

Thermal Behaviour and Microstructure of Blended Portland cement with Libyan Steelmaking Slag

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Abstract: Eleven blends of slag cement were prepared, namely 100, 95/5, 90/10, 85/15, 80/20, 75/25, 70/30, 65/35, 60/40 and 50/50 mass% of Portland cement (Derna) and granulated slag (Mosrata) respectively. Non - evaporable water content of hydrated sample were determined by noting loss at 1000 °C. Hydration phases and hydration mechanism were investigated by means of XRD, SEM, DTA and TG tests.

Key words: Portland cement • Hydration • Water content

INTRODUCTION

The utilization of by-products from various sectors of industry is a present-day concern involving the problem of energy and pollution. Cement plants generate solid waste air pollutants during the course of their operation. The furnace slag is the by-product released from blast furnace. The main chemical composition includes CaO, SiO₂ and Al₂O₃. In addition, it contains very little MgO, FeO and a little sulfide, such as CaS, MnS and FeS. High proportions of CaO, Al₂O₃ and MgO are advantageous to the activity of slag while the viscosity increases with high content of SiO₂. It is easy to form CaSiO₃ and the high silicate glass that decreases the activity of slag. The activity of granulated blast furnace slag (GBFS) is determined by the quantities and the properties of amorphous glass, as well as the chemical compositions.

Facts have been proved that the higher the proportion of glass, the greater is the activity of slag at the same chemical composition. Thus, slag has been widely used as an active additive in China. Since

mechanical shaft kiln factories produce 60% of cement, the blending quantity of slag is 25±30% in normal cement. Ground granulated blast furnace slag without an activator does not react with water at room temperature. The hydraulic activity of slag depends on its chemical composition, glass content, particle size distribution and surface morphology [1,2]. Mehta [3] reported that a coating film of aluminosilicate forms on the surface of slag grains within a few minutes of exposure to water, which inhibits further hydration. The rate of hydration is very slow, but it increases in alkaline media. Portland cement clinker or liberated lime is normally used to provide this alkalinity [4].

In the presence of lime, reaction occurs, removing the acidic film and hydration is continued as the lime breaks the silica film on the slag grains. The hydration products usually detected in the granulated slag-lime mixtures are calcium silicate hydrates and calcium aluminate hydrates with varying compositions, in addition to hydrogarnet [4,5]. During subsequent hydration of the slag cement, there is a consumption of calcium hydroxide liberated from the hydration of Portland cement clinker and residual

alkalis incorporated in the slag [6]. The use of GBFS as a partial replacement of ordinary Portland cement improves strength and durability of concrete by creating a denser matrix and thereby increasing the service life of concrete structures. Grinding slag for cement replacement requires approximately 25% energy needed to produce Portland cement [7-9].

GBFS has been known to reduce the degree of which ASR occurs in concrete. The alkali in cement is used by the GGBFS during hydration, which prevents the alkali from reacting with the potential deleterious aggregates. In addition, GGBFS typically reduces the permeability of the concrete that in turn prevents the alkalis from migrating through the pores [10]. Total porosity generally decreases with curing time for all hardened cement pastes due to the filling up of the available pore volume with the hydration products, as the hydration proceeds. Also, it is seen that with increasing GBS, the total porosity decreases due to the increase of the rate of hydration of cement paste at early ages. The OPC pastes show the higher of total porosity. Compressive strength generally increases with curing time for all cement pastes. This is due to the increase in the amount of hydration products such as calcium hydro silicate and calcium sulpho aluminates. As hydration proceeds, more hydration products and more cementing material are formed and therefore the porosity decreases which lead to an increase in the compressive strength of all cement pastes with curing time up to 90 days [11].

MATERIALS AND METHODS

Ordinary Portland cement (OPC) provided by Derna Cement Manufactory (cement Libya) and granulated blast furnace slag (GBFS) was obtained from the Libyan steelmaking, with the following oxides are given in Table 1. The Blaine surface for Ordinary Portland cement (OPC) and granulated blast furnace slag (GBFS) are 340, 4400 respectively (Table 2).

The total water content of hydrated cement pastes consists of evaporable and non-evaporable portion. The evaporable water represents that portion which is present in the pore system and adsorbed on its surface. The non-evaporable water content represents that portion retained in the sample after drying. The non-evaporable water is also known as the water of constitution or chemically combined water. In order to determine W_t (total water), of the paste, saturated surface dry specimens were used from the crushed samples after the determination of compressive strength. Approximately

Table 1: Chemical analysis of the starting materials, (Wt %).

Materials	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	L.O.I.
OPC	22.49	5.48	2.99	61.97	1.41	1.63
GBFS	18.80	9.13	2.86	40.89	11.39	

Table 2: Mix composition of the prepared mixes, (Wt %).

Mix	C ₀	C ₅	C ₁₀	C ₁₅	C ₂₀	C ₂₅	C ₃₀	C ₃₅	C ₄₀	C ₄₅	C ₅₀
OPC	100	95	90	85	80	75	70	65	60	55	50
GBFS	00	05	10	15	20	25	30	35	40	45	50

2 g were placed in a porcelain crucible and ignited in a muffle furnace. The temperature of the surface was gradually increased up to 1000°C and left for 30 min. Cooled in desiccators and weighed. I_g is considered as the ignition loss calculated as:

$$I_g = (\text{weight before ignition} - \text{weight after ignition}) / \text{ignited weight}$$

Correction was made for the ignition loss of the original cement, which was determined by a separate experiment (unhydrated cement). In order to determine W_n (combined water), two representative samples of the dried specimens (about 2g each), were accurately weighed in a porcelain Crucible and ignited for 30min. at 1000 °C cooled in a desiccators then weighed. The combined water content was calculated as W_n using the following equation:-

$$W_n = (W_1 - W_2 / W_2) - L$$

Where

W_n : Is the non- evaporable water.

W_1 : Is the weight of saturated sample before ignition (g).

W_2 : Is the ignition weight of specimen (g) and L: is the ignition loss of unhydrated specimen.

The free water content, we was calculated as the difference between the combined water content, W_n and the total water content, w_t , i.e.

$$W_e = W_t - W_n$$

Where W_e : is the free water content, W_t : is the total water content and W_n : is the chemically combined or the non-evaporable water content. X- ray fluorescence spectroscopy is now the main and the most precise tool for the analysis of silicate mineral. The principle of analysis lies in subjecting the powder sample in the form

of a disc made from the sample and diborate to x-ray source. The irradiation of the surface causes, the excitation of certain atoms that emits x-ray with specific wavelength characteristic of the constituting elements. The emerged x-ray are collected and then diffracted and identified. The intensity of x-ray emerged is proportional to the quantity of the element in the sample. The chemical analysis for the different samples was carried out by x-ray fluorescence using Phillips equipment type (spectrometer pw 1370, Holland).

The measuring instrument used for XRD was a system with Co K α radiation ($\lambda = 1,789\text{\AA}$) at 40kV and 30mA. The 2-Theta values ranged from 4 to 70 and were recorded in 0.04° steps with a counting time of 10S per step. The measurement was carried out on a crushed sample passing through a 40 μm Sieve the production and consumption of reaction products through the hydration of the original binder products (cement and Mk) was following using XRD. DTA locates the ranges corresponding to the thermal decomposition of different phases in paste, which TGA measures the weight loss due to the decomposition. TGA coupled with DAT makes it possible for the hydration reactions to be followed qualitatively, semi-quantitatively and quantitatively. Such thermal analysis is useful to observe the evolution of the hydration and especially to estimate the process of pozzolanic reaction, e.g the consumption of calcium hydroxide (Portland diet). Although these techniques are more suitable for studying hydration at later stages, they can be used as here, to consider the early phase of hydration accelerated by high temperature curing. Concerning DTA, 40 μm powder specimens were placed in a refractory steel crucible and analyzed using a hybrid system with oven drying at a heating rate of 5.8°C/min up to 95°C.

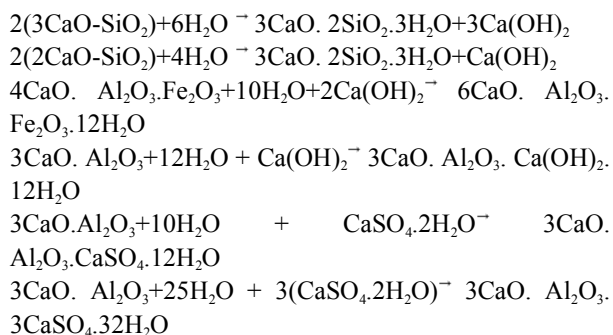
Sample masses ranged from 1.00 to 1.10g. In the case of TGA, the specimens (40 μm powder) were introduced into a quartz crucible and analyzed using system at a heating rate of 7.5 °C/min up to 600°C. Masses of sample were between 200 and 220 mg. no trace of calcium carbonate was detected during analysis as the freeze-drying technique prevented carbonation of the samples Hence thermograms will be presented up to 600 °C for DAT and 650°C for TGA. The shape and size of different crystalline phases as well as pores play an important critical role in the properties displayed by cements. Macrostructure and pore size distribution were studied by using scanning electron microscope. Scanning electron microscope (SEM) (Joel -Jem. T 200) is useful means for studying the morphology of the different

crystalline phases developed in a body. The parameters, which can be readily verified, are crystal shape, size of various crystalline constituent, glassy phase, pore size and distribution. The electron microscope makes use of directing a finely focused beam of primary electron accelerated under a maximum potential difference of 30-50 kV to scan (raster) on the specimen. The developed image can be displayed on the screen of a cathode tube. Examination was carried out for polished specimens etched chemically. Pieces from the disc specimens were fired at the optimum conditions and were polished on the plan surface with carborundum paper of different grades 300,600 and 1000 followed with three grades of diamond 7, 2.5 and 1 micron.

RESULTS AND DISCUSSION

When cements are in contact with water, calcium hydroxide is liberated during the hydration of the activator (Portland cement), reacts with the colloidal acid hydrates to form hydrates calcium aluminates, silicates and hydro garnet. the reactions of tri calcium aluminate and ferrite solid solution phases at the very early ages of hydration. the reactions of the calcium silicates phases predominate from about the time of initial set onward. The setting and hardening of the cement paste is due to several chemical reactions which start as soon as the water is mixed with cement.

The Reactions Are Summarized as Follows:-



Tri calcium aluminate react with gypsum to form either calcium aluminate monosulphate hydrate ($3\text{CaO}\cdot \text{Al}_2\text{O}_3\cdot \text{CaSO}_4\cdot 12\text{H}_2\text{O}$) or calcium aluminate trisulphate hydrate known as ettringite ($3\text{CaO}\cdot \text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 31\text{H}_2\text{O}$) which formed in the early stages of hydration of Portland cement the type and quantity of the hydration products of C₃A, the product is ettringite on the hand, mono sulphate hydrate is found in hardened pastes made from cements rich in C₃A the ferrite solid solution phase of Portland

Table 3: Chemically combined water contents of blended cement pastes containing different ratios of GBS

Curing time days Mix No.	Combined water content,%				
	1	3	8	28	90
C ₀	2.50	2.88	3.45	3.52	3.64
C ₅	3.10	3.30	3.93	4.50	4.62
C ₁₀	3.52	3.78	4.32	5.11	5.25
C ₁₅	3.85	4.29	4.80	5.43	5.56
C ₂₀	4.22	4.80	5.03	5.83	5.99
C ₂₅	4.48	5.09	5.11	6.35	6.48
C ₃₀	4.63	5.43	5.62	6.80	6.94
C ₃₅	4.82	5.52	5.70	6.86	6.99
C ₄₀	4.90	5.63	5.89	6.90	7.00
C ₄₅	5.12	5.74	5.92	6.97	7.06
C ₅₀	5.20	5.82	6.00	7.00	7.12

cement reacts with water to form a ferrite aluminates silica containing hydrate which resembles a series of natural minerals called hydro garnets. The calcium silicate C₃A and β-C₂S are the main cementing compounds in Portland cement and the physical behavior of cement during hydration is similar to that of these two compounds. The hydration of these two calcium silicates are calcium silicate hydrates which is called to bermorite gel. the reactivity and strength development of calcium silicates are influenced by the substitution of minor compounds which form solid solution with the silicate phases. Also in blended cement granulated blast--furnace slag is known to have a hydraulic activity. When it is finely ground and mixed with activator (Portland cement), it can be made into cement. As the hydration proceeds, more hydration products mainly as calcium sulpho aluminate and tobermorit -like investigation of the phases are formed. This section deals with the hydration characteristics of Portland-blended cement pastes produced by blending various proportion of granulated blast furnace slag with ordinary Portland cement.

The non-evaporable water (combined water) content, of hydrated OPC cement pastes is employed as a measure of the degree of hydration. The combined water content (W_n) of various cement blends containing different ratios of GBS (5, 10, 15, 20, 25, 30, 35, 40, 45 and 50% by weight of cement) and hydrated for 1,3,8,28 and 90 days are given in Table 3 and graphically plotted as function of curing time in Fig. 1. The results indicate that the combined water contents increase with curing time for all hardened OPC cements pastes. This due to the progress of the hydration and later accumulation of hydration products as calcium silicate and sulphoaluminates hydrates. At a given age, the contents of combined water are increase of GBS until they reached a maximum.

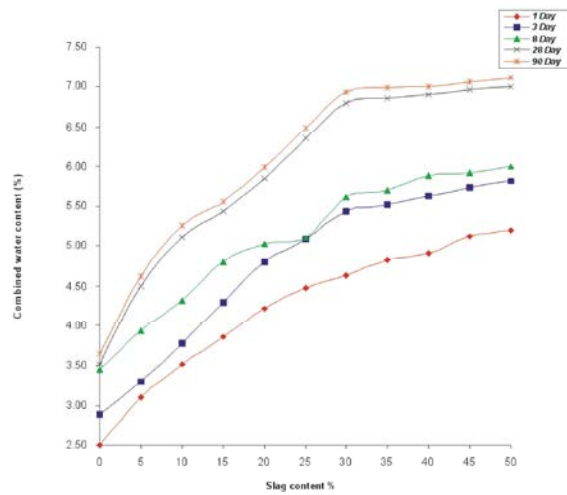


Fig. 1: Effect of GBS on Combined water content of OPC pastes

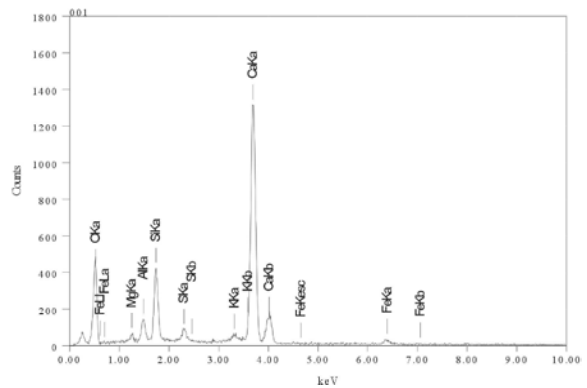


Fig. 2: XRF of sample C₁₀ which containing 10% GBS

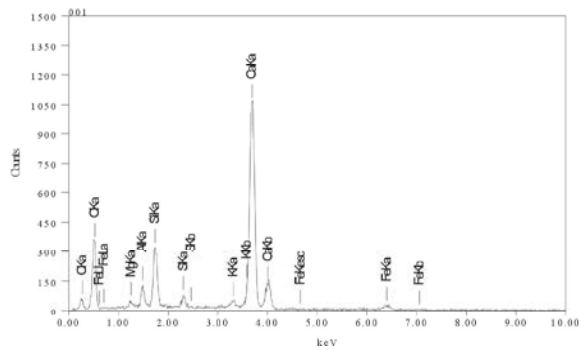


Fig. 3: XRF of sample C₄₀ containing 40% GBS

The results of XRF of the different raw materials and the hardened blast furnace slag cement pastes made with 10 and 40% GBS, by weight of hydrated for 8 days are given in Figs (2,3) as oxides respectively. We fined that, the increase of the percentage of GBS in the different samples leading to increase the percentage of FeO and decrease the content of CaO which due the formation of

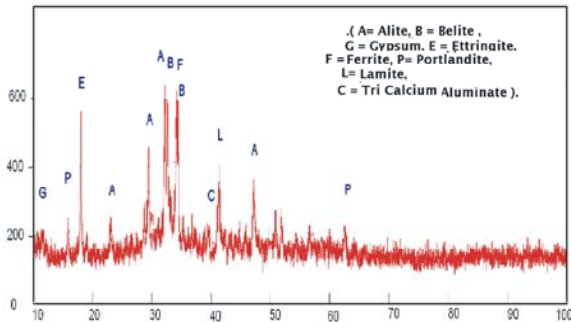


Fig. 4: XRD of sample C₁₅ containing on ordinary Portland cement with 15%GBS after 8 days of hydration.

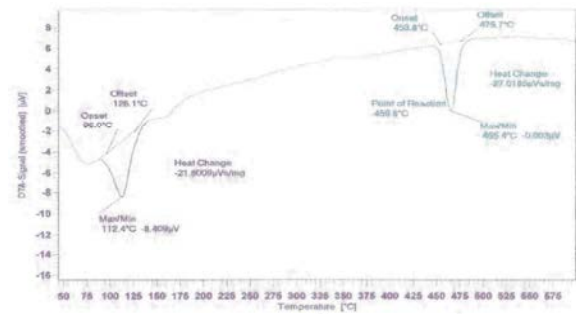


Fig. 6: The DTA thermogram of hydrated ordinary Portland cement paste containing 10% GBS at 8 days.

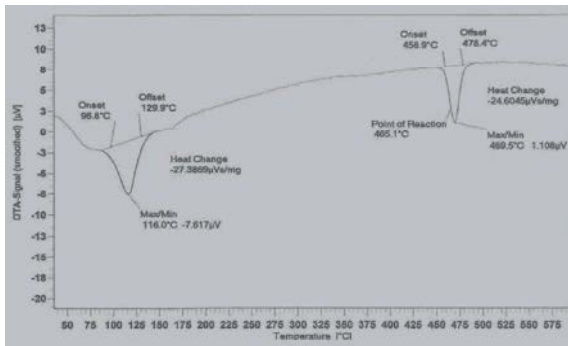


Fig. 5: The DTA thermogram of hydrated ordinary Portland cement paste cured at 8 days

Alite, Belite, aluminate, ferrite, gypsum and ettringite. It is known that granulated furnace slag is glassy Calcium-magnesium aluminosilicate with potential cementations reactivity [7]. Some slag hydration take place immediately after mixing with water and a protective layer is formed on the surface, inhibiting the water penetration to the slag particle and the further dissolution of ions from the slag alkaline activators, such as Ca(OH)₂, NaOH and KOH, etc. accelerate the dissolution of Si and Al ions by breaking the Si-O and Al-O bonds in the slag glass structure, which is followed by precipitation of low solubility calcium silicate, calcium aluminate hydrates due to increased ionic concentration in the liquid phase. When the gypsum is present, the concentration of Ca and Al ions are reduced because they interact to form ettringite. When the PH of the liquid phase reaches approximately 12, where ettringite is formed stably the hydration of slag is most accelerated. That is so say, in order to maintain active hydration of slag it is necessary to supply sufficient to supply sufficient hydroxyl (to create a high PH environment for the breaking the network of glass and stabilizing the ettringite product and SO₃ as well as alumina (to form ettringite).

Figure 4 shows the X-ray diffraction pattern of paste containing on hydrated ordinary Portland cement with 15% GBS in which, gypsum can be detected by the diffraction peak at about $2\theta=11.6155$ ($d=7.61235\text{\AA}$), ettringite can be observed at about $2\theta=18.0715$ ($d=4.90479\text{\AA}$), alite occur at about $2\theta=23.0698$ ($d=3.85218\text{\AA}$), $2\theta=29.4621\text{\AA}$, $2\theta=32.2293$ ($d=2.77525\text{\AA}$) and $2\theta=47.1562$ ($d=1.92576\text{\AA}$), belite can be observed at about $2\theta=32.6448$ ($d=2.74087\text{\AA}$), $2\theta=34.4260$ ($d=2.60303\text{\AA}$), the diffraction peak at about $2\theta=39.4480$ ($d=2.28244\text{\AA}$) corresponds to tri calcium aluminum, ferrite can be detected at about $2\theta=34.1560$ ($d=2.62298\text{\AA}$), portlandite corresponds to the diffraction peak at $2\theta=15.8620$ ($d=5.58268\text{\AA}$) and, $2\theta=62.4844$ ($d=1.48518\text{\AA}$) lamite can be detected by the diffraction at about $2\theta=41.2930$ ($d=2.18462$).

Figure 5 shows the DTA thermo gram of hydrated ordinary Portland cement pastes cured for 8 days. The thermo gram show endothermic effect in which, the onset of the peak at 95.5°C, the offset at 129.4°C, the mix / min at 115°C is equal to -7.388μV and heat change is equal to -29.9222μVs /mg. In addition to endothermic effect in which, the onset at 453.8°C, the offset at 478.7°C, point of reaction at 462.8 °C, the Mix / Min at 468.7 °C is equal to 2.110μV and heat change is equal to -23.1837μVs -mg. Figure 6 shows the DTA thermo gram of hydrated ordinary Portland cement pastes containing 10% GBS cured for 8 days. The thermo gram show endothermic effect in which, the onset of the peak at 96.0 °C, the offset at 126.1°C, the mix / min at 112.4 °C is equal to -8.409μV and heat change is equal to -21.8009 μVs /mg. In addition to endothermic effect in which, the onset at 453.8 °C, the offset at 475.7°C, point of reaction at 459.8 °C, the Mix / Min at 465.4 °C is equal to 0.003μV and heat change is equal to -27,0185μVs/mg. Figure 7 shows the DTA thermo gram of hydrated ordinary Portland cement pastes

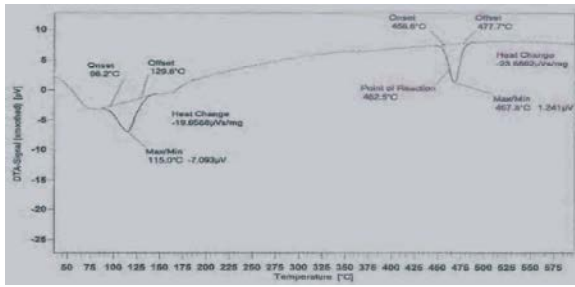


Fig. 7: The DTA thermogram of hydrated ordinary Portland cement paste containing 40% GBS at 8 days.

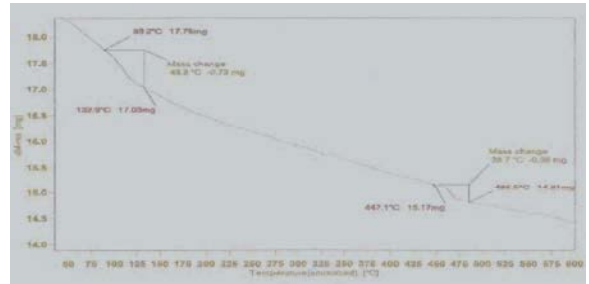


Fig. 10: The TG thermogram of hydrated ordinary Portland cement paste containing 15 GBS at 8 days

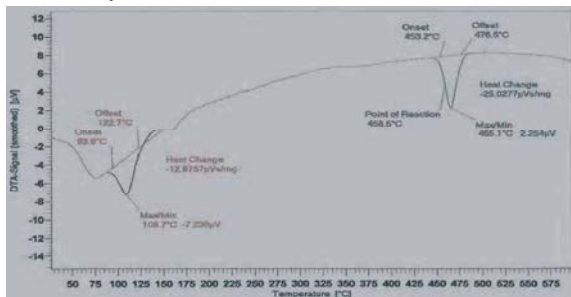


Fig. 8: The DTA thermogram of hydrated ordinary Portland cement paste containing 50% GBS at 8 days.

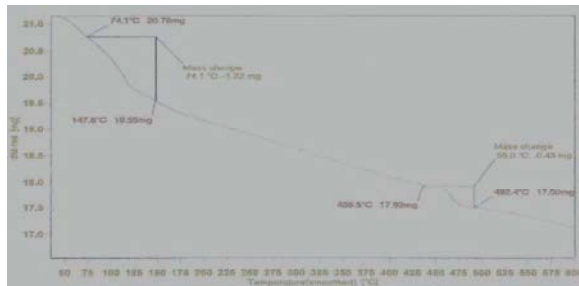


Fig. 9: The TG thermogram of hydrated ordinary Portland cement paste cured at 8 days.

containing 40% GBS cured for 8 days. The thermo gram show endothermic effect in which, the onset of the peak at 96.2°C, the offset at 129.6°C, the mix / min at 115°C is equal to -7.093μv and heat change is equal to -19.6568μVs /mg. In addition to endothermic effect in which, the onset at 456.6°C, the offset at 477.7°C, point of reaction at 462.5°C, the Mix / Min at 467.8 °C is equal to 1.241μv and heat change is equal to -23.6692μVs /mg. Figure 8 shows the DTA thermo gram of hydrated ordinary Portland cement pastes containing 50% GBS cured for 8 days.

The thermo gram show endothermic effect in which, the onset of the peak at 93.3°C, the offset at 122.7°C, the mix / min at 108.7°C is equal to -7.230μv and heat change is equal to -12.9757μVs/mg. In addition to endothermic

effect in which, the onset at 453.2°C, the offset at 476.5°C, point of reaction at 458.5°C , the Mix / Min at 465.1 °C is equal to 2.254μv and heat change is equal to -25.0277μVs /mg. The endothermic peaks for all cement pastes are similar due to the pozzolanic reaction can be seen by observing the decomposition of hydration products in the temperature (100-180). This observation can be explained by the development of alarge amount of C-S-H phases and the occurrence of Silica-aluminate phases when (GBS) is incorporating in the mix. Indeed, in GBS - based systems, hydrated gelignite C₂ASH₈ decomposition in the temperature range of (140-150) coexists with and C-S-H hydro garnet C₃ASH₆. In the presence of CH, C₂ASH₈ become unstable and turns into C₃ASH₆. That is why the small quantity of CH present in GBS blended pastes explains the simultaneous presence of C₂ASH₈ and C₃ASH₆, as already noted in. The presence of C₄AH₁₃ located at about 250°C is confirmed in blended pastes. The endothermic peaks for all pastes are similar due to amount of CH is visible in the temperature range of (450 -500) in pastes with GBS indicating the amount of CH by the pozzolanic reaction.

Figure 9 shows the TG thermo gram of hydrated ordinary Portland cement pastes cured for 8 days in which, mass of the sample at 74.1°C is equal to 20.76mg, mass of the sample at 147.8 °C is equal to 19.55mg and mass change is equal to -1.22 mg. In addition, mass of the sample at 436.5°C is equal to 17.93 mg, mass of the sample at 492.4 °C is equal to 17.50mg and mass change is equal to -0.43 mg. Figure 10 shows the TG thermo gram of hydrated ordinary Portland cement pastes containing 15% GBS cured for 8 days in which, mass of the sample at 89.2°C is equal to 17.76mg, mass of the sample at 132.9 °C is equal to 17.03mg and mass change is equal to -0.73 mg. In addition, mass of the sample at 447.1°C is equal to 15.17 mg, mass of the sample at 485.5 °C is equal to 14.81mg and mass change is equal to -0.36 mg. Figure 11 shows the TG

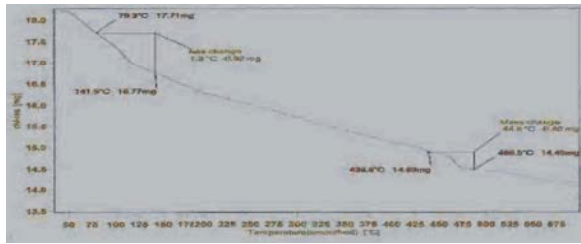


Fig. 11: The TG thermogram of hydrated ordinary Portland cement paste containing 25% GBS at 8 days.

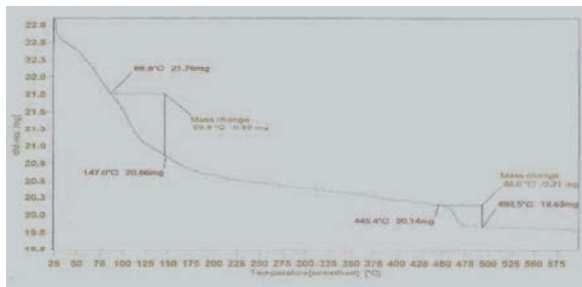


Fig. 12: The TG thermogram of hydrated ordinary Portland cement paste containing 45% GBS at 8 days.



Fig. 13: SEM of sample C0 X= 5000.

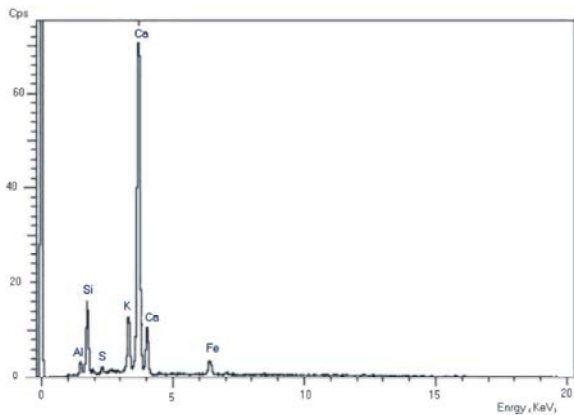


Fig. 14. EDXA of sample C₀ showing.

thermo gram of hydrated ordinary Portland cement pastes containing 25% GBS cured for 8 days in which, mass of the sample at 86.6°C is equal to 21.76mg, mass of the sample at 147.0 °C is equal to 20.86mg and mass change is equal to -0.89 mg. In addition, mass of the sample at 445.4°C is equal to 20.14 mg, mass of the sample at 493.5 °C is equal to 19.83mg and mass change is equal to -0.31 mg. Figure 12 shows the TG thermo gram of hydrated ordinary Portland cement pastes containing 45 GBS cured for 8 days in which, mass of the sample at 79.3°C is equal to 17.71mg, mass of the sample at 141.5°C is equal to 16.77mg and mass change is equal to -0.92 mg. In addition, mass of the sample at 438.8°C is equal to 14.89 mg, mass of the sample at 486.5 °C is equal to 14.49mg and mass change is equal to -0.40 mg. Two-temperature interval were preferentially investigated regarding the pozzolanic reaction. The first concerned the temperature range (50-250 °C) where the decomposition C - S - H was considered (74-150)°C. This initial portion of TG curves gave information about the quantity of hydration products. From 50 °C to 575 °C, all curves in figs (9 -12) are parallel, indicating that the amounts of hydrated phases are mainly governed by the decomposition existing within the (50 250)°C range. The second temperature interval, from (436-500), is related to the decomposition of calcium hydroxide (CH).

Microstructure of the different samples was examined in polished, chemically etched surface. The main constituting elements of the formation phases were determined by EDAX. SEM of mix (C₀) ordinary Portland cement, Fig. 13, shows micro raking of the paste, ettringite nets, gypsum bands, alite and belite crystals with different crystal sizes 1.14, 1.59, 2.27, 3.18 and 7.95 μm. spot analysis by EDAX Fig. 14 shows the distribution of different elements in the inter granular accumulation. SEM of mix (C₅) which containing 5% GBS, Fig. 15 shows micro raking, ettringite, gypsum formation, ferrite white matrix with different crystal sizes 1.78, 2 and 2.67 μm. EDAX analysis Fig. 16, shows the distribution of different element (Mg, Al, Si, K, Ca and Fe) with different ratios. SEM of mix (C₁₀), which containing 10% GBS, Fig.17 shows micro raking and pores, ettringite nets, gypsum bands, alite (light grey), belite (dark grey), ferrite (white matrix) and aluminate (dark inclusion in white matrix), with different crystal sizes (1.59, 1.82, 2.05, 2.27 and 4.32) μm. EDAX of grain present in Fig. 18 showing main constituting elements. SEM of mix (C₂₀) which containing 20% GBS, Fig. 19, shows the well-identified alite (light grey), belite (dark grey), curved boundaries, ferrite (white matrix), aluminate (dark inclusion in white matrix)

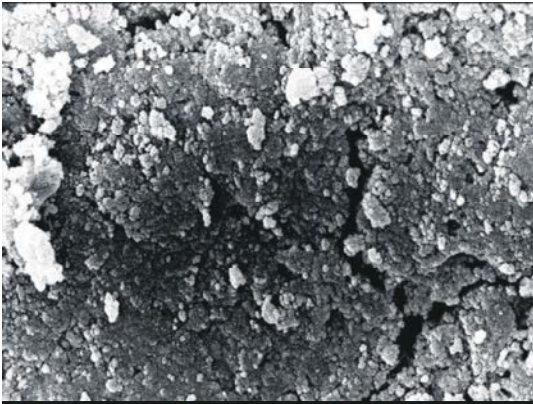


Fig. 15: SEM of sample C₅, X=5000.



Fig. 19: SEM of sample C₂₀.

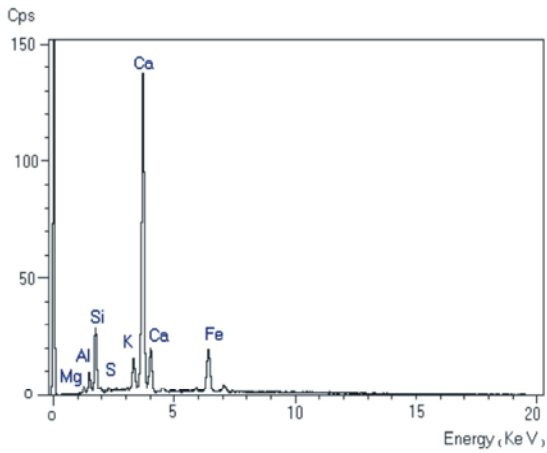


Fig. 16: Line scanning of sample C₅.

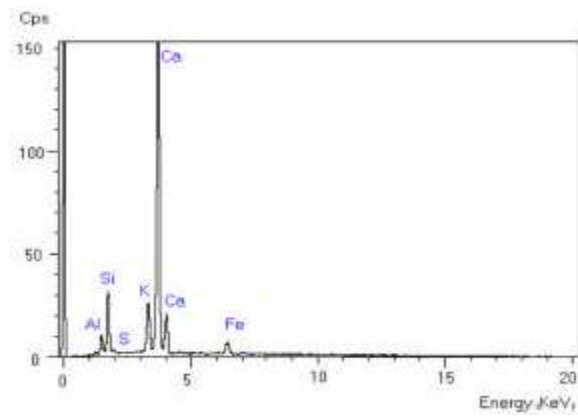


Fig. 20: EDAX microscope of sample C₂₀

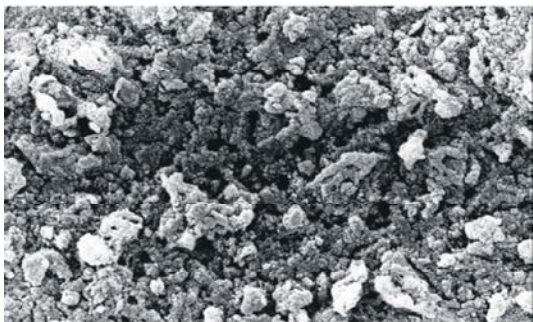


Fig. 17: SEM of sample C₁₀, X = 5000.

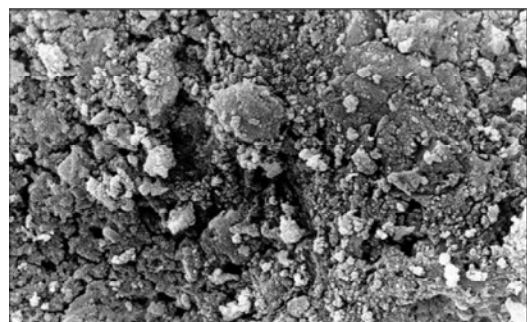


Fig. 21: SEM of sample C₄₀, X = 5000

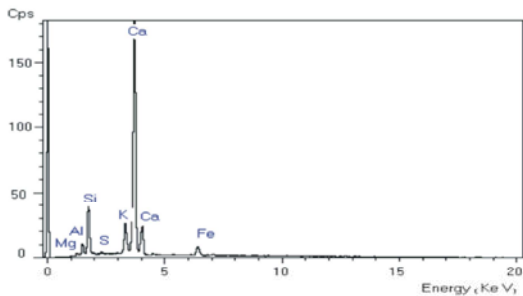


Fig. 18: Line scanning of sample C₁₀

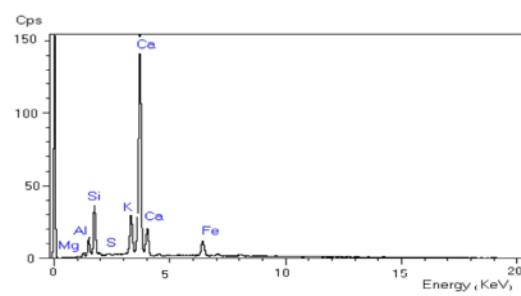


Fig. 22: EDAX microscope of sample C₄₀



Fig. 23: SEM of sample C₅₀, X =5000.

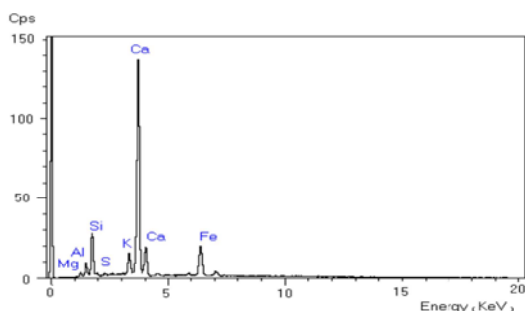


Fig. 24: EDAX microscope of sample C₅₀

and with different crystal sizes (1.36, 1.82, 2.50) μm and cracks and pores (black). EDAX of grain present in Fig 20 showing main constituting elements (Mg, Al, K, Ca and Fe). SEM of mix (C₄₀) which containing 40%GBS, chemically etching Fig. 21, presenting micro cracking and pores, large darker areas are of belite and interstitial material, ferrite (light) in matrix of aluminat with different crystal sizes (2.14, 3.81, 5.84, 6.43) μm .

The increase % of slag leading to increase the crystal size of different grains until 40% slag. EDAX of grain present in Fig. 22 showing main constituting elements (Mg, Al, K, Ca, Si, S and Fe). SEM of mix (C₅₀) which containing 50% GBS, chemically etching Figs 23 & 24, presenting alite, light grey with straight boundaries, belite, dark grey, curved boundaries, ferrite, white matrix, aluminat, dark inclusion in white matrix with different crystal sizes (1.59, 2.05, 2.50, 3.41) μm . EDAX of grain present in Fig. 24 showing main constituting elements (Mg, Al, K, Ca, Si, S and Fe).

CONCLUSION

Blends of slag cement with Portland cement (Derna) and granulated slag (Mosrata) were studied respectively. The increase percentage of slag leading to increase the

crystal size of different grains until 40% slag. Furthermore, the addition of slag cement improved the characterization of Portland cement and slag.

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