A STUDY ON THE MECHANICAL ACTIVATION OF EGYPTIAN LOCAL BY-PRODUCT SLAG

A.M.K. ABDELALIM[1], G.E. ABDELAZIZ[2], M.O. RAMADAN[3] and H.I. AHMED[4]

ABSTRACT

This article reports the results of an investigation on the microstructure related characteristics and compressive strength of OPC matrix incorporating an activated local by-product slag that cooled by either water or air. Both types of slag (water-cooled slag (WCS) and air-cooled slag (ACS)) were mechanically activated through definite grinding procedures to produce a slag with various finenesses (0.5, 2.0 and 3.3 m^2/g). The impacts of mechanical activation extent (fineness) and content of either WCS or ACS on the nature and amount of hydration products, capillary porosity, sorptivity and compressive strength of OPC mortars were examined and then compared, using thermo-gravimetric analysis, de-sorption, sorptivity and compressive strength approaches, respectively. Thirteen cement paste mixes and thirteen OPC mortar mixes were therefore prepared, using different slag contents (0, 20, 35 and 50%, by mass of OPC). The mechanical activation of the local by-products slag had led to significant improvements in the microstructure, sorptivity and compressive strength of OPC matrix. These improvements are mainly dependent on the content of slag. It was found that the proper content of WCS or ACS to be considered in OPC mixes was about 20%, by cement mass. It also suggested that cooling of local slag using water is more appropriate approach than cooling of slag in air. However, ACS could be utilized in concrete mixes after considering a careful and an effective activation program.

KEYWORDS**:** Slag; Activation; Pore structure; Hydration; Sorptivity

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1. INTRODUCTION

Blast-furnace slag is the non-metallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases, that is developed in a molten condition simultaneously with iron in a blast furnace [1]. Dependent upon the cooling method used, slag is converted into three basic types, air-cooled, granulated and expanded slag. Air-cooled slag is a predominantly crystalline material resulting from solidification in a pit under atmospheric conditions. After cooling, it is dug, crushed, and screened to the desired size. Granulated slag is a glassy, granular product resulting from rapid quenching of the molten slag. Quenching with water is the most common process, but air or combinations of air and water may be used. Expanded slag is produced by treating the molten blast-furnace slag with controlled quantities of water, usually less than that used for granulation. The product is more vesicular and lighter in weight than the air-cooled slag [2].

Great interests of research have been considered on the utilization of water cooled slag (WCS), as a cement replacement material, for improving the various concrete hardened properties [3]. However, two opposite opinions were provided in literature regarding such aspect. Some authors believe that the inclusion of WCS in OPC mixes has a positive significant impact on the compressive strength and microstructure [4,5]. Whilst, others revealed that the main drawback in the use of slag in concrete is that its strength development is considerably slower than that of OPC concrete [6]. Thus, great deals of research have been conducted on the use of slag in cement and concrete based on its activation by cement clinker and gypsum to overcome such drawback [7].

Simultaneously, several activation methods namely mechanical activation and chemical activation have been introduced and adopted in the literature to improve the performance of such type of cement replacement material [4,8]. Despite of these immense efforts, the various characteristics of concrete made with WCS are still far away from the corresponding of that made with the other common used cement replacement materials, namely silica fume and fly ash. Generally, the use of local-made slag in the Middle East countries is not a widely accepted cement replacement material in concrete industry due to its poor impact on the various hardened properties of concrete [9]. So, an extensive research work has to be conducted to improve the quality of local by-product slag for enhancing the various characteristics of concrete.

Although water-cooled slag has been widely used for producing slag cement for a quite long time, other slag types such as air-cooled slag (ACS) is not relatively commonly used in concrete industry. The feasibility of using ACS has been earlier disregarded due to the prejudgment that ACS is not hydraulically deliberated [9]. Consequently, the use of this sort of slag in concrete industry is minimal worldwide and hence it has low value applications. Therefore, a great effort has to be done to activate such waste material to be used in concrete mixes and simultaneously to minimize the harmful environmental impacts of slag, using an effective approach of activation such as mechanical activation.

Moreover, there is a contradiction in the literature regarding the optimum content of slag to be induced in OPC mixes. Some authors [10] reported that, at all ages, the compressive strength of sulphate-resisting cement concrete containing slag decreases with increasing the level of slag replacement. They attributed their observations to the decrease of the clinker portion, which has higher hydration characteristics. On the other hand, others [4] found that, at the age of 91 days, all the slag concretes were found to have higher compressive strength than the OPC concrete. So, there is a need to resolve this contradiction and to determine the optimum content of the local by-product slag to be recommended for concrete technologists, to achieve the highest possible benefits as a result of its utilization in concrete industry.

So, in an effort to gain improved understanding of the above-mentioned aspects, the present study was undertaken with the following objectives:

1. To study the possibility of adoption of the mechanical activation approach for enhancing the performance of the local by-product slag, aiming to improve various

microstructure and mechanical related characteristics of OPC matrix made with such material.

2. To investigate impacts of activated water-cooled slag (WCS) and activated air-cooled slag (ACS) contents on hydration products, amount of interconnected pores (capillary porosity), rate of water flow into cover zone (sorptivity) and strength development of OPC matrix. On other words, to determine the proper content of WCS and ACS to be used in OPC mixes.
3. To differentiate between the performance of OPC matrixes made with either WCS or ACS, and consequently determining the possibility of utilization ACS in concrete industry.

2. EXPERIMENTAL

2.1 Materials, Slag Preparation and Mix Proportions

A clean siliceous natural sand complying with ASTM C33 was used. Local ordinary Portland cement (OPC) complying with BS 12 (1978) and ESS 373 (1991) was utilized throughout the work. Local water-cooled slag (WCS) and air-cooled slag (ACS) were considered. The chemical analysis and surface areas of OPC, WCS and ACS are listed in Table 1.

The water-cooled slag (WCS) was produced by rapid quenching of slag in water, while the air-cooled slag (ACS) was produced by slow cooling of slag in air. The water-cooled slag was oven dried at 105 ºC for 24 hours to remove the moisture, which occurred during the granulation process, using an electrical oven with digital monitoring. The grinding of both WCS and ACS were performed using a laboratory ball mill with maximum capacity of 10 kg. The surface area of the slag was measured volumetrically from the adsorption of the nitrogen gas at the liquid nitrogen temperature (-195.8 C) using a BET volumetric apparatus. The surface area of the produced slag was 0.5, 2.0 and 3.3 m^2/g.

Table 1 Chemical analysis and surface areas of OPC, WCS and ACS.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI	Surface area, m^2/g
OPC	21.51	6.01	2.54	66.3	1.5	0.62	0.21	1.81	2.61	0.37
WCS	44.05	13.78	1.73	36.2	0.3	0.6	0.15	2.07	0.23	0.5, 2, 3.3
ACS	40.16	5.04	2.5	44.6	4.24	0.31	0.17	1.62	0.41	0.5, 2, 3.3

Also, the crystal structure of the used WCS and ACS was identified, using X-ray diffraction approach. The X-ray diffractograms of WCS and ACS are plotted in Figures 1 and 2, respectively. As observed from Figure 1, the X-ray diffractograms of WCS is completely vitreous with an amorphous hump characteristic of the glass. Whilst, the data plotted in Figure 2 shows that ACS is not completely amorphous material and mainly composed of gehlenite crystal ($Ca_2AL_2SiO_7$). Furthermore, it can be seen from Figure 2 that the heights of gehlenite peaks existed in ACS were remarkably decreased with amount of grinding. This assured that increasing the extent of mechanical activation can lead to diminishing the amount of crystals in ACS.

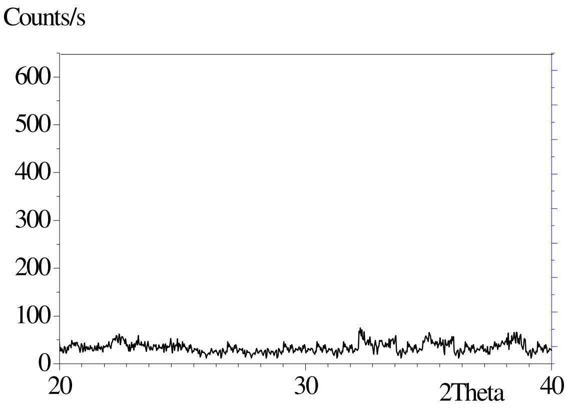


Fig. 1 X-ray diffraction graph of WCS.

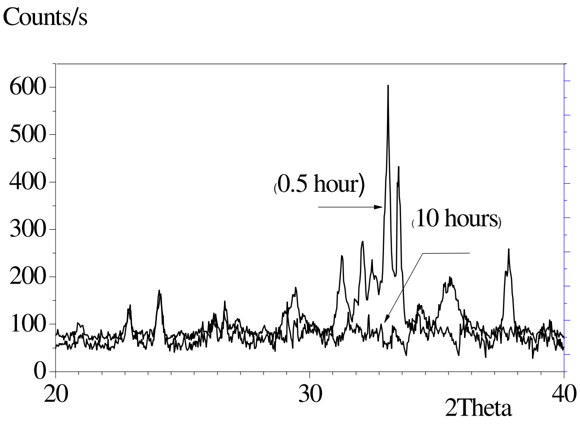


Fig. 2 X-ray diffraction graphs of ACS.

The experimental program of this study includes two phases. In the first phase, the effect of different contents of either activated WCS or ACS (0, 35, and 50%, by weight of OPC), as a cement replacement material, on the various characteristics of OPC mortars was considered. The surface areas of WCS and ACS were kept constant (0.50

m^2/g) throughout of this phase of study. In the second phase, various finenesses (0.5, 2.0 and 3.3 m^2/g) of WCS and ACS were regarded. A constant level of replacement of WCS or ACS (20%, by weight of OPC) was adopted. Therefore, thirteen cement paste mixes and another thirteen OPC mortar mixes were prepared, using different WCS and ACS contents (0, 20, 35 and 50%, by weight of cement mass) with various finenesses (0.50, 2.00 and 3.30 m^2/g). For mortar mixes, constant ratios of sand: binder and water/binder were 2:1 and 0.40, respectively, were considered. On the other hand, for cement paste mixes, a constant water/binder ratio of 0.50 was considered.

2.2. Preparation of Test Samples

The mixing procedures of mortar were carried out according to ASTM C305-82. 50x50x50 mm mortar cube specimens were then taken from the mortar mixes to assess their mechanical properties (in terms of compressive strength) and transport characteristics (using sorptivity approach). On the other hand, mixing of cement paste was carried out manually, till complete homogeneity of mixes was achieved. Circular cement paste discs of thickness 5 mm and 50 mm diameter were then prepared for microstructure analysis (using thermo-gravimetric and de-sorption approaches). After casting, all molded samples were covered with polythene sheets for 24 hours and then immersed in water curing tank (20 ± 2ºC + 65% RH) till the age of testing.

2.3. Test Techniques

2.3.1. Compressive strength

50x50x50 mm cubes were used for determination of compressive strength of mortar mixes. The strength development of WCS and ACS specimens were examined by determining the compressive strength at different ages (7, 28, 56 and 90 days). The reported values for compressive strength of mortar represent the average results of three specimens.

2.3.2. Sorptivity test

The amount of water absorbed by capillary action through a specified area of the tested specimen at certain periods can be determined by calculating the difference in weight of the specimen before and after exposure to water [11]. The sorptivity of the tested specimens can be calculated using the classical square root-time relationship described by Hall [12] and Claisse et al [13], where the water absorption into concrete increases with increasing the square root of elapsed time (t), according to the following equation;

$$i = a + St^{0.5}$$

Where, i = cumulative volume of water absorbed per unit area of inflow surface, a = constant, S = sorptivity of concrete, t = elapsed time from starting the test.

The sorptivity of mortar specimens was measured in this study using the abovementioned basics. Three samples from each mix were tested and the average result was then considered.

2.3.3. De-sorption test

This test was used for estimating the amount of interconnected pores (capillary porosity), as described earlier [14,15]. The saturated specimens specified for this study were dried at 90.7% relative humidity by placing them above saturated salt solution of barium chloride contained in a desiccators until a near constant sample weight was obtained. The weight loss on drying was then converted to volume fraction of the bulk paste. This particular capillary porosity corresponds to pores wider than about 30 nm [15,16]. The Full details of this test techniques and procedures are described elsewhere in literature, where reliable results were attained [14,15]. The average capillary porosity results were calculated using five specimens.

2.3.4. Thermo-gravimetric analysis

The hardened cement paste specimens specified for this study were subjected to thermo-gravimetric analysis (TGA), by monitoring the % weight loss (% decomposition) that can take place as a result of raising the temperature with a defined range. Previous studies found that calcium silicate hydrate (CSH) and calcium hydroxide (CH) decomposes at a range of temperature of 110 to 250 ºC and 450 to 600 ºC, respectively [17,18]. Therefore, the amount of CSH and CH can be expressed as a function of the difference in the % weight loss occurred at that defined range of temperatures [18].

Following this concept, the hardened cement paste samples were subjected to a wide range of temperature increase and the specimen weight was recorded at 110, 250, 450 and 600ºC. The % weight loss due to decomposition of CSH and CH were consequently estimated for all tested samples. The full details of this analysis are described elsewhere [18]. The average results of these abovementioned parameters for five samples were then calculated.

3. RESULTS AND DISCUSSION

Prior to studying the impact of utilizing the mechanically activated local slag in its two forms (water-cooled and air cooled) on the mechanical and mass transport properties of OPC matrix, the microstructure of OPC hardened cement paste containing such type of cement replacement material have been firstly investigated, for clarifying its role on hydration products and pore structure. Two approaches were therefore adopted, namely the thermo-gravimetric analysis and de-sorption test, to elucidate the hydration products and pore structure of such matrix. These approaches were adopted in literature and found to be a reliable, simple and cheap techniques for characterizing the microstructure of OPC matrix [14-18].

3.1. Microstructure of OPC/Slag Matrix

3.1.1. Hydration products

The results obtained from thermo-gravimetric analysis for different hardened OPC paste made with either WCS or ACS are shown in Figures 3 and 4. It is apparent from the results shown in Figure 3 that the partial replacement of 20% of OPC by either

WCS or ACS resulted in an increase in the amount of C-S-H and the amount of increase reaches about 15 and 10%, respectively. While, at 35 and 50% slag replacement levels, the amount of CSH was lower than that the corresponding of pure OPC matrix and the amount of decrease in CSH increase with increasing the level of replacement of OPC with slag. Also, it is obvious from the results shown in Figure 4 that, at 20, 35 and 50% slag replacement levels, the amount of CH was reasonably lower compared to the corresponding of that of OPC matrix.

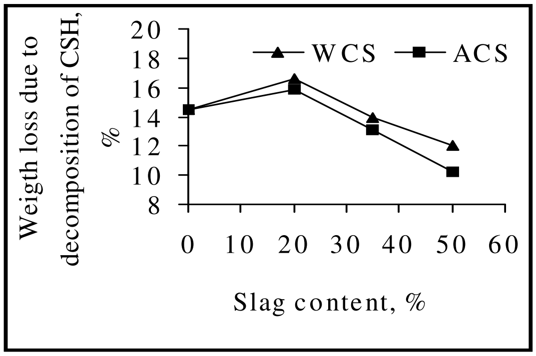


Fig. 3 CSH of OPC/slag pastes.

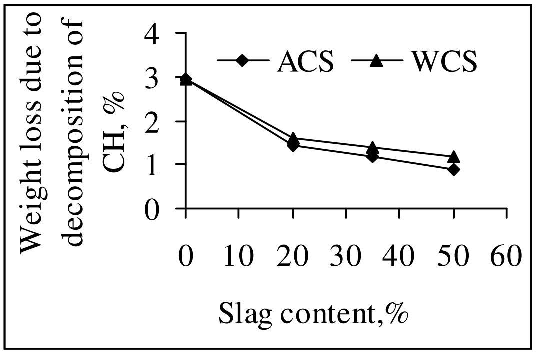
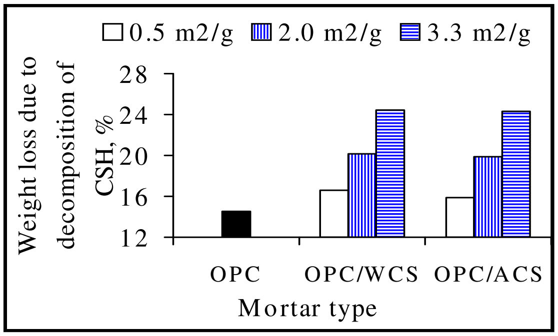


Fig. 4 CH of OPC/slag pastes.

Increasing the amount of CSH and reducing the amount of CH when 20% replacement level of either WCS or ACS was considered may be due to the pozzolanic reaction of WCS or ACS which combines with $Ca(OH)_2$ resulted from the hydration of OPC, to form a fine CSH [19]. While, at 35 and 50% slag replacement levels, the amount of CH released from the reaction of OPC with water and needed for slag to react with decreases as a result of using a lower content of OPC. So part of cementitious material (OPC) replaced by either WCS or ACS did not contributes to the pozzolanic reaction. As a result, the amount of CH and CSH was decreased [4,10].

In addition, it can be noted from Figures 3 and 4 that ACS specimens contains the highest portions of CH as well as the smallest portions of CSH, when compared to the corresponding of that of WCS specimens. Such effect was pronounced with increasing slag content. This may be attributed to the difference in the pozzolanic reactivity of WCS and ACS [9].

Figures 5 and 6 demonstrate the impact of WCS and ACS fineness on the % decomposition of CSH and CH, respectively. As seen, the amount of CSH is significantly increased with increasing fineness of both WCS and ACS. The amount of increase in the % decomposition of C-S-H for WCS specimens reaches about 15, 40 and 69%, when 0.5, 2.0 and 3.3 m^2/g fineness were adopted, respectively. On the other hand, the corresponding increase in the % decomposition of CSH for ACS specimens reaches about 10, 38 and 69%, when 0.5, 2.0 and 3.3 m^2/g finenesses were regarded, respectively.



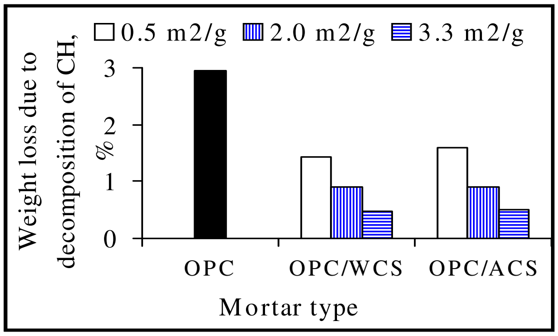


Fig. 5 Effect of fineness of slag on CSH.

Fig. 6 Effect of fineness of slag on CH.

On contrary, the amount of CH was significantly decreased when the finenesses of either WCS or ACS were increased. This means that the pozzolanic reaction of both WCS and ACS increases with increasing the amount of grinding (fineness). The amount of decrease in % decomposition of CH of WCS specimens reaches about 51, 70 and 84%, when the fineness of slag 0.5, 2.0 and 3.3 m^2/g were considered, respectively. The amount of decrease in % decomposition of CH for ACS specimens reaches about 48, 69 and 82%, when 0.5, 2.0 and 3.3 m^2/g finenesses were considered, respectively. These effects may be attributed to the surface area of the slag particles that would expose to the pozzolanic reaction. Where, the finer slag particles, the larger the surface area for the calcium hydroxide to react with and hence more pozzolanic reaction can be expected. Consequently, higher amounts of CSH and lower amounts of CH would be produced [4].

On other words, it can be generally stated from the data shown in Figures 5 and 6 that the difference between the effectiveness of the ACS and WCS specimens on the amount of CSH and C-H decreases as the extent of slag fineness increases, which may be attributed to the difference in the pozzolanic reactivity of WCS and ACS [9]. This agrees with the observed graphs demonstrated in Figure 2 and obtained by XRD, which emphasized that the crystallization of ACS was diminished with the excessive grinding (i.e. with increasing the fineness). The reduction in the crystallization of ACS with increasing the extent of grinding could have a positive impact on enhancing its pozzolanic reactivity, thus increasing the amount of CSH and reducing the amount of CH in ACS pastes.

3.1.2. Pore structure

The results obtained by de-sorption test for the different OPC hardened cement pastes made with various WCS or ACS contents are shown in Figure 7. As seen, the partial replacement of 20% of OPC by either WCS or ACS resulted in a reasonable reduction in the amount of capillary porosity. The amount of reduction for WCS and ACS specimens reaches about 27 and 17%, respectively, compared to the corresponding of that of pure OPC specimens. While, at 35 and 50% slag replacement levels, the amount of capillary porosity is higher than that of pure OPC cement paste. The amount of increase in the capillary porosity for WCS specimens reaches about 44 and 89%, and, for the ACS specimens reaches about 73 and 96%, respectively, when compared with those of pure OPC specimens.

The decrease in the capillary porosity at 20% slag replacement level may be attributed to the fact that the slag retains the alkali and calcium hydroxides in its hydration products, and hence forming new C-S-H phase with dense structure and finer pore sizes than that equivalent OPC paste [20]. It also can be attributed to the participation of the pozzolanic reaction's product on pathways between pores, thus leading to a reduction of the amount of interconnected pores, capillary porosity. On the other hand, at higher contents of slag (35 and 50%), the amount of interconnected pores is relatively high due to replacing of high proportions of OPC by slag. As a consequence, some of the utilized slag may be not fully reacted with the hydration products of OPC, thus occupying large spaces in OPC matrix and increasing the amount of capillary pores in OPC/slag hardened cement paste.

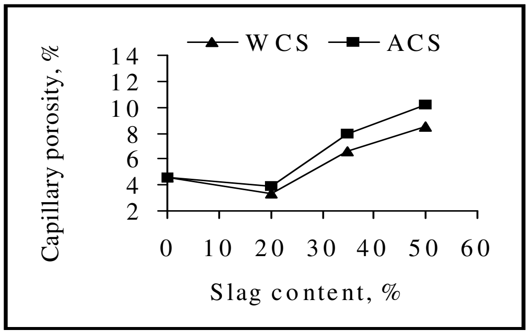


Fig. 7 Capillary porosity of OPC paste made with different contents of slag.

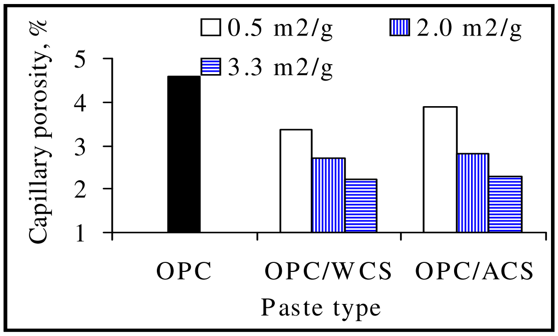


Fig. 8 Capillary porosity of OPC paste made with different finenesses of slag.

The effect of slag fineness on the capillary porosity is illustrated in Figure 8. As seen, the amount of capillary porosity is significantly reduced with increasing the finenesses of WCS and ACS. The amount of reduction in the capillary porosity of WCS specimens reaches about 27, 41 and 52%, when 0.5, 2.0 and 3.3 m^2/g finenesses were considered, respectively compared to the corresponding of that of pure OPC paste. While, the corresponding amount of decrease in the capillary porosity of ACS specimens reaches about 17, 38 and 49%, when 0.5, 2.0 and 3.3 m^2/g finenesses were considered, respectively. This effect may be attributed to the surface area of the slag particles that is exposed for the pozzolanic reaction, where, the finer slag particles, the larger the surface area for the calcium hydroxide to react with and hence more pozzolanic reaction may be occurred. Consequently, a higher amount of CSH can be produced, which in turn would fill the unoccupied spaces within the paste matrix and then reduce the amount of continuous pores (capillary pores) [4].

Also, it can be noted from the results shown in Figures 7 and 8 that the amount of capillary porosity of OPC/WCS specimens are lower than that of OPC/ACS specimens, and this was pronounced with decreasing the slag fineness. This may be attributed to the difference in the pozzolanic reactivity of WCS and ACS [9]. However, this gap difference between the capillary porosity of WCS and ACS pastes were diminished with increasing the extent of grinding due to the significant impact of the excessive grinding on the crystallization of ACS, as concluded from the XRD graphs shown in Figure 2.

The results obtained from the de-sorption test agree with that obtained from thermo-gravimetric analysis test, where an increase in the amount of C-S-H and a decrease in the amount of C-H of the 20% slag mixes compared to the OPC control mixes was produced. This affirms that the unoccupied spaces within the paste matrix were filled by the pozzolanic reaction products, thus reducing the amount of continuous pores (capillary pores). Similarly, there is a significant agreement between the results of the two adopted approaches when the microstructures of specimens containing 35 and 50% slag were regarded.

Generally, it can be stated that the considered local by-product material (slag) in its both forms (water-cooled and air-cooled) has shown a considerable efficacy on the microstructure of OPC matrix. Where, a positive effect for such type of cement replacement material on altering the amount of hydration product and reducing the amount of inter-connected pores was found. However, this can only be achieved if proper content of highly-activated slag (i.e. with high fineness) is adopted.

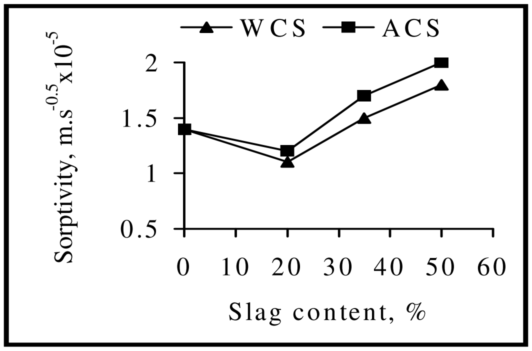
3.2. Fluid Transport Characteristic of OPC/Slag Matrix

The mass transport properties of OPC matrix containing the local-activated material was investigated in this study using sorptivity test. This test is widely accepted and commonly used in literature to express the fluid transport into the surface zone of concrete [11-13].

Figure 9 demonstrates the sorptivity values of OPC mortar mixes containing either WCS or ACS. It is apparent from the results that the partial replacement of 20% of OPC by either WCS or ACS resulted in a remarkable reduction in the sorptivity. The amount of reduction for WCS and ACS reaches about 21 and 14%, respectively. While, at 35 and 50% slag replacement levels, the sorptivity results were higher than the corresponding of that of pure OPC matrix, by about 7 and 29% for WCS specimens and 21 and 43% for ACS specimens, respectively. Also, it can be noted from the results shown in Figure 8 that the OPC/ACS specimens showed higher values of sorptivity compared to that of OPC/WCS specimens. Such effect was pronounced with increasing slag content. This difference may be attributed to the variation in the pozzolanic reactivity of WCS and ACS [9].

The effect of slag fineness on the sorptivity of OPC/slag mortars were also investigated, and the results are shown in Figure 10. As seen, the sorptivity of OPC containing either WCS or ACS decreases as the fineness of WCS and ACS increase, i.e. with increasing the extent of mechanical activation. The amount of decrease in the WCS specimens reaches 21, 42 and 74%, when 0.5, 2.0 and 3.3 m^2/g finenesses were considered, respectively. The amount of decrease in the ACS specimens reaches 14, 38 and 71%, when 2.0 and 3.3 m^2/g finenesses were considered, respectively. This is easily explained through the surface area of the slag particles that is exposed for the pozzolanic reaction. The finer slag particles, the larger surface area available for the calcium hydroxide to react with, thus more pozzolanic reaction and reduction in the amount of interconnected pores can be existed, as discussed above and confirmed from the results plotted in Figures 5, 6 and 8.

Also, it can be noted from the results shown in Figure 10 that the OPC/ACS specimens showed higher values of sorptivity compared to the corresponding of that of OPC/WCS specimens. Such effect was pronounced with decreasing slag fineness. This may be attributed to the difference in the pore structure of WCS and ACS, as described above and reported earlier [9]. The results obtained from the sorptivity test are fully agreed with that obtained from the de-sorption test where, a reduction in the capillary porosity of the 20% slag mixes compared to that of OPC control mix was found. While, the capillary porosity of the 35 and 50% slag mixes were reasonably much higher than the corresponding of those of OPC control mix.



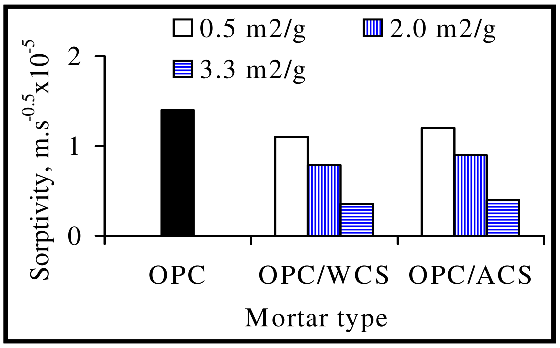


Fig. 9 Sorptivity of OPC mortar made with different contents of slag.

Fig. 10 Sorptivity of OPC mortar made with different finenesses of slag.

Based on the results obtained from this study, it can be generally stated that the optimum content of local by-product slag (WCS or ACS) which can be recommended for concrete technologists, is about 20% by weight of cement mass. Where, at this content, the highest possible enhancement in the microstructure and mass transport characteristics would be achieved, as revealed from the results demonstrated Figures 3 to 10. This optimum content of slag is similar to that obtained previously in literature [21]. While, the work that reported by Bleszinski et al [21], revealed that the optimum content of WCS which produced the highest significant reduction in the chloride permeability was around 50%, by weight of cement mass. This dissimilarity between the results reported herein and that found in literature may be raised due to the differences in the pozzolanic reactivity, crystal structure and chemical composition of the adopted local by-product slag and that used in literature.

3.3. Compressive Strength of OPC/Slag Matrix

The mechanical characteristics of OPC mortar mixes containing either WCS or ACS were investigated by evaluating their compressive strength development. The effects of WCS and ACS contents on the compressive strength of OPC mortar mixes made with constant w/b ratio of 0.4, constant slag fineness (0.5 m^2/g) and cured in water for 7, 28, 56 and 90 days are demonstrated in Figures 11 and 12, respectively. It can be seen from these Figures. that, at all ages, the increase of the substitution of OPC with either WCS or ACS up to 20%, increases the compressive strength. However, at higher contents of slag (greater than 20%), the compressive strength decreases with increasing the contents of either WCS or ACS. It can be noted from Figure 11 that the rate of strength gain is directly proportional to the slag content.

Furthermore, the results shown in Figures 11 and 12 emphasized the beneficial role of prolonging the water curing period on the compressive strength of OPC matrix containing either WCS or ACS. Where, increasing the period of water curing has led to significant enhancements in the compressive strength of OPC matrix made with such pozzolanic materials. Consequently, it is recommended to cure the OPC matrix containing such replacement material for a quiet long period to gain the most possible intended beneficial role.

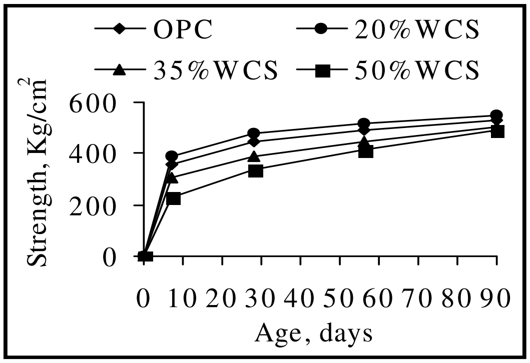


Fig. 11 Strength development of OPC/ WCS mortars.

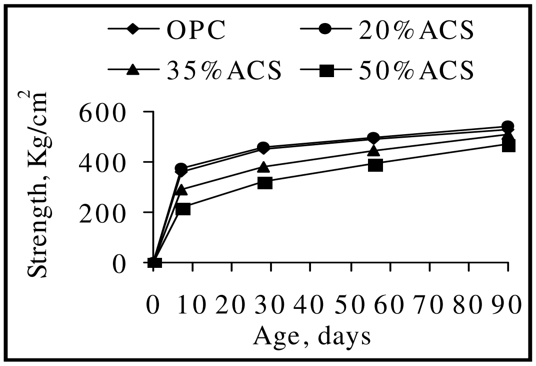


Fig. 12 Strength development of OPC/ ACS mortars.

This may be attributed to the produced alterations occurred in the pore structure and hydration products of OPC matrix due to the inclusion of such pozzolanic material. Where, increasing the amount of C-S-H and consuming of C-H has a considerable role in enhancing the compressive strength of OPC matrix. On the other hand, the noted reduction in compressive strength when 35 and 50% slag replacement levels were utilized in OPC mixes may be attributed to the excessive adopted content of WCS or ACS, which is greater than the quantity required to combine with $Ca(OH)_2$. As a result, part of cementitious material (OPC) replaced by either WCS or ACS did not contribute to the hydration and pozzolanic reactions of OPC matrix [4,10].

The effect of mechanical activation of WCS and ACS (expressed by the fineness) on the compressive strength of OPC mortar mixes made with constant w/b ratio of 0.4, constant slag content (20% by weight of cement) and cured in water for 28 days was finally investigated. The results are illustrated in Figure 13. It can be seen that the compressive strength increases with increasing the fineness of WCS and ACS. The amount of increase in the 28-day compressive strength reaches about 7, 60 and 92% when 0.5, 2.0 and 3.3 m^2/g finenesses of WCS were considered and 1, 60 and 92% when 0.5, 2.0 and 3.3 m^2/g finenesses of ACS were considered, respectively compared to the corresponding of that of OPC mortar. However, it seems from the results shown in Figure 13 that the compressive strength of OPC/WCS and OPC/ACS mortar specimens was almost similar, regardless the adopted slag finenesses used in mortar mixes.

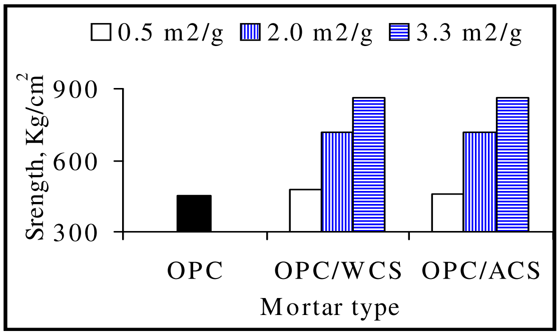


Fig. 13 Strength of OPC mortars incorporating slag with different finenesses.

This is easily explained through the surface area of the slag particles exposed to the pozzolanic reaction. The finer slag particles, the larger the surface area for the calcium hydroxide to react with and hence a faster reaction might be expected [4]. The results shown in Figure 13 agree with that reported by Lim and Wee [4] who showed that the compressive strength of OPC concrete containing slag increases as the WCS fineness increases. However, the finding obtained in the literature was based on adopting of slag cooled by water and not on slag that cooled in air.

It can be generally stated that the various properties of OPC matrix containing local by-product water cooled slag is not far away from that made with the local by-product air- cooled slag. This led the authors to believe on the adoption of utilizing the activated local by-product slag in its two cooling forms in local concrete industry. This would provide a good solution for deducting the cost of concrete production, prolonging the service life of concrete structures made with such blending material, and finally reducing the harmful environmental impacts of such by-product.

4. CONCLUSIONS

According to the experimental work carried out in this investigation, the main conclusions can be summarized as follow:

1. Inclusion of activated local by-product slag that cooled by water (WCS) or by air ACS, in OPC matrix has a notable effect on its compressive strength, sorptivity, and hydration products. Where, a partial replacement of OPC with 20% WCS or 20%ACS in OPC mortar mixes has led to a significant enhancement in the compressive strength, a illustrious modification in nature and amount of the main hydration products (C-S-H and C-H), and, consequently reasonable reductions in the amount of interconnected pores (capillary pores) and the rate of fluid transfer into cover zone (sorptivity). However, these improvements would be diminished when a greater dosage of either WCS or ACS is adopted in OPC mixes.

2. The mechanical activation of local by product (slag) was proved as a vital approach for enhancing the various hardened properties of OPC matrix containing such activated material. Where, increasing the degree of grinding of the by

product material (fineness) has a remarkable positive impacts on enhancing the compressive strength, pore structure, hydration and reducing the rate of water flow into the cover zone.

3. It was confirmed that cooling of local slag using water is more appropriate approach than cooling of slag in air, where all considered characteristics of OPC/WCS mortars are slightly better than the corresponding of that of OPC/ACS. However, ACS could be utilized in OPC mixes after considering a careful and an effective activation program.

REFERENCES

1. ACI COMMITTEE 226, "Ground granulated blast-furnace slag as a cementitious constituent in concrete", American Concrete Institute Manual of Concrete Practice, 1987, 11 pp.
2. ASTM C125-79a, "Standard definitions of terms related to concrete and concrete aggregates", Annual Book of ASTM Standards, part 14, 1980.
3. Jianyong, L. and Pei, T., "Effect of slag and silica fume on mechanical properties of high strength concrete", Cement and Concrete Research, Vol. 27, No. 6, pp. 833-837, 1997.
4. Lim and Wee, "Autogenous shrinkage of ground granulated blast-furnace slag concrete", ACI Material Journal, Vol. 97, No. 5, pp. 586-593, 2000.
5. Hou, W., Chang, P. and Hwang, C., "A study on anticorrosion effect in high-performance concrete by the pozzolanic reaction of slag", Cement and Concrete Research, Vol. 34, No 4, pp. 615-622, 2004.
6. Barnett, S.J., Soutsos, M.N., Millard, S.G. and Bungey, J.H., "Strength development of mortars containing ground granulated blast-furnace slag", Cement and Concrete Research, Vol. 36, No 8, pp. 434-440, 2006.
7. Wang, S.H. and Scrivener, L., "Hydration products of alkali activated slag cement", Cement and Concrete Research, Vol. 25, No 3, pp. 561-571, 1995.
8. Marta, P., Banfill, F.G. and Puertas, F., "Rheology and setting time of alkali-activated slag pastes and mortars", ACI Material Journal, Vol. 97, No. 5, pp. 140-148, 2008.
9. Mostafa, N. Y., El-Hemaly, S.A.S., Al-Wakeel, E.I., El-Korashy, S.A. and Brown, P.W., "Characterization and evaluation of the hydraulic activity of water-cooled slag and air-cooled slag", Cement and Concrete Research, Vol. 31, No. 6, pp. 899-904, 2001.
10. Abd El.Aziz, M., Abd El.Aleem, S., Heikal, S. and El Didamony, H., "Hydration and durability of sulphate-resisting and slag cement blends in Caron's Lake water", Cement and Concrete Research, Vol. 35, No 8, pp. 1592-1600, 2005.

11. Parrott, L. J. "Water absorption in cover concrete", Materials and Structures, Vol. 25, No. 5, pp. 284-292, 1992.
12. Hall, C., "Water sorptivity of mortars and concretes: A review", Magazine of Concrete research, Vol. 47, No. 147, pp. 51-61, 1989.
13. Claisse, P.A., Elsayad, H. I. and Shabaan, I. G., "Absorption and Sorptivity of cover concrete", Journal of Materials in Civil Engineering Vol. 11, No. 2, pp. 105-110, 1997.
14. Ngala, V.T., Page, C.L., Parropp, L.J. and Yu, S.W., "Diffusion in cementitious materials: II. Further investigation of chloride and oxygen diffusion in well-cured OPC and OPC/30%PFA pastes", Cement and Concrete Research, Vol. 25, No. 4, pp. 819-826, 1995.
15. Parrott, L. J., "Variation of water absorption rate and porosity with depth from an exposed concrete surface: Effect of exposure conditions and cement type", Cement and Concrete Research, Vol. 22, No. 6, pp. 1077-1088, 1992.
16. Young, J. F., "Humidity control in the laboratory using salt solutions – A review", Journal of Applied Chemistry, Vol. 17, pp. 241-245, 1967.
17. Ramachandran, A. I., "Application of different thermal analysis in cement chemistry", Pub. Chemical Publishing Company, London, 1969.
18. Rahman, A. A. and Glasser, F. P., "Comparative studies of the carbonation of hydrated cements", Advances in Cement Research, Vol. 2, No. 6, pp. 49-54, 1989.
19. Roy, D. M. and Idorn, G. M., "Hydration, Structure, and Properties of Blast Furnace Slag Cements, Mortars, and Concrete" ACI Journal, Proceedings, V. 79, No. 6, pp. 445-457, 1982.
20. ACI COMMITTEE 233R, "Ground granulated blast furnace slag as a cementitious constituent in concrete", American Concrete Institute Manual of Concrete Practice (Detroit, Michigan), 16 pp, 1995.
21. Bleszynski, R., Hooton, R. D., Thomas, M. D. A. and Rogers, C. A., "Durability of Ternary Blend Concrete with Silica Fume and Blast-Furnace Slag: Laboratory and Outdoor Exposure Site Studies", ACI Materials Journal, V. 99, No. 5, pp. 499-508, 2002.

دراسة عن التنشيط الميكانيكى لجلخ الحديد المصرى

الملخص

يتناول هذا البحث دراسة تأثير كلا من نعومة و محتوى جلخ الحديد المحلى على الخواص المختلفة للمونة الأسمنتية بدلالة مقاومة الضغط و الإمتصاصية و المسامية الشعرية وطبيعة و كميات مواد الأيدرة الرئيسية. تم إجراء برنامج عملى على ثلاثة عشر خلطات من المونة الأسمنتية و ثلاثة عشر خلطات من عجينة الأسمنت محتوية على نسب مختلفة من جلخ الحديد المصرى (٠، ٢٠، ٣٥ و٥٠ % من وزن الأسمنت) وذات نعومات مختلفة (٠,٥، ٢,٠ و ٣,٣ م^{٢}/جم). أوضحت النتائج المعملية بأن التنشيط الميكانيكى لجلخ الحديد المبرد بالماء أو الهواء قد يؤدي إلي تحسين مقاومة الضغط و الإمتصاصية و التكوين الدقيق و يعتمد هذا التحسن على محتوى جلخ الحديد الموجود بالمونة. كما أوضحت النتائج التأثير الإيجابى للتنشيط الميكانيكى لجلخ الحديد سواء المبرد بالماء أو الهواء على الخواص المختلفة للمونة المتصلدة التى تم دراستها. وبناءاً على ذلك تم التأكيد على أهمية استخدام جلخ الحديد المبرد بالطرق المختلفة فى صناعة الخرسانة.