Int. J. Electrochem. Sci., 11 **(2016)** 2297 - 2305

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Short Communication

Effect of Durability and Chloride Ion Permeability in Ternary Cementitious Concrete with Additions of Fly Ash and Blast Furnace Slag

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Received: 1 January 2016 / *Accepted:* 19 January 2016 / *Published:* 1 February 2016

Ternary mixtures of concrete with Portland, fly ash and finely ground granulated slag were produced to investigate their effects on the compressive strength and corrosion resistance. Portland cement was partially replaced by alternative materials with water / cement ratio (w / c) of 0.50. The mechanical strength it was evaluated by compression tests and the corrosion resistance using Half-cell potentials. The results indicate that fly ash and blast furnace slag, greatly reduce the chloride permeability of concrete and increases the corrosion resistance both short- and long- time evaluation. Therefore it is concluded that to control the corrosion resistance in the presence of chloride ion, including pozzolan is an effective method.

Keywords: Portland cement, fly ash steel slag, mechanical strength and corrosion.

1. INTRODUCTION

The use of concrete with additives has been widely used worldwide [1]. For example, in Asia, the blast furnace slag has-been used as an Addition to cement and concrete [2]. So, this resource is widely utilized. In contrast, production of fly ash worldwide is not utilized in full [3]. For example, more than 88 million tons of fly ash are generated in India every year mostly Class F type (low calcium), and its use is only 10% to 15% [4]. This scenario is also evident in Latin America, not being reused these materials in the industrial sector and construction.

Since fly ash and blast furnace slag are employed in construction, the study of their properties has been important [5]. However, cement fly ash in large volumes has some disadvantages such as low resistance, high water requirements, and low resistance to carbonation [6]. Therefore, a good method the partial replacement of cement by fly ash in low volumes for producing compound. Moreover, when mineral additives used additives can be added to the mixture to accelerate the hydration of fly ash slag and improve the mechanical strength and the properties of the pore structure [7].

Slag reactions are significantly affected by the amount of free water available in the cement hydration. Therefore, a difference between hydration characteristics of fly ash and slag occurs, fly ash is a pozzolanic material, while the slag is a hydraulic material [8]. The blast furnace slag can react with the plaster and produce etringita [9]. The heat release in said reaction it is related to the amount of slag and the melting temperature of the specimens. In the cement-fly ash and cement-slag mixtures when the reaction wheel fly ash or slag are interrupted by lack of Ca $(OH)_2$ available stalled fly ash or slag particles have a material effect on microllenante with clinker. When the percentage replacement of fly ash or slag are high, the stagnation microllenante effect becomes significant [10].

Fly ash and blast furnace slag having different chemical compositions, such as the glassy phase, the contents of SiO_2 and CaO and generally different stoichiometry in the hydration reactions [11]. In the interaction cement-fly ash, calcium hydroxide is produced by the hydration of cement and the time consumed by the pozzolanic reaction [12].

This paper presents a laboratory study on the influence of the combination of fly ash, Portland cement and blast furnace slag on the electrochemical properties of Ultra-High Performance Concrete. The evaluation of the mechanical performance of concrete mixtures was made in the short and long term. The experimental program comprises testing compressive strength and corrosion resistance. The results showed that the combination of fly ash and blast furnace slag can improve the properties of concrete short and long term, while concrete with high volume fly ash and steel slag they require long periods for their beneficial effect.

2. EXPERIMENTAL METHOD

2.1 Materials

In this study commercial Type I Portland cement is used, Fly Ash from Thermal Power Plants Sochagota and granulated blast furnace slag from the plant of Paz del Rio. Characterization of these materials was performed by testing X-ray fluorescence and its chemical composition is summarized in Table 1.

Table 1. Chemical composition of the cementitious materials.

Composed	Portland cement, %	Fly Ash, %	Blast furnace slag, %
SiO_2	18.15	54.30	33.70
Al_2O_3	4.65	20.8	12.80
Fe_2O_3	3.80	5.30	0.48
CaO	60.03	6.40	45.40
MgO	2.50	0.80	1.00

Na_2O	0.80	0.90	0.12
K_2O	0.50	0.70	1.50
P_2O_5	-	0.70	-
TiO_2	-	1.20	0.50
MnO	-	0.01	-
SO_3	2.40	0.92	-
SiO_2/Al_2O_3	3.90	2.61	2.63
unburned carbon	0.6	8	-

As stony material fine aggregate was used type of river sand with fineness modulus of 3.04 and absorption of 0.81%. As coarse aggregate fine gray gravel was used with nominal maximum size of 12 mm.

2.2 Concrete mixtures

All mixtures were designed to cementitious material content of 448 kg / m^3 and a water / cement ratio of 0.5. For this purpose, 4 ternary mixtures of varying composition with Portland cement and partial replacement of fly ash and blast furnace slag are prepared. The abbreviations B, F and S are used to identify materials Portland cement, fly ash and blast furnace slag, respectively. The proportions of the blends are summarized in Table 2. Were also introduced to the nomenclature percentages replacement main cementitious material for example B8-F1-S1 represents the mixture of 80% Portland cement, 10% fly ash and 10% blast furnace slag; B4-F2-S2 represents the mixture of Portland cement 40%, 20% fly ash and 40% blast furnace slag [13].

Table 2. Proportions of concrete mixtures.

Identification	*B (kg/m^3)*	*F (kg/m^3)*	*S (kg/m^3)*	*Gravel or Stone (kg/m^3)*	*sand (kg/m^3)*	*Water (kg/m^3)*	*Sodium silicate (kg/m^3)*	*Plasticizers (kg/m)^3*
B8-F1-S1	358.4	44.8	44.8	997.3	830.4	224	22.4	0.5
B-F2-S2	268.8	89.6	89.6	997.3	830.4	224	22.4	0.5
B4-F2-S4	179.2	89.6	179.2	997.3	830.4	224	22.4	0.6
B4-F4-S2	179.2	179.2	89.6	997.3	830.4	224	22.4	0.8

2.3 Description of equipment and instrumentation

They conducted tests characterizing the mechanical properties of concrete with total and partial replacement of Portland cement. These tests were performed in order to determine the effects of additions of fly ash and slag on the properties of concrete is to say modification of its strength and performance [14].

2.4 Compressive strength

Compressive strength it is determined from the specimens in the form of cylinders having dimensions of 15x30 cm at ages 28 and 90 days following the procedure of ASTM-C-39 standard. The load is applied using a hydraulic press controlled by an automated system and load application speed was 0.25 MPa/s. For proper application of the load without eccentricities is using metal discs and neoprene. Additionally, to record the complete stress-strain curve and observe the maximum capacity obtained in compression deformation, the longitudinal strain to failure by adapting a strain gauge on the specimen is measured [15].

2.5 Electrochemical characterization

The electrochemical characterization was performed on a potentiostat / galvanostat, through the techniques of half-cell potential, using a cell consisting of a graphite counter electrode, a reference electrode, $Cu/CuSO_4$ electrode and as structural steel work NTC 2289 was used with an exposed area of 10 cm^2. Electrochemical measurements were performed for the concrete at 0, 3, 6, 9 and 12 months exposure to a solution composed of 3.5% Sodium Chloride Solution [16].

2.6 Chloride Ion Permeability

To evaluate the performance of concrete added with fly ash and steel slag against the penetration of chloride ions, the test was performed rapid chloride permeability based on the ASTM C1202 standard. These tests were performed after 28 days of curing.

3. RESULTS AND DISCUSSION

3.1 Compressive strength

In Figure 1, the results of compressive strength, evaluated at 28 and 90 days are obtained, where it is evident that at early ages (28 days) when no pozzolanic reaction, fly ash and steel slag acting as an inert material, therefore, the effect of fly ash and steel slag on concrete strength is evident with the curing and condition of the concrete, since they develop the pozzolanic reaction products and thus increases the mechanical strength and refinement of the porous structure occurs, This last factor is linked to the durability of concrete, especially reinforced concrete because the pore size reduced carrying capacity of corrosive liquids and gases is limited through their porous system [17-19].

This is mainly because the pozzolanic activity of fly ash continues to develop, evidencing in the corresponding graph at 90 days, because contributing to increase the mechanical strength at later ages. The optimal values of the mixture corresponding to 10 and 20% fly ash and steel slag, because the higher values of resistance is obtained, the effect of synergy between additions of fly ash and blast furnace slag, it indicates that the increase in performance is due to be added in an appropriate ratio between the steel slag and fly ash. The value of compressive strength of this ternary mixture has the highest values that mixtures; obtained only with fly ash or steel slag [Reference], implying that the combination of fly ash and blast furnace slag has a higher activity, than each of these components added separately [20].

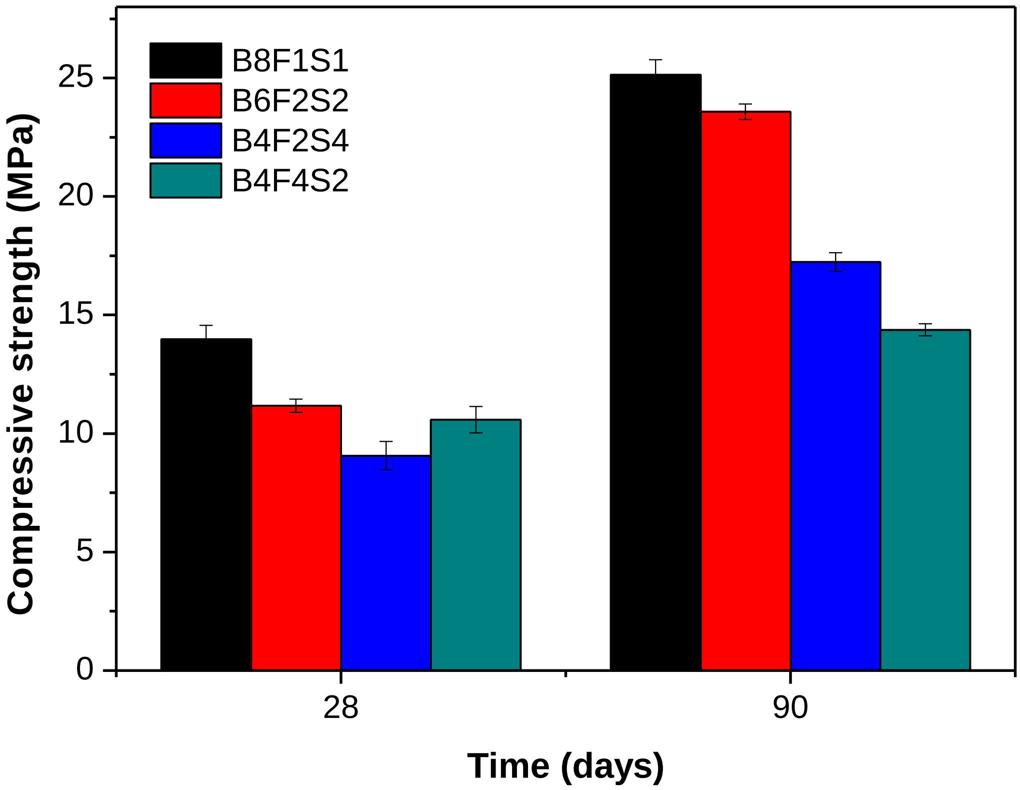

Figure 1. Compressive strength of ternary mixtures evaluated at 28 and 90 days.

3.2 Half Cell Potential

In Figure 4 measurements of half-cell potential is observed where 2 different responses in particular evaluated are obtained concrete with pozzolanic additions fewer B8F1S1, shows a high probability of corrosion is because the ions have reached the steel have since found a continuous conductive path because of the open porosity has the cement matrix, this because it has high content of Portland cement the other answer corresponds to a discontinuous conductive path; and can generate an area of insulation this behavior is because there is greater amount of pozzolanic material ranging between 40 and 60% [21-22].

The half-cell potential; It is a technique commonly used to evaluate the interface steel - concrete; when an ion penetration establishing a corrosive effect on metal embedded. From the results it can be seen clearly that for the 4 mixtures analyzed there are two areas one with high likelihood of corrosion and the other with an uncertain region these regions are generated by contact with the NaCl solution and the cement matrix. In Figure 2, it observed that as the evaluation time for mixtures with Portland fewer (40%) cement potential is decreased, which indicates a decrease in the resistivity of the system and also the diameter of the steel may increase because a corrosive behavior is generated at the interface-specific matrix. To the mixture 60% cement Portlad (B6F2S2) the effect of the potential is reversed in time because after the first measurement of the potential changes from an area of high likelihood of corrosion in the zone of uncertainty [23].

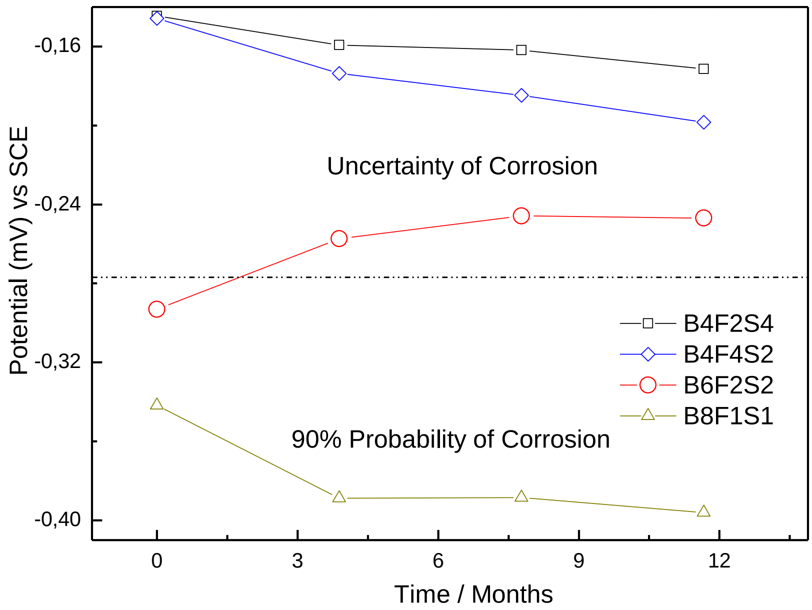

Figure 2. Potential half-cell corresponding the 4 ternary mixtures evaluated versus time.

One of the parameters that influence protection against corrosion phenomena is the thickness because in the concrete evaluated all have the same value this does not affect this assessment so the study focuses on the permeability to aggressive agents in order to control the spread of chloride ions. As mentioned in the experimental development simulates the evaluation means similar to a marine environment so that corrosion is caused by chloride ions that come from the mixture generated, these ions diffuse through the cement matrix from the outside until the reinforcing steel, these ions have the ability to disrupt the stability of the passive film beginning the process of corrosion. In Figure 2 it shows that the concrete with corrosion process is the one with a high amount of cementitious Portland so from early loses its steel passivation generating an anode reaction where Fe releases two electrons which diffuse through the concrete and react with water and oxygen, occurring cathodic reactions. The problem created by this type of structures is that once the iron oxide hydrates, it becomes porous and can reach increases the volume occupied by the steel which produces very high internal stresses producing cracks and can cause material removal [24].

3.3 Performance against chloride penetration

The results are interpreted according to Table 1, reported in the ASTM C1202 standard. This rule refers to the classification of materials according increase or decrease its ion permeability chloride these values are in Figure 3.

Table 3. Rating of chloride permeability of concrete

Charge passing (coulombs)	Chloride permeability
≥4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
≤100	Negligible

According to Table 1, the concrete less amount of fly ash and steel slag it has moderate permeability to chloride ion attack; concrete added with 20% slag and 20% fly ash had a low permeability classification entering columbios the range 1000-2000, However mixtures with 40% of Portland cement was the best performance record. As can be concluded the chloride ion permeability is seriously affected by the rate of addition since the 10% higher load values were obtained while the 60% addition the lowest values were obtained this means that as the percentage of addition of ash and steel slag is increased behaviour towards chlorides remarkably improved. The reduction in total charge passed through the concrete the four mixes the best that behaviour with a higher content of fly ash that is attributed to the effect remains lower porosity in concrete [25]. The saline environment directly affects performance against corrosive phenomena and it is due to chloride ions coming from the sea water and the sea breeze, these ions diffuse through the concrete structure from the outside until the reinforcement and accumulate to reach the reinforcing steel, reaching a critical concentration, to which this ion has the ability to disrupt the stability of the passive film beginning the process of corrosion [26-27].

Chloride ions are present in this study is dissolved in water, these ions are retained in the pores starting the dissolution of the pore, thereby generating a damage on reinforcing steel to correlate with the mechanical test is determined that the ions do not have a significant influence on the concrete, but about its rebar that can eventually cause corrosion reducing its area losing mechanical properties such as compressive strength and fatigue they can reach disable the structure.

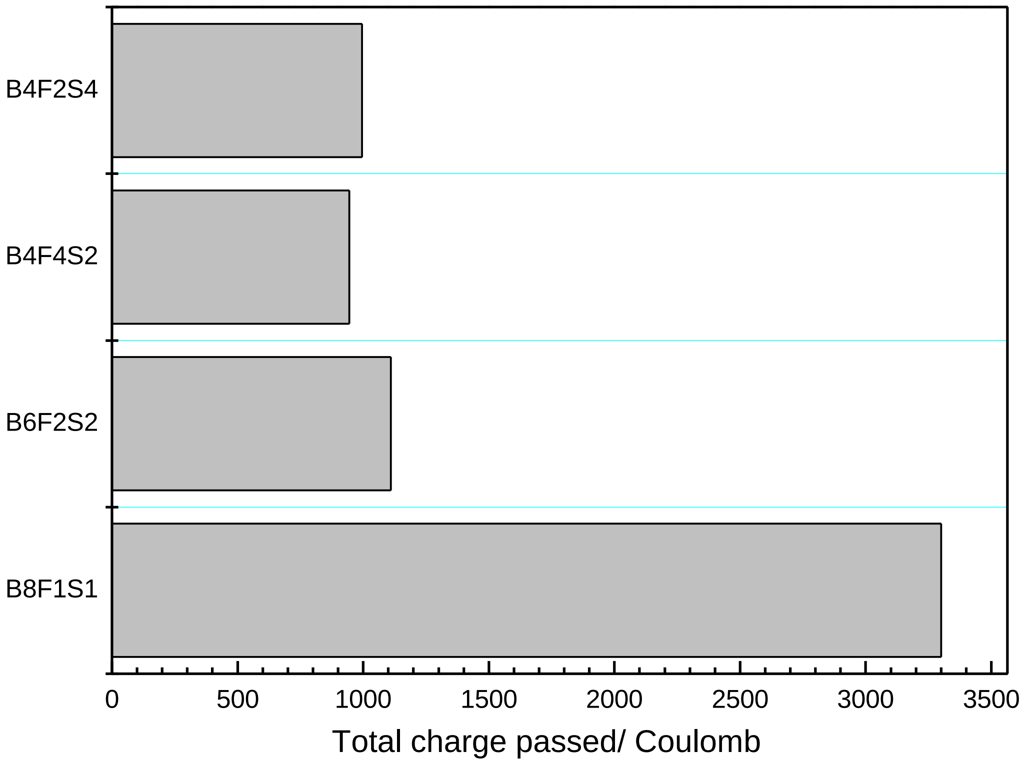

Figure 3. Total charge passed corresponding to the last ternary mixtures evaluated.

4. CONCLUSIONS

Because the main problem of the armed structures is corrosion of the embedded armor a solution with ternary mixtures which have a protective effect in terms of durability of constructions is proposed this can reduce costly repairs and it allows for greater safety of structures near shorelines.

The microstructure obtained by mixing Portland cement, fly ash and steel slag, it is of considerable importance that governs the mechanical and durability properties of concrete and it has a significant influence on the performance against corrosion of steel reinforcement in concrete. The resistance to chloride it was significantly higher as the cementitious Portland is decreased thus increasing its durability properties.

ACKNOWLEDGEMENT
This research was supported by "Vicerrectoría de investigaciones de la Universidad Militar Nueva Granada" under contract ING 1760.

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