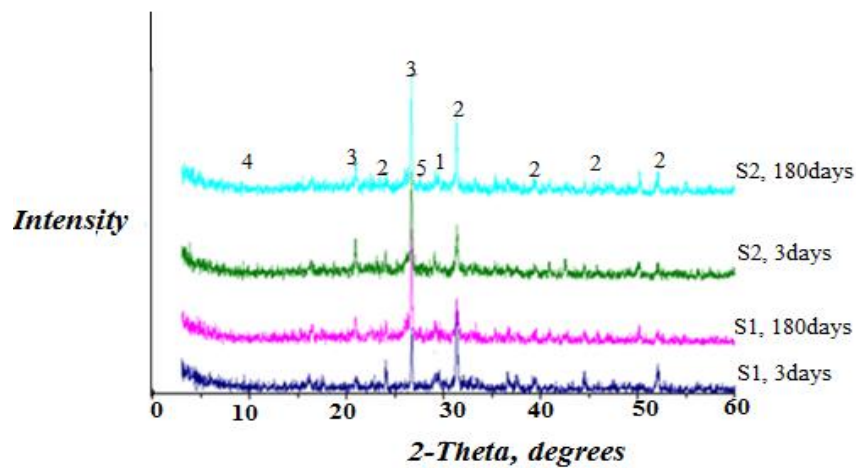


Fig. 5, B: Total porosity of alkaline activated GBFS binder upto 180 days.

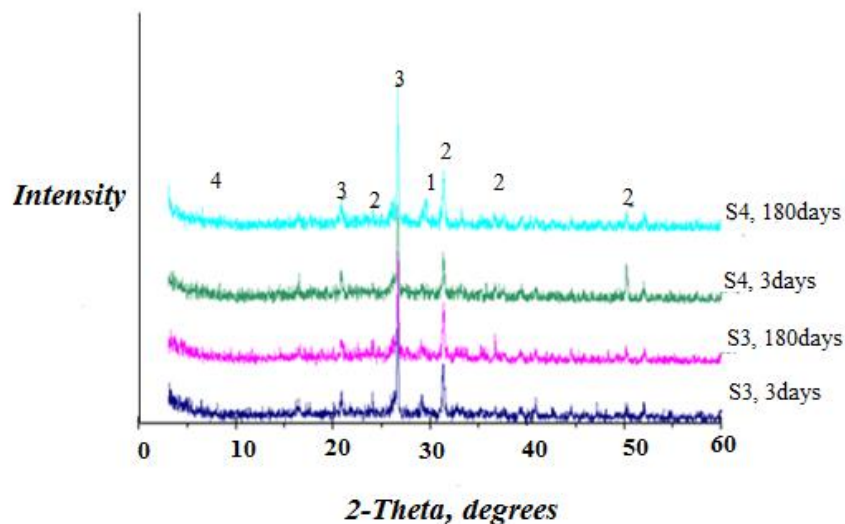
### 3.1.5. X-ray diffraction:

Figure. (6, A and B), presented the XRD patterns of alkali-activated GBFS binders cured at 3, 180 days at 25°C and 65°C with (0.5:0.75 Na<sub>2</sub>O:SiO<sub>2</sub>) and (1.00:0.75 Na<sub>2</sub>O:SiO<sub>2</sub>). XRD analyses are conducted on subjected mixes to examine the effect on the CS of AAGSB. The XRD of GBFS geopolymer as given in Fig. (6, A and B) consisted of mainly amorphous and some crystalline phases such as SiO<sub>2</sub>, CaCO<sub>3</sub>, CSH, gehlenite (C<sub>2</sub>ASH<sub>8</sub>), wollastonite and tobermorite. The geopolymer

pastes showed an improve in the mechanical characteristic as represented in Fig.2. The broad and diffuse peaks as represented in Figure. (6), including short-ordering structure or amorphous phases which existing in the AASG. Very small tobermorite and wollastonite ( $C_2ASH_8$ ) phases appeared in the XRD patterns, on the other side the  $CaCO_3$  phase give an enhanced at 180 days.



**Fig. 6, A:** XRD diffractograms of alkali activated GBFS binders cured upto 180 days at 25°C and 65°C (1=C-S-H; 2=gehlenite; 3= quartz; 4= tobermorite; 5 = wollastonite

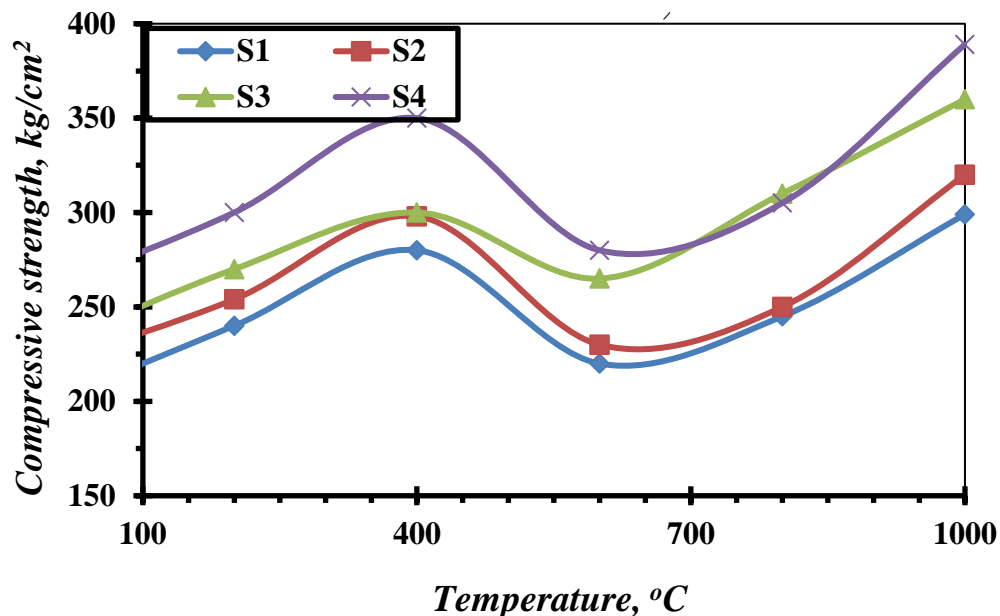


**Fig. 6, B:** XRD diffractograms of alkali activated GBFS binder cured upto 180 days at 25°C and 65 °C, (1=C-S-H; 2=gehlenite; 3= quartz; 4= tobermorite; 5 = wollastonite.

### 3.2. Resistance to thermally treated temperatures:

#### 3.2.1. Compressive strength:

Compressive strength values of AAGSB mixes, exposed to various temperatures at 200, 400, 600, 800 and 1000 °C are given in Fig. (7). It is cleared that the CS of all specimens improved with the elevated temperature up to 400°C, due to the acceleration effect on the geopolymerization process of alkaline activated slag particles producing self autoclaving effect, which increase the CS values [27]. Increase of the treatment temperature up to 600°C, the CS values decreased, due to partial decomposition of the geopolymer network leading to the weaken of mechanical properties. Further increasing in the CS observed when the mixes subjected to the 800 and 1000°C, this is attributed to the sintering process or solid-state reaction to produce a ceramic bond of mineral ingredients. Mix S4 exhibits the highest values of the CS at all thermally treated temperatures as compared to the other mixes. This is due to the presence of additional alumina-silicate networks during geopolymerisation process such as nepheline [NaAlSiO<sub>4</sub>], gehlenite [Ca<sub>2</sub>Al(AlSiO<sub>7</sub>)], analcime [Na(AlSi<sub>2</sub>O<sub>6</sub>).H<sub>2</sub>O] and quartz as shown later in XRD pattern. The data showed that samples cured at 65 °C showed an increase in the CS than the samples cured at 25 °C.



**Fig. 7:** Compressive strength values of activated binders at various firing temperature upto 1000 °C.

### 3.2.2. Bulk density and Total porosity:

The BD and TP of alkali activated GBFS mixes fired at different temperatures upto 1000°C are represented in Figure.(8, A and B). The data showed that the BD of activated binders enhanced by increasing the temperature upto 400°C, when the samples exposed to further heating temperature at 600 °C the bulk density showed a small decrease. On the other hand after the specimens thermally treated upto 800 and 1000 °C, an increase in the values of bulk density are observed again. From represented data, it is showed that the alkali activated, S4 mix exhibited the higher values of the bulk density and less values of the TP in comparison with the other mixes. Bulk density of GBFS based geopolymer which observed at 65 °C was more homogeneous than that of specimens at 25 °C. The production of more effective (N,C) ASH gel promoting the structure matrix with the lower values of the TP.

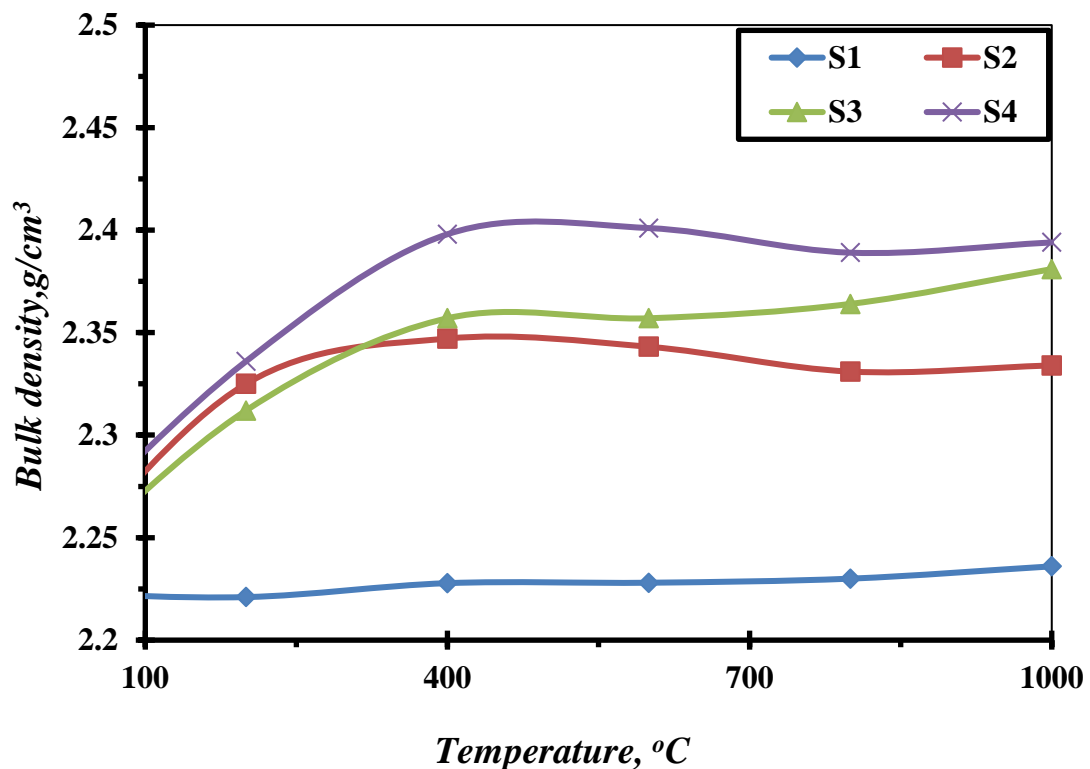
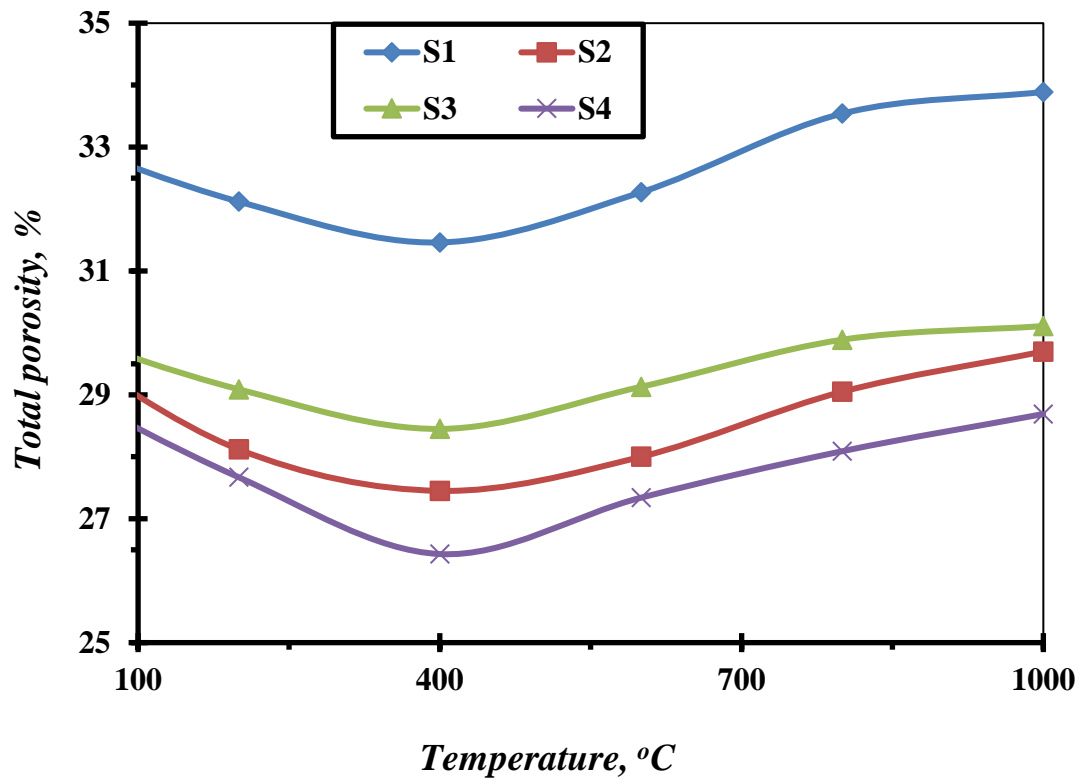


Fig. (8, A): Bulk density values of activated mixes at various firing temperatures upto 1000°C.

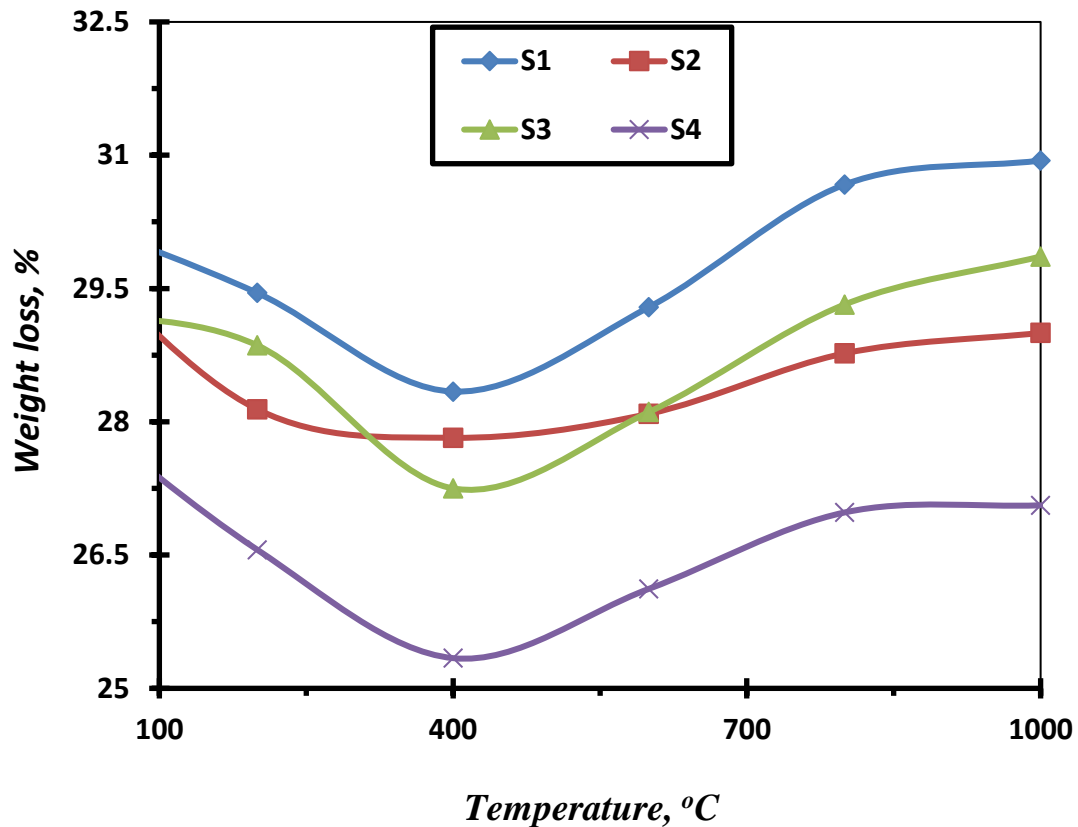


**Fig. 8, B:** Total porosity values of alkaline activated mixes at various firing temperatures upto 1000°C.

### 3.2.3. Weight loss:

The weight loss values of alkali activated GBFS mixes exposed to different temperatures at 200, 400, 600, 800 and 1000 °C are plotted in Fig. (9). The weight losses of the specimens are determined by measuring the mass losses of the samples after and before the exposure to treated temperature. It is found that the weight losses of the specimens reduced with elevated temperature upto 600°C, due to deterioration the internal structure of the samples and the evaporation of free water [28]. Almost very slight reduction in the weight of the specimen is appeared with the further increased in the temperature from 800°C to 1000°C.

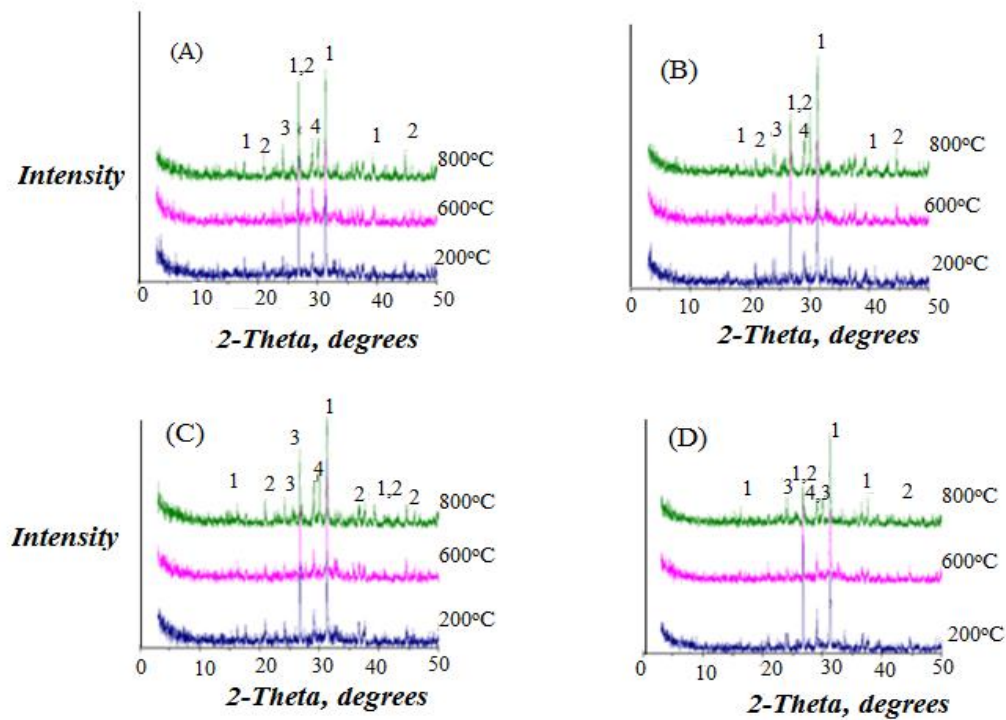
The weight losses of the geopolymers cured at low temperature (25°C), are greater than the weight losses of the samples cured at high temperatures (65°C) [29]. The weight loss of the S1 mix when exposed to 1000°C was 29.64%, whereas the weight loss of S4 was 27.06%.



**Fig. 9:** Weight losses values of all mixes at various firing temperature upto 1000 °C.

### 3.2.4. The XRD diffraction patterns:

Figure. (10, A-D) shows XRD patterns of AASGB binders of mixes S1, S2, S3 and S4 exposed to different elevated temperature; 200, 600, 800°C, respectively. The XRD diffractogram of GBFS geopolymers showed the presence of various crystalline phases like (calcium silicate hydrated, quartz, mullite, maghemite, and lamite phases). XRD confirmed that the CS values of all mixes resist the elevated temperature up to 400°C followed by sharp decrease at 600. The XRD patterns of all mixes at 200°C shows an amorphous CSH phase which responsible for the increasing of the CS, due to the production of alumina-silicate networks through the geopolymerisation steps in binders containing high Na<sub>2</sub>O concentration (1 mol/kg of binders) [30]. Furthermore, as the concentration of Na<sub>2</sub>O increased, sodium ion increased in solution that balanced more alumina-silicate network leading to formation of more crystalline phases. A sharp decrease in CS at 600 observed due to the decomposition of the CASH and CSH phases.



**Fig. (10, A-D):** XRD diffractograms of alkali activated slag A=(S1), B=(S2), C=(S3), D=(S4) at different elevated temperatures at, 200,600,800 °C; 1=mullite; 2=quartz; 3= gehlenite; 4= Calcium silicate hydrate (CSH).

### 3.3. Resistance to sulphate and chloride ion attack:

#### 3.3.1. Magnesium sulphate solution:

##### 3.3.1.1 Compressive strength:

The CS values of OPC and AAGSB mixes containing 0.5 and 1 mol/kg Na<sub>2</sub>O immersed in 5% magnesium sulphate solution up to 9 months are represented in Figure. (11). Data showed that the CS values of AAGSB enhanced with the curing period as the geopolymerization progresses up to 9 months. AAGSB enhances the resistance to chemical attack, this is attributed to continuous activation of GBFS producing CSH, (N,C)ASH and CAH geopolymer gel. On the contrary the CS of OPC paste enhances up to 3 months then reduces up to 9 months [29]. The reduce in the CS of OPC paste after 3 months, due to the existing of more amount of belite and alite phases that liberated Ca(OH)<sub>2</sub>. portlandite reacts with MgSO<sub>4</sub> producing MgOH<sub>2</sub> (brucite) and CaSO<sub>4</sub> (gypsum). The formed gypsum combines with C3A and produced tri -sulphatealuminat hydrate (AFt) which causes expanding and softening



of the concrete, meanwhile the formation of AFt in the AAGSB was not observed [22,10]. It is also observed that the CS values are improved with increasing the alkali concentration as showed by [31,32]. Mix S4 has a higher value of the compressive strength than neat OPC and other mixes.

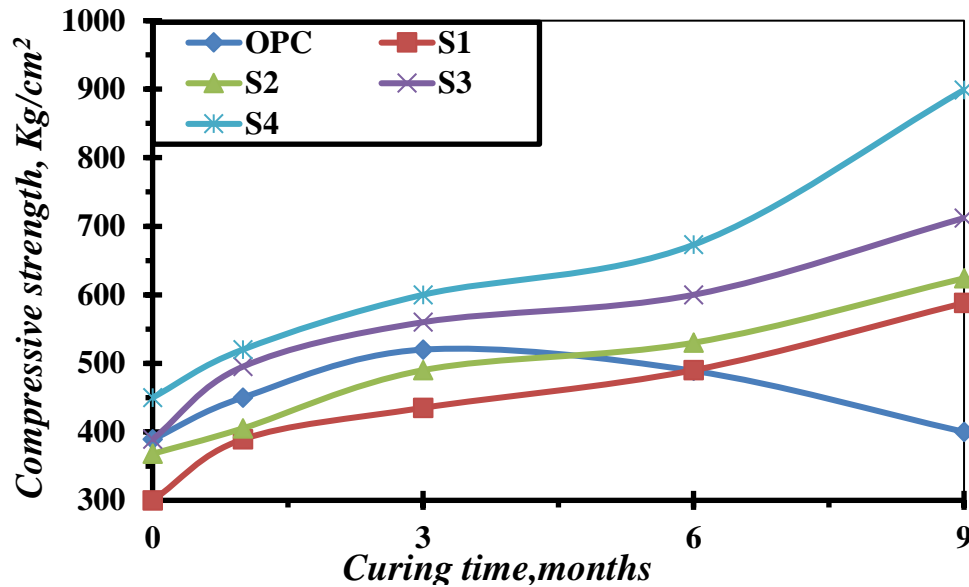


Fig. 11: Compressive strength of OPC and AASGB exposed to 5% MgSO<sub>4</sub> solution up to 9 months.

### 3.3.1.2. Bulk density and total porosity:

Changes in the values of BD and TP of OPC and AAGSB mixes including 0.5 and 1 mol/kg Na<sub>2</sub>O subjected to 5% MgSO<sub>4</sub> solution up to 9 months are given in Figure. (12, A & B). The BD of OPC pastes improved up to 3 months, then reduced up to 9 months. The decreases in the BD after 3 months were observed due to the influence of aggressive attack of sulphate ions exposed to cement phases. On the other side, the BD of AASGB mixes increased with curing period up to 9 months and with alkaline activator up to 1 mol/kg. This is due to the continuous polymerization process, which contributes to the creation of more hydrated materials, rendering the microstructure more compact and homogeneous, raising the BD and decreasing the TP. The BD values are enhanced and the TP decreased by increasing the alkali concentration. Mix S4 has a higher value of the BD and lower value of the TP than neat OPC and other mixes.

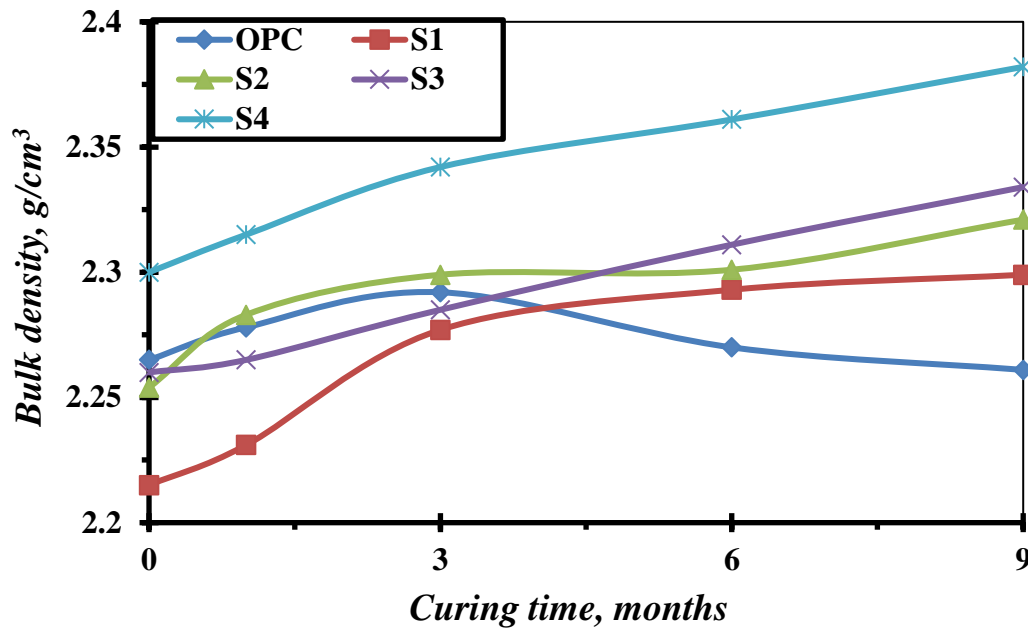


Fig. 12, A: Bulk density of OPC and AAGSB subjected to 5% MgSO<sub>4</sub> solution upto 9 months.

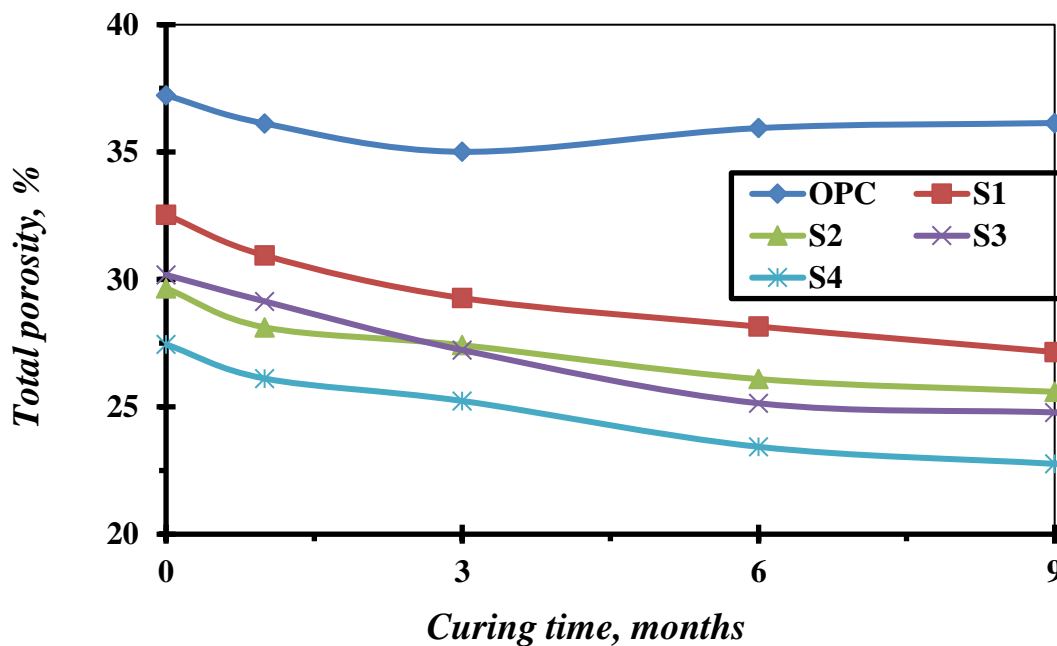
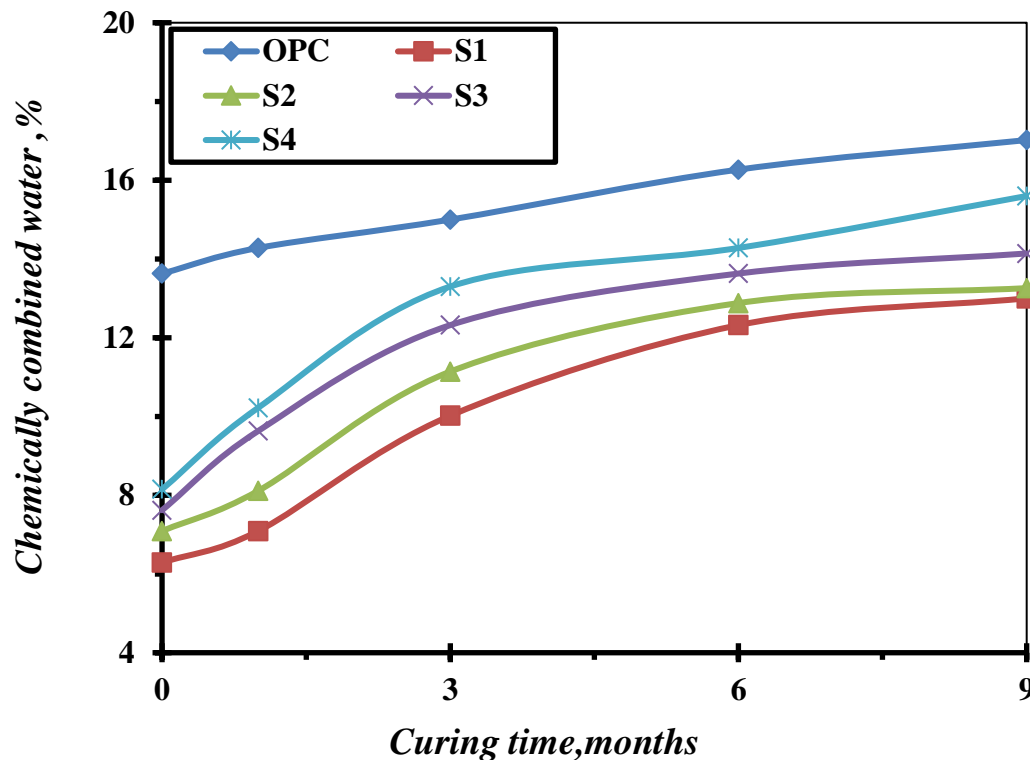


Fig. 12, B: Total porosity of OPC and AAGSB immersed in 5% MgSO<sub>4</sub> solution up to 9 months.

3.3.1.3 Chemically combined water contents:

The combined water content of OPC and AASGB activated by 0.5 and 1 mol/kg Na<sub>2</sub>O immersed in 5% magnesium sulphate solution up to 9 months are given in Figure. (13). Chemically combined water content improved with curing period upto

9 months for all mixtures owing to the advancement of geopolymer processes. Generally, chemically combined water content is increased dramatically up to 1 month due to the acceleration impact of  $MgSO_4$  on the pastes [7]. Chemically combined water of alkali-activated binder improved with alkali content up to 1 mol/kg. By increasing alkaline activator concentration, AASGB hydration improved by increasing GBFS dissolution rate to form polymeric gel goods.

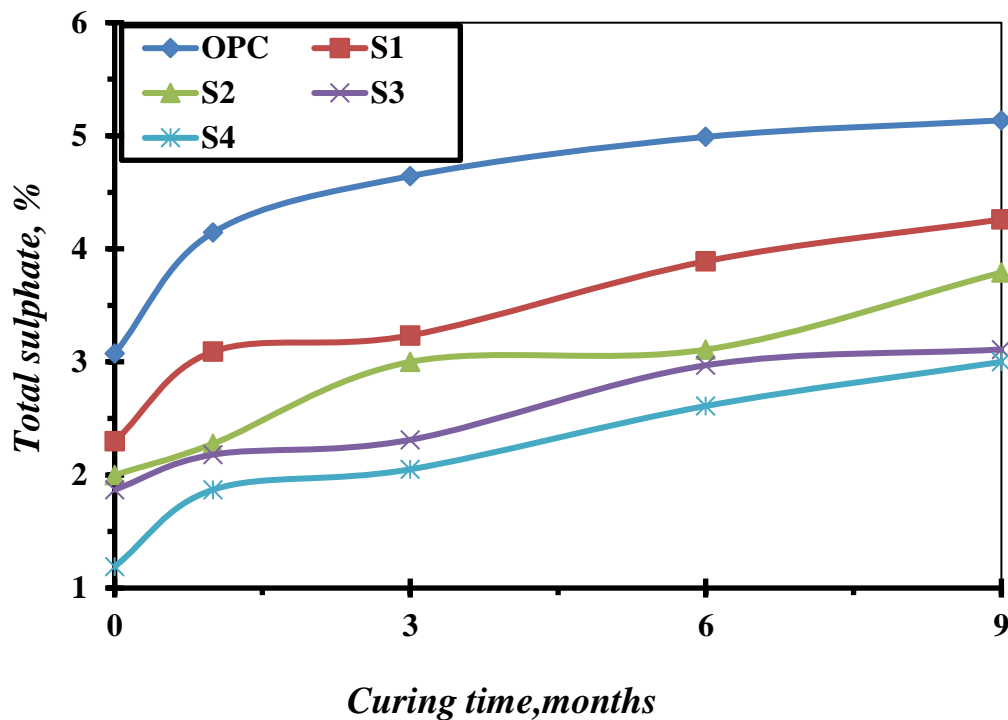


**Fig. 13:** Chemically combined water contents of OPC and alkali activated GBFS binder subjected to 5%  $MgSO_4$  solution up to 9 months.

#### 3.3.1.4. Total sulphate contents:

The total sulphate contents of OPC and AAGSB immersed in 5% magnesium sulphate solution up to 9 months are given in Figure . (14). The results showed that the total sulphate content is increased upto 9 months for all AAGSB. OPC pastes give a higher values of the total sulphate contents than other mixes, due to a higher content of portlandite liberated in OPC paste. The data also represented that the total sulphate contents of AAGSB reduces as a result of synergetic action of thermally treated temperatures and effect of increase the alkaline activator. S4 mix represented the

lowest values of total sulphate content upto 9 months, this is attributed to the reduce of the penetration of  $\text{SO}_4^{2-}$  anion into pore system.

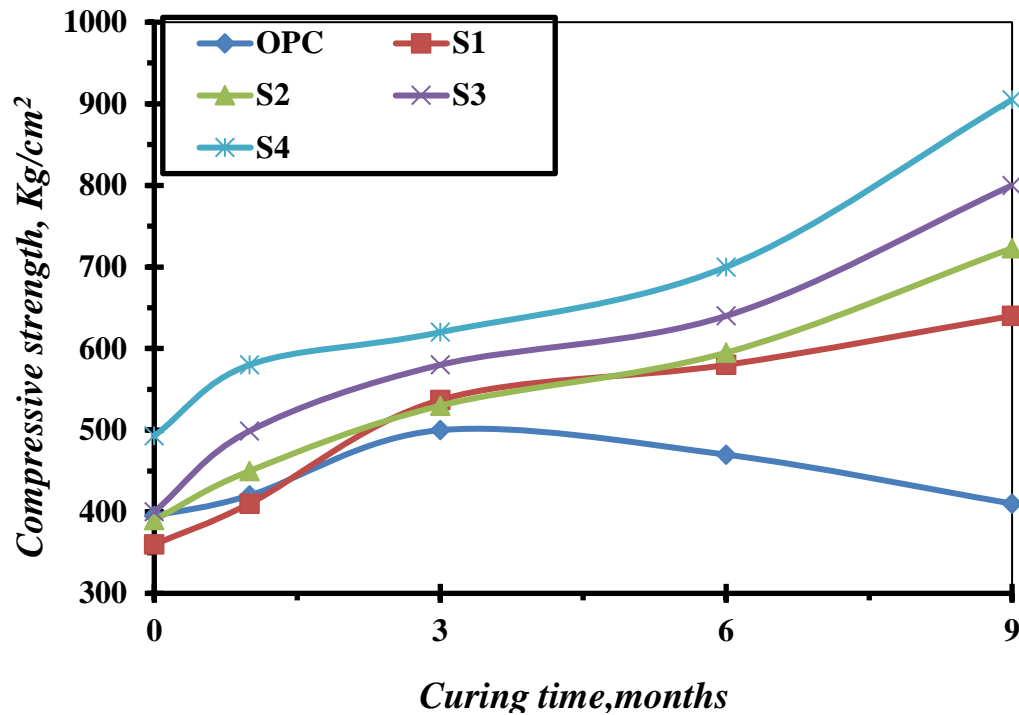


**Fig. 14:** Total sulphate contents of OPC and AASGB exposed to 5 %  $\text{MgSO}_4$  solution upto 9 months.

### 3.3.2. Magnesium chloride solution:

#### 3.3.2.1. Compressive strength:

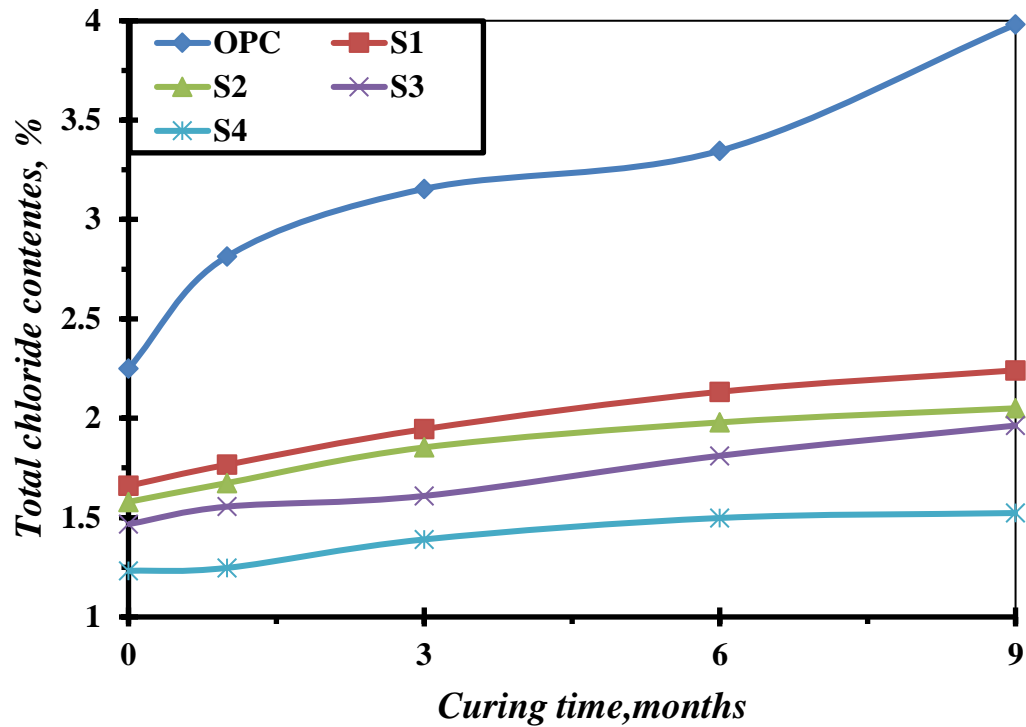
The CS values of OPC and AAGSB mixes containing 0.5 and 1 mol/kg  $\text{Na}_2\text{O}$  subjected to 5 %  $\text{MgCl}_2$  solution up to 9 months are given in Figure. (15). Results of the CS of the AAGSB enhanced with immersion time up to 9 months, attributed to the acceleration of hydration products with period time, due to the incorruption and adsorption of a part of  $\text{Mg}^{+2}$  ions on to the particles of CSH which enhance the crystallization of CSH. The data showed that S4 mix represented the higher durability to the penetration of the chloride ions attack, leading to formation of a denser structure and enhances the durability to chloride medium up to 9 months. Whereas the CS values of OPC showed a lower values from 3 months upto 9 months, this is attributed to the production of Friedel's salt (chloro-aluminate hydrate) phase which causes a softening of concrete, so that the CS is reduced [15].



**Fig. 15:** Compressive strength of OPC and AASGB exposed to 5% MgCl<sub>2</sub> solution up to 9 months.

### 3.11.2.2. Total chloride content:

The total chloride contents (TC) of AASGB and OPC pastes suspended in 5 % MgCl<sub>2</sub> solution upto 9 months are given in Figure. (16). Data showed that the OPC pastes result the higher contents of TC than those of AASGB, attributed to liberation of CH as a result of the hydration of OPC phases which reacted with Cl<sup>-</sup> ions producing CaCl<sub>2</sub>. The CaCl<sub>2</sub> reacts 3CaO.Al<sub>2</sub>O<sub>3</sub> to produce chloro-aluminate hydrate (C<sub>3</sub>ACaCl<sub>2</sub>10H<sub>2</sub>O). In the other side, the AASG binders are not produced C<sub>3</sub>ACaCl<sub>2</sub>10H<sub>2</sub>O. AASGB forms CSH, (N,C)ASH geopolymer gel which fills the empty pores. Then they decrease the Cl<sup>-</sup> ions penetration within the binder matrix. The radius of chloride anion is small. It can easily penetrate through the hole of pores producing C<sub>3</sub>A.CaCl<sub>2</sub>10H<sub>2</sub>O, which increases of the softening of binders [10].



**Fig. 16:** Total chloride contents of OPC and alkali activated GBFS treated in 5%  $MgCl_2$  solution up to 9 months.

#### 4. Conclusions

**It may be concluded that:**

1. The compressive strength of the AAGSB enhanced by thermally treated temperature, and synergetic effect of the alkali contents.
2. Mix S4 is the optimum mix composition, which showed a higher CS value than other mixes at all curing period up to 180 days as well as showed the higher resistance to penetration of chloride and sulphate ions .
3. The combined slag values and Wn contents of the mixes cured at 65 °C (mixes S2 and S4) are higher than the mixes cured at 25°C.
4. Compressive strength of all specimens enhanced by increasing the elevated treatment temperatures to 400°C but when the samples exposure to heating temperature at 600 °C has caused the further strength degradation. On the other hand, increase of the thermally treated temperatures after the material had been heated upto 800 and 1000°C, an increase in CS was shown due to the formation of ceramic bonds.

5. It can be concluded the mix S4 represent a good durable mix, which increases the compressive strength in both  $MgCl_2$  and  $MgSO_4$  attack solutions.

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## الملخص باللغة العربية

تأثير املاح الكبريتات والكلوريدات ودرجات الحرارة المرتفعة على خصائص خبث الحديد المصرى

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هذا البحث يهدف دراسة الخواص الكيميائية والميكانيكية والفيزيائية لمواد الجيوبوليمر (خبث الحديد المنشط قلويًا). وقد تم إضافة سيلكات الصوديوم وهيدروكسيد الصوديوم كمادة محفزة للتفاعل حيث تم إضافتهم على كمية ماء الخلط بنسب مختلفة من التركيزات ولذلك تم تجهيز عدد من المخاليط بكميات مختلفة من تلك المواد. وتم دراسة خواص كل خليط بعد عملية التأدرت في الماء بعد فترات زمنية مختلفة. وقياس الكثافة الظاهرية، المسامية الكلية، ماء الخلط، الماء المتحدة كيميائي، مقاومة الضغط الميكانيكي او دراسة التركيب الدقيق باستخدام حيود الأشعة السينية. و هذه الدراسة تهدف ايضا تأثير درجات الحرارة المرتفعة (200، 400، 600، 800 و 1000 درجة مئوية) وتأثير أملاح الكبريتات والكلوريدات على الخلطات المختلفة. ويمكن تلخيص اهم النتائج التي حصلنا عليها فيما يلي.

- وضحت جميع المخاليط مقاومة ضغط ميكانيكى جيدا حتى 180 يوم و يرجع ذلك الى المحتوى القلوى العالى للبورولانا الصناعية والذي ينشط التفاعل ويجعل له مقاومة ضغط ميكانيكى عالى.
- أظهر خليط خبث الأفران المنشط باستخدام 1 مول لكل كيلوجرام من هيدروكسيد الصوديوم اعلي مقاومة لأملاح الكبريتات والكلوريدات.
- ولقد بينت جميع العينات زيادة فى قوة التحمل حتى 400 درجة مئوية يليها نقص فى قوة التحمل عند 600 درجة مئوية وذلك النقص يرجع إلى إزالة الهيدروكلوكسى من شبكة الجيوبوليمر التى تؤدى إلى ضعف خصائصه الميكانيكية.