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Effect of Local Activated Blast Furnace Slag on Chloride Ingress in Hardened Mortar.

H.M.Ali , M. S. Saif, G. E. Abdelaziz, M. O. R. El-Hariri.

Department of Civil Engineering, Faculty of Engineering at Shoubra, Banha University

ABSTRACT

This study investigates the effect of Local Ground Granulated Blast Furnace Slag (GGBS) with and/or without chemically activators on chloride ingress in hardened OPC Mortar. The used GGBS replaced OPC by 10 and 20%. Three different types of alkali-based chemical activators (sodium silicate, sodium carbonate and lithium hydroxide) were used with the OPC mix containing 20%GGBS. Chloride ingress was assessed by measuring Chloride Penetration Test, as a function of depth (chloride profile). To broaden the understanding, compressive strength, TGA and MIP were conducted. The results reveal that, chloride ingress resistance decreased with increasing local GGBS replacement level without using chemical activators. However; the effect can be enhanced by using chemical activator. The used chemical activators with 20% GGBS mix improve its microstructure. The use of lithium hydroxide as a chemical activator improves chloride ingress resistance for 20% GGBS mix higher than the other used activators (sodium silicate, sodium carbonate).

Key words: Ground Granulated Blast Furnace Slag; chloride profile; TGA and MIP

INTRODUCTION

In the context of reducing CO_2 emissions, the one prospect currently practiced is replacing Portland cement with high volumes of supplementary cementitious materials (SCMs). Effective use of locally available SCMs such as ground granulated blast furnace slag (GGBFS) in producing concrete reduces the burden on the landfills and environmental pollution (Duxson et al, 2007). Conversely, by reducing the Portland cement content in concrete, the ability to activate the SCMs is lowered and the possible alternative to improve the strength is by the use of additional alkaline activator solution. The activation of clinker-free SCMs like GGBFS with alkaline activator solution produces alkali activated concrete (Midhun,2018), (Wongpa et al,2010), (Venu,2017) . Alkali Activated Slag Concrete (AASC) has numerous advantages over Ordinary Portland Cement Concrete (OPCC) like low environmental impact, high strength, rapid gain in strength and better durability characteristics. The main reaction product of AASC is crystalline hydrated calcium silicate gel (C-A-S-H and/or C-S-H) along with hydrated sodium silicate gel (N-A-S-H). The C-S-H gel in AASC is different from the one present in Portland cement concrete with low CaO/SiO_2 ratio and some microstructural differences (Pacheco et al,2008). It is reported that the type and nature of starting material (GGBFS), quantity and nature of alkaline activator solution and curing conditions strongly influence the mechanical and durability properties of AASC (Collins,1999), (Collins,2000), (Chindaprasirt et al,2012), (Bernal et al,2010).

Durability aspects are evaluated mainly based on ingress of chlorine, sulfur dioxide and nitrate into the structure. Chloride and sulfur dioxide in the atmosphere diffuses into the concrete in presence of moisture and deteriorates the concrete structure and corrodes the steel reinforcement (Schneider,2005).Therefore, prevents corrosion of reinforcing steel and reduces spalling of concrete cover under chemical attack. It is reported that AASC have better durability as compared to OPCC in aggressive environments (D.M. Roy,1982). AASC having low permeability and also due to less CaO in its composition, AASC performs better than OPCC in acidic environments (NT BUILD 443). (Roy et al. 2005) reported a very low chloride diffusion in alkali activated cement pastes. (Douglas et al,1992) reported that AASC has good resistance to chloride ion penetration. (Bondar et al 2017) reported that AASC mortars have high resistance to chloride ions. Several parameters like mineralogical composition of GGBFS, type of activators, concentration of activating solution, pH of concrete and curing temperature influence the behavior and reaction mechanism of AASC.

So, there is a need to determine the optimum content of the local by-product slag and type of activators to be recommended for concrete technologists, to achieve the highest possible benefits as a result of its utilization in concrete industry.

So, an effort to gain improved understanding of the above-mentioned aspects, the main objectives of this research are as follows:

1. To study the possibility of adoption of the chemical activators (sodium silicate, sodium carbonate and lithium hydroxide) approach for enhancing the performance of the local by-product slag, aiming to improve the various microstructure and mechanical properties related characteristics of OPC matrix made with such materials.
2. To investigate the impacts of activated local product furnace slag on resistance chloride ion.
3. To determine the proper chemical activators (sodium silicate, sodium carbonate and lithium hydroxide) to be used in GGBS/OPC mixes.

2. EXPERIMENTAL WORK

Ordinary Portland cement (OPC) (CEM1, 52.5N) complying with ESS4756-1/2013 was supplied from the local market. Ground granulated blast-furnace slag (GGBS) used in this study was locally produced and supplied from iron and steel factory in Helwan city. GGBS was grounded to a surface area of (0.42) m^2/gm. The wet chemical analysis of both OPC and GGBS are listed in Table 1. Clean siliceous sand with a fineness modulus of 2.75 complying with ASTM C778-80 and tap water were used for the mortar

Table1: Chemical analysis of OPC and GGBS

Oxide,%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_3	MnO	Cl	L.O.I
OPC	19.14	5.20	3.55	61.60	1.90	0.45	0.20	1.81	-	-	0.08	2.40
GGBS	31	4.92	0.34	53.09	3.78	0.35	0.44	-	0.69	4.63	-	<0.01

Sodium chloride (NaCl) was used as a source of chlorides ions. The purity of Sodium chloride was 99.9%. The purity of Solution of lithium hydroxide, sodium silicate and sodium carbonate used as chemical activators were 99.9%. All salts were brought from El-Gomhoria Company, Cairo. All salt were in powder shape. Water was used for mixing and curing of mortar and hardened cement paste specimens, was chemically neutral water (PH=7).

Six OPC mortar mixes of constant 0.6 w/b ratio were made to determine total chloride profile. The first three mixes incorporating 0, 10 and 20% GGBS and the other containing 20% GGBS activated with three different types of chemical activators (lithium hydroxide, sodium silicate and sodium carbonate), with content of 1% by weight of OPC. The details of the mix proportions of the mortars are summarized in Table 2. Another six OPC mortar mixes of constant 0.485 w/b ratio were made to determine compressive strength. Furthermore, Six cement paste mixes of constant 0.485 w/b ratio were prepared to study microstructure analysis using thermo-gravimetric and Mercury intrusion porosimetry,

The hardened cement paste specimens specified for this study were subjected to thermo-gravimetric analysis (TGA), by monitoring the percentage weight loss that can take place (%decomposition) as a result of raising the temperature with a defined range. Other researcher found that C-S-H and C-H decomposes at a range of temperature of 105 to 250 ºC and 450 to 600 ºC, respectively (Ramachandran, 1969, Rahman and Glasser, 1989 and Abdelaziz, 1998).

Table 2 Mix proportions of the mortars used to determine total chloride profile

Mix NO.	Mix code	OPC (%)	GGBS (%)	Sand/binder ratio	Activator Content (%)	*W/b ratio
1	OPC	100	-	2.75	-	0.6
2	OPC/10GGBS	90	10	2.75	-	0.6
3	OPC/20GGBS	80	20	2.75	-	0.6
4	OPC/20GGBS/$Li(OH)_2$	80	20	2.75	1	0.6
5	OPC/20GGBS/$NaCO_3$	80	20	2.75	1	0.6
6	OPC/20GGBS/$NaSiO_3$	80	20	2.75	1	0.6

* w/b = water/(OPC + weight of supplementary materials).

For total chloride profile test, mortar specimens of 75 mm height x150 mm diameter cylinders were subjected to wetting and drying cycles of solution of NaCl of concentration 5% every week for a period of 56 days. The mixing procedures of mortar were carried out according to ASTM C305-82. 50x50x50 mm mortar cube specimens were taken from the mortar mixes to assess their compressive strength .On the other hand, mixing the 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 mercury intrusion porosimetry approaches). After casting, all moulded samples were covered with plastic sheets for 24 hours and then immersed in water curing tank (20 ± 2ºC) till the age of testing (56 days).

3. RESULTS AND DISCUSSION

The total chloride profile results show that, whatever the concrete depth, a partial replacement of OPC in mortar mix by 10% GGBS slightly decrease the total chloride content compared with the control OPC mix, while 20% GGBS replacement increase the total chloride content at all concrete depth. Moreover the use of chemical activator with OPC/20GGBS mortar mix improves its chloride penetration resistance and the percent of improvement is higher for mix containing lithium hydroxide, sodium carbonate and sodium silicate respectively as shown in Fig. 1.

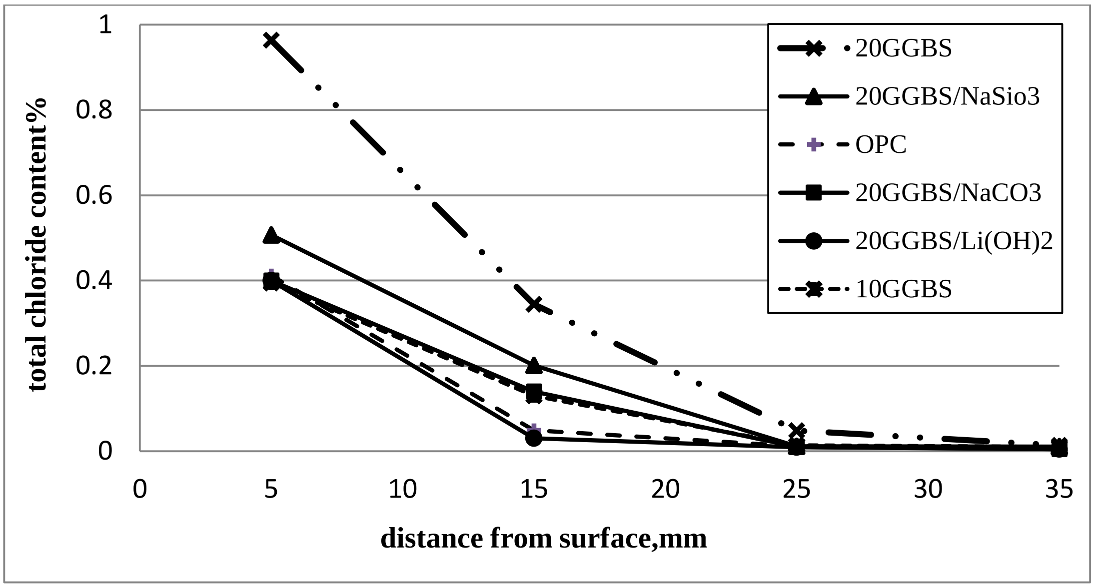

Fig.1 Total chloride profiles and penetration depth of OPC mortars made with different GGBS contents and different activators at 56 days.

The compressive strength test results show that, generally incorporating GGBS to OPC mortar increase the compressive strength however, the percent of was increase decreased with increasing GGBS content as it reaches to 17.5% and 2.9% for 10% GGBS and 20% GGBS respectively. Moreover the use of chemical activator with OPC/20GGBS mortar mix improves its compressive strength and the amount of increasing reaches about 9%, 7% and 5% for mixes containing $Li(OH)_3$, Na_2SiO_3 and Na_2CO_3 respectively compared OPC mortar containing 20% GGBS as shown in Fig.2. However, the percent of increase reaches about 12%, 10% and 8% for mixes containing $Li(OH)_3$, Na_2SiO_3 and Na_2CO_3 respectively compared with OPC mortar.

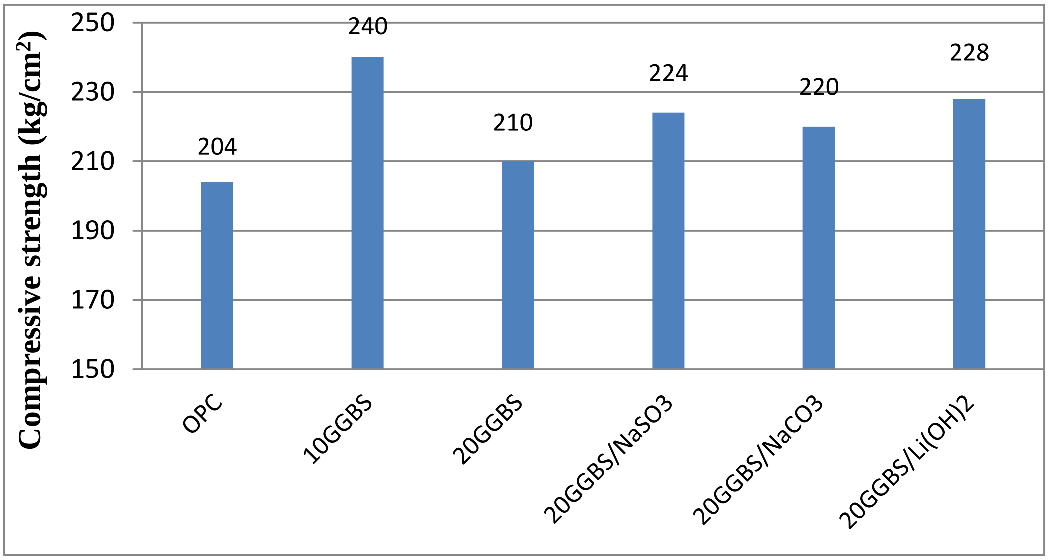

Fig. 2. Compressive strength of OPC mortar made with w/b ratio of 0.485 and different slag contents at 56 days

The improvement of chloride penetration resistance and compressive strength for mix containing 10% GGBS could be attributed to enhanced microstructure of OPC mortar mix as a result of incorporating 10% GGBS as indicated by the higher amount of CSH in 10% GGBS mix and lower amount of CH compared with OPC control mix as shown in Figures 3 and 4. The percent of increase in CSH reached to 3% where the percent of reduction in CH arrived to 25%.

On the other hand the mix containing higher replacement level (20% GGBS) shows a reduction in chloride penetration resistance and compressive strength compared with control OPC mix. These results probably due to the lower aluminate content (low AL_2O_3 = 4.94%) of GGBS compared with OPC and consequently resulting a reduction in the chloride binding capacity in mix containing 20% GGBS (De Weerdt et al, 2014).

Moreover, the use of chemical activator with OPC/20GGBS mortar mix improves its mictostructure in terms of an increase in CSH and reduction in CH, where the amount of increase in CSH reaches about 28%, 9% and 5% for mixes containing $Li(OH)_2$, Na_2SiO_3 and Na_2CO_3 respectively compared with OPC mortar containing 20% GGBS only, while, the amount of reduction in CH reaches about 43%, 15% and 25% for mixes containing $Li(OH)_3$, Na_2SiO_3 and Na_2CO_3 respectively compared with OPC/20% GGBS, as shown in Fig.3.

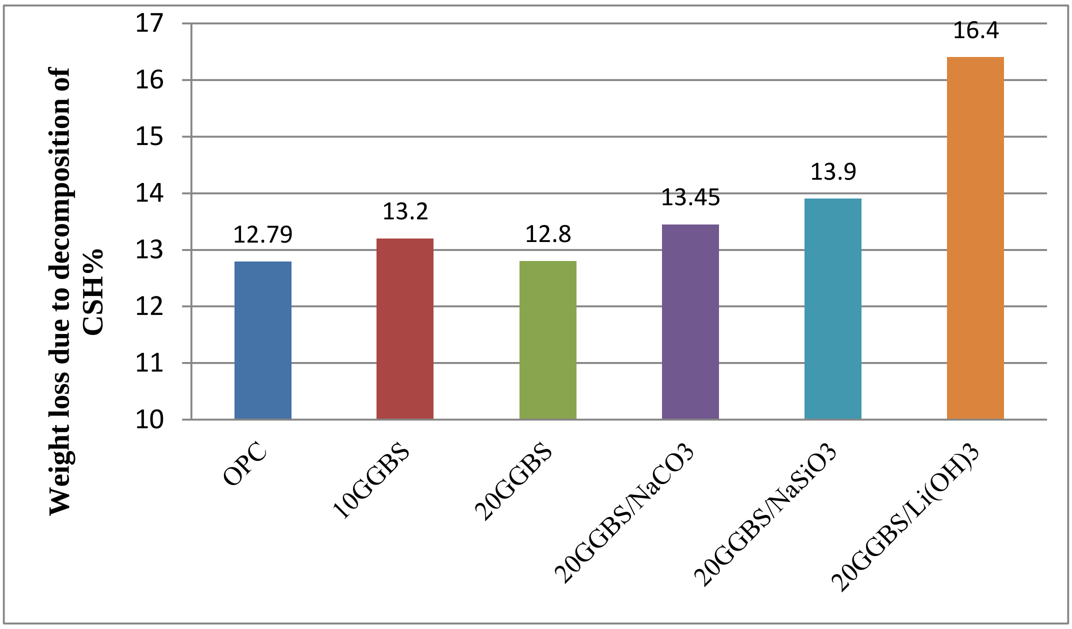

Fig. 3 CSH of OPC cement paste made with w/b ratio of 0.485 made with different slag contents.

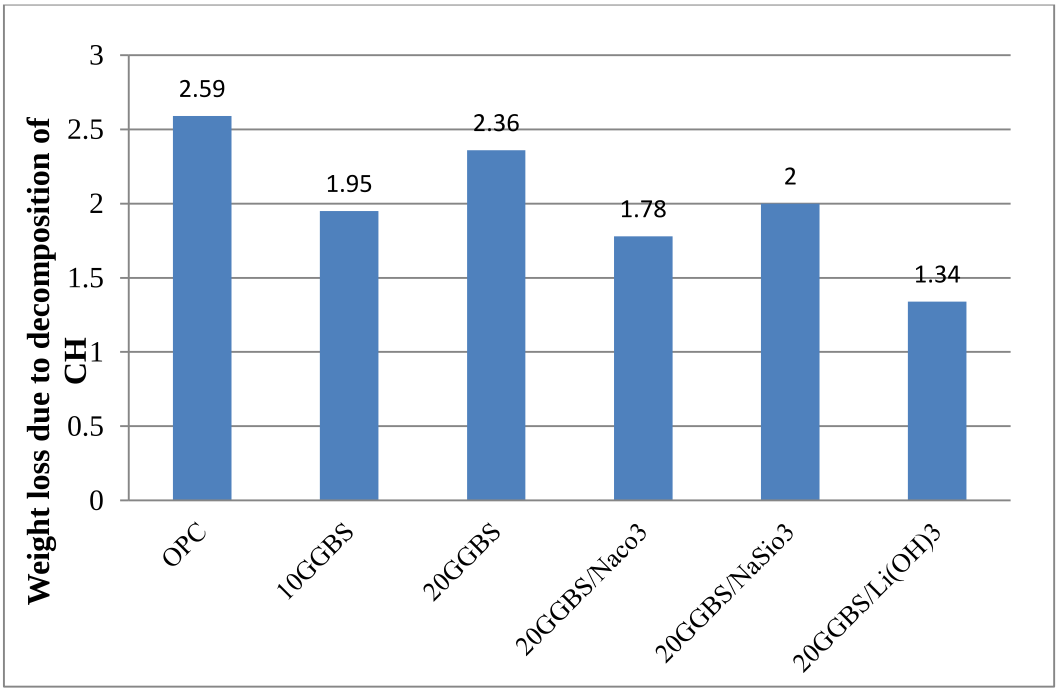

Fig.4 C-H of OPC cement paste made with w/b ratio of 0.485 made with different slag contents.

The improved microstructure of OPC/10%GGBS mortar mix reflected by pore refinement (decrease the volume and the diameter of the pores) as confirmed by MIP test results as shown in Figure 5, where, inclusion of 10% GGBS in control mix decreases pores volume from 0.34 to 0.14 (ml/g), where, 20% GGBS decrease pores volume from 0.34 to 0.28(ml/g). The use of chemical activators with OPC/20%GGBS mix decreases the volume of pores. Volume of pores for OPC/20%GGBS mix decrease from 0.29 to 0.19, 0.18 and 0.16 (ml/g) by using sodium carbonate, sodium silicate and lithium hydroxide respectively. The reduction in the volume of pores could be attributed to increasing the amount of C-S-H and/or micro-filler effect which, fill the unoccupied spaces and consequently reduces the amount of interconnected pores and improve the chloride penetration resistance.

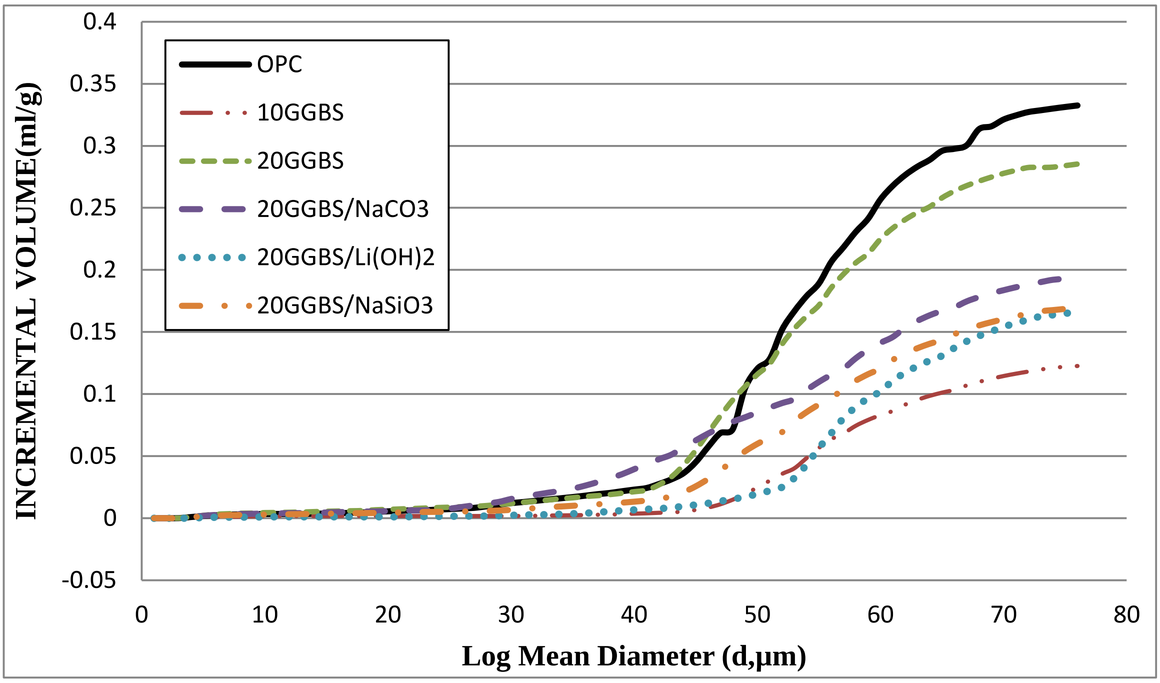

Fig. 5 Incremental volume with mean diameter at OPC cement paste made with w/b 0.485.

4. Conclusions

1. Chloride ingress resistance decreased with increasing local GGBS replacement level.
2. Inclusion of local GGBS by 10% as a partial replacement in OPC matrix has a slight effect on its chloride penetration resistance. However, it has a notable effect on compressive strength and paste microstructure.
3. Increasing local GGBS content to 20 % in OPC matrix decreases its chloride ingress resistance, compressive strength and adversely affects paste microstructure.
4. The used chemical activators (sodium carbonate, sodium silicate and lithium hydroxide) with 20%GGBS mix improve chloride penetration resistance and the paste microstructure in terms of hydration products and consequently decreasing the porosity.
5. The use of lithium hydroxide as a chemical activator improves chloride ingress resistance, compressive strength and the paste microstructure for 20% GGBS mix higher than the other used activators (sodium carbonate and sodium silicate).

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