



## Effect of electric arc furnace slag on sorptivity coefficient, bond strength and corrosion properties of smart concrete

A.G. Asran<sup>1</sup>, M.M. Sadawy<sup>2</sup>, M. Nooman<sup>3</sup>, A.A. Nada<sup>4</sup>

<sup>1</sup>Civil Engineering Department, Faculty of Engineering, Al-Azhar University, Nasr City, Cairo, Egypt.

<sup>2</sup>Mining and Petroleum Engineering Department, Al-Azhar University, Nasr City, Cairo 11371, Egypt.

<sup>3</sup>Civil Engineering Department, Faculty of Engineering, Al-Azhar University, Nasr City, Cairo, Egypt.

<sup>4</sup>Civil Engineering Department, Higher Technological Institute 10<sup>Th</sup>. Of Ramadan city, El Sharqiya, Egypt

### الملخص العربي

يتعرض هذا البحث بالدراسة المعملية لإختبار تأثير مادة خبث فرن القوس الكهربائي كبديل جزئي للأسمنت ودراسة تأثيره على الخواص الفيزيائية للخرسانة و معامل الامتصاص و قوة التماسك بين الخرسانة و حديد التسليح و كذلك خصائص التآكل للخرسانة. تم فحص سلوك التآكل باستخدام تقنيات كهروكيميائية. وقد أشارت النتائج إلى أن قوة التماسك والمقاومة للتآكل قد ازدادت بزيادة نسبة الإحلال في حين أن معامل الامتصاص يتناقص مع زيادة خبث فرن القوس الكهربائي كبديل جزئي للأسمنت. وقد أظهرت النتائج أن القيمة المثلى للاستبدال هي 15% من وزن الاسمنت.

### Abstract

The aim of this paper is to investigate the influence of electric arc furnace slag as cement replacement on sorptivity coefficient, bond strength and corrosion properties of smart concrete. The corrosion behavior was investigated using electrochemical techniques. Electric arc furnace slag was used as partial cement replacement with percentage of 0, 5, 10, 15 and 20 %. The results indicated that the bond strength and corrosion resistance increased while the sorptivity coefficient decreasing with increasing electric arc furnace slag as cement replacement up to 20%. on the other hand the results indicated that the optimum value of replacement was 15 wt % of cement.

**Keywords:** Concrete, electric arc furnace slag, Bond strength, Corrosion, sorptivity coefficient.

### 1. Introduction

Cement is one of the important construction materials, which is widely used in civil engineering across the world. However, the manufacture of cement causes serious environmental pollution. It is well known that 1 ton of cement will approximately produce 1 ton of CO<sub>2</sub> [1, 2]. Therefore, the sustainability development has spurred renewed interest in reducing the cement dosage of concrete. Supplementary cementitious materials (SCM), such as fly ash, limestone powder, natural pozzolans [3], slag [4-5], and silica fume are usually used as blender to replace some portion of Portland cement [6]. However, the continuous increasing demand in 2 SCM results in great shortage of traditional blenders. So it is necessary to develop new types of SCMs in cement and concrete industry.

The use of reinforced concrete structures is based on the principle that concrete is an ideal environment for steel. The high alkalinity of concrete causes the formation of a saturated hydrated iron oxide passivating film on reinforcing steel, which provides good

protection against corrosion. However, depassivation may be induced by carbonation of the cover concrete or by the presence of chloride salts, thus initiating expansive corrosion of the steel, causing eventual damage to the surrounding concrete [6-10]. Concrete structures, bridges, buildings, sanitary and water facilities, and other reinforced concrete structures get severely damaged due to corrosion of the reinforcing steel. The resultant cracking and spalling of the concrete costs billions of dollars each year [6].

In recent years, blended cements (BCs) have attracted intensive attention. The study of Jiang et al. [9] indicates the significant contribution of these cements to the durability of the hydration products. For a wide range of cements, Parrott [10] has shown that the initial 4-day mass loss generally reduced as the strength at the end of curing period was increased. Ngala and Page [11] have shown that the diffusion resistance of some pastes such as ordinary Portland cement (OPC), OPC/30% PFA and OPC/65% BFS are adversely affected by pre-drying and carbonation, but the effects were considerably more severe for BCs than for the OPC.

In Europe, nearly 12 million tons of steel slag is produced annually [12]. This material has been considered to be an excellent artificial raw material for the production of aggregate For various applications in civil engineering. About 65% of the produced steel slag is used as aggregate in road construction; due to its excellent characteristics, is used as a substitute for high-quality natural aggregate in asphalt wearing courses [13]. Smaller amounts of steel slag are used as aggregates in mortar and concrete mixtures, although this application is slightly more risky, since small quantities of certain unstable minerals (mainly in the form of free lime and periclase) are usually present in the slag. In the presence of moisture these minerals transform into  $Mg(OH)_2$  and/or  $Ca(OH)_2$ , which occupy a larger volume than the primary components. The result is swelling of the composite into which the slag has been placed. Successful use of steel slag in concrete has been reported by Maslehuddin et al. [14], who found that the physical properties of steel slag aggregate were superior to those of crushed limestone aggregate, and that concrete prepared with steel slag exhibited better performance than concrete prepared with limestone aggregate, especially with regard to strength and durability.

The present work focused on the effect of electric arc furnace slag on sorptivity coefficient, bond strength and corrosion properties of concrete.

## 2. Experimental Work

### 1- 2.1 Materials

#### 2- 2.1.1 Electric arc furnace (EAF)

Table 1 shows the chemical composition of EAF determined by XRF analysis.

Table 1 Chemical properties of the EFA (mass ratio, %)

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	MnO	L.O.I
15	11	37	26	3	6	2

### 2.1.2 Ordinary Portland cement (OPC)

The present study was carried out using a commercial Portland cement type CEM I 42.5 N conforming to Egyptian standard code ESS 2421/2007. The physical, chemical and mechanical properties of this cement are given in Table. 2.

Table 2 properties of cement type (CEM 42.5 N)

Chemical	Composition (wt. %)	Physical properties	Compressive strength (N/mm <sup>2</sup> )
SiO <sub>2</sub>	20.36	Fineness (cm <sup>2</sup> /gm) 3290	2 days 22.4
Al <sub>2</sub> O <sub>3</sub>	5.12	Specific Gravity 3.15	7 days 33.7
Fe <sub>2</sub> O <sub>3</sub>	3.64	Expansion (mm) 1.2	28 days 56.8
CaO	63.39		
MgO	1.03		
SO <sub>3</sub>	2.21		
L.O.I	1.3		

### 2.1.3 Coarse and Fine Aggregates

Natural siliceous sand having a fineness modulus of 2.66 and a specific gravity of 2.67 was used as fine aggregate. The coarse aggregate was a crushed dolomite with a maximum nominal size of 18 mm with a specific gravity of 2.64 and a crushing modulus of 23 percent.

### 2.1.4 Steel

High tensile ribbed steel bars of 12 mm diameter with length 20 cm for each. its chemical composition is shown in Table.3

Table 3: Chemical composition (wt %) of steel bars.

C	Si	Mn	Ni	Cr	Mo	Fe
0.39	1.43	0.55	1.62	0.70	0.32	Bal

## 2.2. Preparation of test specimen

Concrete mixes were prepared using a tilting drum mixer. The weighted coarse and fine aggregates were placed in the mixer and started dry mixing for 30 seconds to obtain a homogeneous mix. The cementitious materials were added to the mixer and stirred for 2 min. The water was slowly added and mixed for 2 min. The mixing process was continued for 3 min, Under a laboratory conditions. For sorpitivity, five cubes of (100 x 100) mm and five cylinders of diameter 100 with 200 mm in length for bond strength were prepared and compacted by a vibrating rod. For the corrosion tests, steel bars were cleaned with ethanol and then dried prior to embedding in the center of cylinders with dimension (100 mm as diameter x 200 mm in length), have an embedded length 175 mm. After casting, all specimens were covered with plastic sheet and stored in the

laboratory for 24 hours. The specimens were then demolded, and placed in curing water for 28 days.

### 3. Experimental Test

#### 3.1 Sorptivity

For sorptivity tests, cubes of 10\*10\*10 cm were cast from each mixture; the specimens were demolded after 24 h and cured for 28 days. Measurements of capillary sorption were carried out using specimens preconditioned in the oven at about 120 °C until constant mass. As shown in Fig. 1, test specimens of 10\*10\*10 cm were exposed to the water on the plane of 100\*100 cm by placing it in a pan. The water level in the pan was maintained at about 5 mm above the base of the specimens during this experiment. The lower areas on the sides of the specimens were coated with paraffin to achieve unidirectional flow. At certain times, the mass of the specimens was measured using a balance, then the amount of water adsorbed was calculated and normalized with respect to the cross-section area of the specimens exposed to the water at various times such as 1, 2, 3, 4, 5 and 6 hours. The sorptivity coefficient (k) was obtained by using the following expression:

$$\frac{Q}{A} = K\sqrt{t} \quad (1)$$

where Q= the amount of water adsorbed in (cm<sup>3</sup>); A= the cross section of specimen that was in contact with water (cm<sup>2</sup>); t = time (s); k = the sorptivity coefficient of the specimen (cm/s<sup>1/2</sup>).

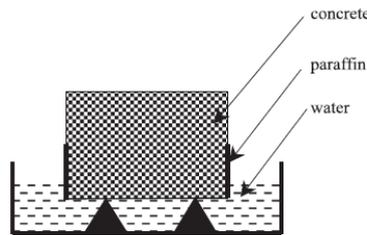


Fig. 1. The measurement of water capillary sorption.

#### 3.2 Bond strength tests

The bond strength of steel substrate with concrete structure (Fig. 2) was evaluated by pull-out method. The reinforcing bars have a nominal diameter of 10 mm. The load was applied at a loading rate of 0.075 kN /s. The bond stress is calculated using the following expression equation [11]:

$$\tau = \frac{P_{max}}{\pi \cdot \phi \cdot l} \quad (2)$$

Where  $\tau$  is the bond strength;  $P_{max}$  is the maximum pullout load;  $\Phi$  is the bar diameter; and  $l$  is embedment length of bar.

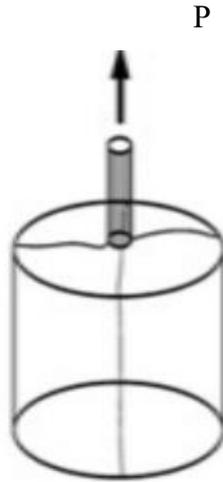


Fig 2. Cross-section of the bond strength specimen.

### 3.3 Corrosion tests

The electrochemical corrosion tests were performed using a Potentiostat/ Galvanostat (EG&G model 273). M352 corrosion software from EG&G Princeton Applied Research was used. A three-electrode cell composed of a concrete specimen as a working electrode, Pt counter electrode, and Ag/AgCl reference electrode were used for the tests (see Fig.3). Potentiodynamic polarization tests at scan rate of 0.5 mV/s were carried out. PAR Calc Tafel Analysis was used to fit the experimental data. All solutions were freshly prepared from analytical grade chemical reagents using distilled water. analytical reagent grade chemicals and distilled water.

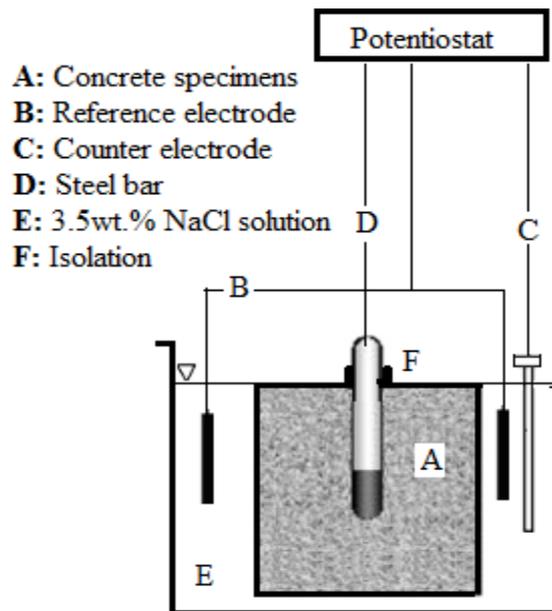


Fig. 3: Experimental setup of electrochemical corrosion measurement

## 4. Results and Discussions

### 4.1 Effect of slag on sorptivity coefficient of concrete

Figs. 4 and shows the results for sorptivity coefficient of different slag mixes concrete. It was noticed that all slag mixes have low sorptivity coefficient values than that of the control mix. However, beyond 15wt% replacement the sorptivity coefficient increases, but still less than the control mix. The trend is similar to the trend of bond strength development of concrete. This behavior is due to decreasing the cementitious material per surface area of fine aggregate and increasing the voids beyond this value.

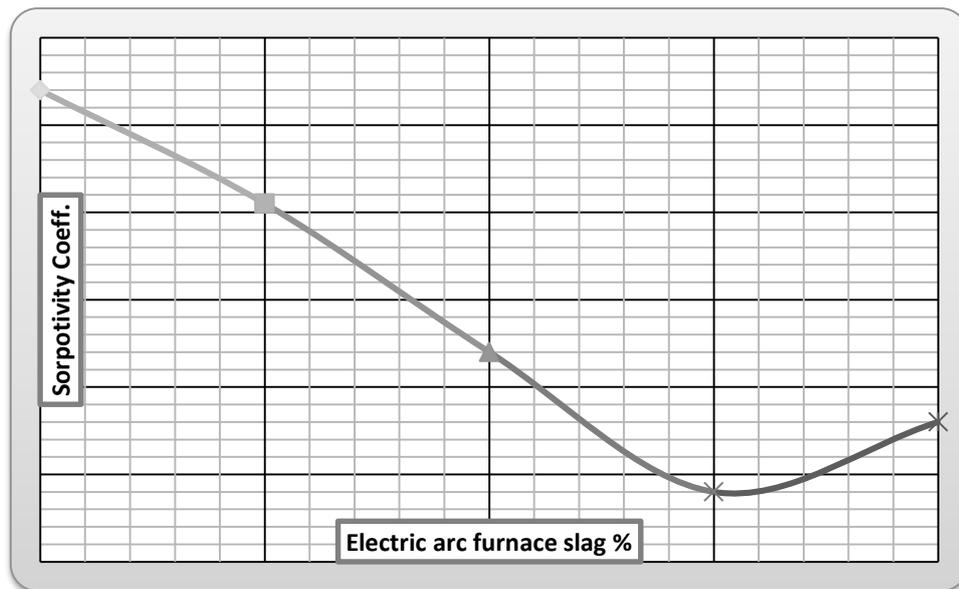


Fig. 4: Relation between sorptivity and % of replacement of arc furnace slag

### 4.2. Effect of slag on Bond Strength of concrete

In this study the bond strength has been evaluated from the peak load obtained after 28 days. It can be seen from Fig 5 that the bond strength depends on the amount of slag added. The bond strength increases with slag to 15 %. Replacement of cement beyond this amounts the bond strength decreases. This behavior is attributed to agglomeration of particles which exert more voids in concrete and decreases of  $C_3S$  content.

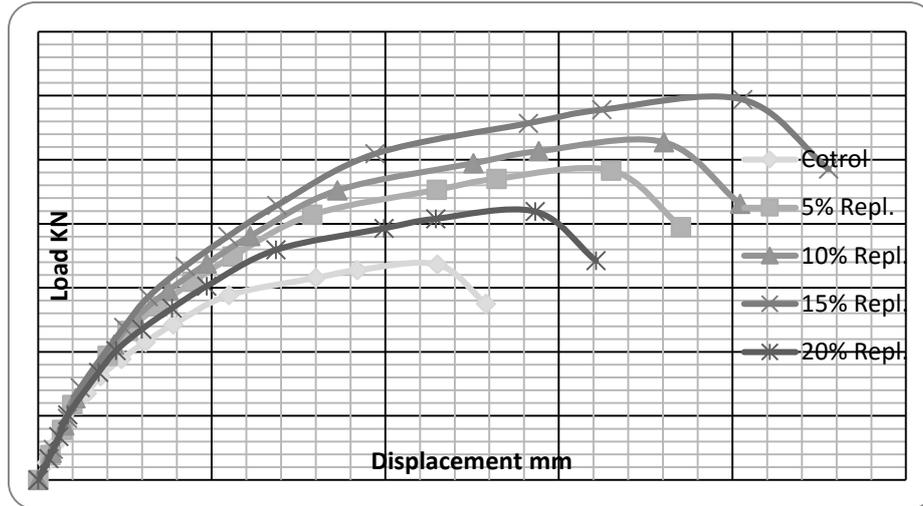


Fig 5 relation between load-displacement of bond behavior

#### 4.3. Effect of slag on corrosion behavior of concrete

The corrosion curves of steel imbedded in concrete with and without electric arc furnace slag are shown in Figs. 6 -8. All samples were immersed in 3.5 wt. % NaCl solution for 10 days before polarization tests to achieve their stable OCP values. The anodic polarization curves (Figs. 6 and 7) show that increasing slag content to 15 wt. % as cement replacement, the corrosion potential ( $E_{cor}$ ) shifts to more noble potential and the corrosion rate decreases from 3.2 to 1.05 mpy (Fig. 8). This behavior may be attributed to decreasing the pore size in concrete, leading to decreasing the chloride ions mobility. El Shazly and Sadawy [15] have found that the passivity of steel in concrete is due to the formation of a protective barrier oxide film which is formed in high pH environment. Also they found that the passive region increases with increasing slag content due to the rapid consumption of crystalline  $Ca(OH)_2$  which are quickly formed during early hydration and formation of excessive amounts of hydrated compounds of calcium silicate.

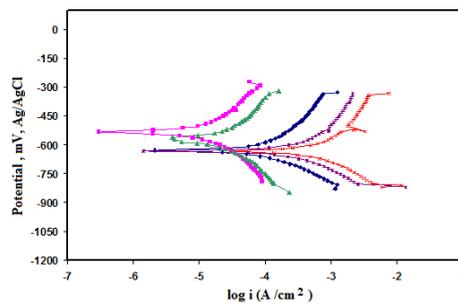


Fig 6 Tafel polarization curves of steel imbedded in concrete with and without slag as a cement replacement in 3.5 wt. % NaCl solution

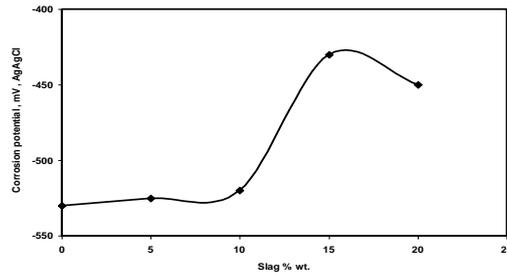


Fig.7 Effect of electric arc furnace slag on corrosion potentials of steel imbedded in 3.5 wt. % Nacl solution

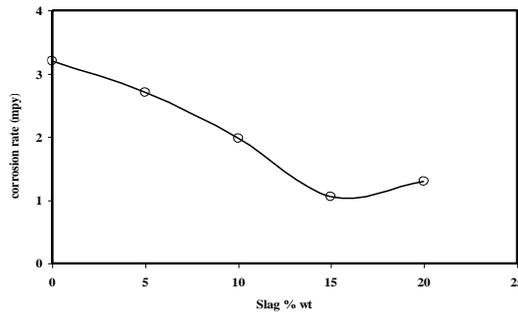


Fig.8 Effect of electric arc furnace slag on corrosion potentials of steel imbedded in 3.5 wt.% Nacl solution

## 5. Conclusions

The effects of electric arc furnace slag as a cement replacement on sorptivity coefficient, bond strength and corrosion resistance of concrete were investigated. The following conclusions were obtained:

- 1- Electric arc furnace slag having high values of fineness increases the bond strength and corrosion resistance of concrete.
- 2- All slag mixes have low sorptivity coefficient values than that of the control mix and the sorptivity coefficient decreases with increasing slag to 15wt% replacement.
- 3- 15wt % of electric arc furnace slag as a cement replacement in concrete was the optimum percentage for the values of sorptivity coefficient, bond strength and corrosion resistance of concrete.

## 6 References

- [1] S.P. Shah, S.H. Ahmad (Eds.), High Performance Concrete and Applications, Edward Arnold, London, 1994.
- [2] A.M. Brandt, Cement-Based Composites: Materials, Mechanical Properties and Performance, E&FN Spon, London, 1994.

- [3] R.P. Khatri, V. Sirivivatnanon, L.K. Yu, Effect of curing on water permeability of concretes prepared with normal Portland cement and with slag and silica fume, *Mag. Concr. Res.* 49 (180) (1977) 167–172.
- [4] A. Bentur, A. Goldman, Curing effects, strength and physical properties of high strength silica fume concretes, *J. Mater. Civ. Eng. ASCE* 1 (1) (1989) 46– 58.
- [5] A. Dinku, H.W. Reinhardt, Gas permeability coefficient of cover concrete as a performance control, *Mater. Struct.* 30 (1997) 387–393.
- [6] F. Jacobs, Permeability to gas of partially saturated concrete, *Mag. Concr. Res.* 50 (2) (1998) 115–121.
- [7] N.S. Martys, C.F. Ferraris, Capillary transport in mortars and concrete, *Cem. Concr. Res.* 27 (5) (1997) 747– 760.
- [8] W. Jiang, M.R. Silsbee, D.M. Roy, Similarities and differences of microstructure and macro properties between Portland and blended cement, *Cem. Concr. Res.* 27 (10) (1997) 1501– 1511.
- [9] L.J. Parrott, Influence of cement type and curing on the drying and air permeability of cover concrete, *Mag. Concr. Res.* 47 (171) (1995) 103– 111.
- [10] M.S. Khan, M.E. Ayers, Minimum length of curing of silica fume concrete, *Mater. Civ. Eng. ASCE* 7 (2) (1995) 134– 139.
- [11] A. Goldman, A. Bentur, The influence of microfillers on enhancement of concrete strength, *Cem. Concr. Res.* 23 (1993) 962–972.
- [12] Motz H, Geiseler J. Products of steel slags, an opportunity to save natural resources. In: Woolley GR, Goumans JJM, Wainwright PJ, editors. *Waste materials in construction* Elsevier Science Ltd; 2000. p. 207–20.
- [13] Wu S, Xue Y, Ye Q, Chen Y. Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. *Building and Environment* 2007;42:2580–5.
- [14] Maslehuddin M, Sharif AM, Shameem M, Ibrahim M, Barry MS. Comparison of properties of steel slag and crushed limestone aggregate concretes. *Construction and Building Materials* 2003;17:105–12.
- [15] R. M. El Shazly, M.M. Sadawy- Effect of Slag as a Fine Aggregate on Mechanical, Corrosion, and Nuclear Attenuation Properties of Concrete, *International Journal of Scientific Engineering and Research (IJSER)* ISSN (Online): 2347-3878 Volume 5 Issue 7, July 2017.