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Effects of blast furnace slag on chloride permeability of concrete cured at elevated temperatures

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ABSTRACT

Concrete made from ordinary Portland cement continues to be used as the main construction materials because of its durability and strength characteristics in service life. But the contrary becomes the case when such concrete is exposed to aggressive environment created by the prevalence of chloride ions that are common in marine/coastal environment characterized by temperature extremes, that is peculiar to Nigeria. Hot marine and coastal environment, constitute an aggressive environment that has been found to be deleterious to the strength and durability characteristics of concrete, thus causing premature deterioration of concrete structures. Research works to reverse this trend go on continuously. This paper presents one of such works which investigates the effect of partial replacement of cement with slag on chloride permeability of concrete cured at elevated temperatures. It was found out that partial replacement of cement with slag increases the resistance of concrete to chloride penetration

Keywords: *Concrete, slag, chloride, temperature, structure*

INTRODUCTION

A durable structure is imperative if it is to survive the harsh environment that it is often exposed to (Stanish *et al*, 1997). In Nigeria, where there is no maintenance culture, it is all the more important. Nigerian hot marine coastal waters, constitute an aggressive environment that has been found to be deleterious to concrete (Jain *et al*, 2010), leading to premature deterioration that affects the strength and durability characteristics of concrete structures. One of the major forms of chemical attack on concrete is the chloride ingress. This ingress leads to corrosion of reinforcement, reduction in strength, unserviceable structures, and structures that are aesthetically poor. According to Stanish *et al* (1997), corrosion products put surrounding concrete in tension thereby causing tension cracking and spalling of the cover of concrete. The attendant adverse structural influences are: loss of bond between the reinforcement and concrete, loss of steel area, and loss of stiffness. The total effects of these is a serious durability problems because of reductions in the strength, serviceability and aesthetics of concrete structures. These may result in early repair or premature replacement of the structures. Libby (1987) and Gallegos and Quesada (1987) listed many chloride-induced structural failures that required expensive rehabilitation work. Thus to increase the service life of coastal concrete structures, increasing the resistance of concrete to chloride penetration is very necessary..

A common approach to prevent such deterioration is to prevent chloride penetration into the structure by using relatively impenetrable concrete. But impenetrability of chloride into concrete depends on its porosity which in itself is defined in terms of pore size, pore distribution and interconnectivity of the pore systems. And in increasing this resistance, it is necessary to take into cognizance the prevalence of elevated temperature curing conditions, lest it works against the durability.

As previously observed by Detwiler *et al* (1994), the effects of hot weather and/or accumulated heat of hydration can be mitigated by various measures, but only to a certain extent. Earlier works by Wee *et a*l (2000), Smith (2001), and Kumar *et a*l (2002) with cement paste containing silica fume, fly ash, and granulated blast furnace slag suggested that supplementary materials could improve the performance of concrete cured at elevated temperatures against chloride intrusion. For this work, the author chose slag because it is available as by products from the steel rolling plants in Osogbo, Aladja, and Katsina in Nigeria. And for the basis of comparison, degree of hydration, rather than the curing time was employed. Perenchio *et al* (1991) had earlier pointed out that conclusions based on constant temperature curing would not necessarily apply to concrete cured under field conditions. And previous work by Detwiler *et al* (1994) gave the number of days to reach 70% degree of hydration for Portland cement paste, cement paste containing silica fume and granulated blast furnace slag (at 30% replacement level). The number of days to reach this degree of hydration were employed for this work. This is shown in Table 1.

Table 1: Time in Days to reach 70% degree of Hydration for Portland cement and Paste; and Cement paste with 30% replacement by Slag cured at temperatures 23^{0}C, 50^{0}C, and 70^{0}C.

Paste	w/c	23^{0}C	50^{0}C	70^{0}C
Portland Cement	0.40 0.50	22 17	11 5	3 2
Slag Cement	0.40 0.50	115 72	30 17	6 4

(Source : Detwiler *et al* 1994)

This is to clearly attribute to the effects of temperature rather than maturity, whatever difference that might exist between identical mix hydrated at different temperatures. This paper investigates how slag can be used to reduce chloride penetration of concrete cured at elevated temperatures.

MATERIALS AND METHODS

The mix design after adjusting for the aggregate moisture content is shown in Table 2.

Table 2 : The Basic Mix Design

W/C Ratio	0.40	0.50
Cement	513 kg/m^3	410 kg/m^3
Sand	867 kg/m^3	954 kg/m^3
Aggregate	745 kg/m^3	745 kg/m^3
Water	201 kg/m^3	201 kg/m^3

For the slag mix, 30% of the cement was replaced by an equal mass of cement. The 30% chosen was representative of the practice where it is used. Water-Cement ratios of 0.4 and 0.5, which are also representative of the practice was also selected. The concretes were mixed for a period of 3minutes in a pan mixer with a capacity of 12 litres. For high temperature mixing, the materials, moulds, and blender were stored overnight in an oven maintained at a temperature of about 40^{0}C. The mixer was also preheated to a temperature of between 35^{0}C and 40^{0}C. These precautions were taken to minimize the effects of temperature. Four 100 x 200mm cylinders were cast for each of the mix. Each cylinder was compacted in three layers by means of an external vibrator. For the high curing temperatures samples, they were immediately placed in an insulated container after compaction to prevent heat loss while in transit to the curing drum. Cylindrical drums maintained at 50^{0}C and 70^{0}C respectively were used. In addition, the drums were kept at 100% relative humidity to promote hydration. The samples were then cured at temperatures of 23^{0}C, 50^{0}C, and 70^{0}C to approximately 70% degree of hydration, according to the number of days as determined by Detwiler *et al* (1994), and presented in Table 1. To perform the chloride permeability test, the concrete cylinders were taken out of the curing drums, once the required 70% degree of hydration had been reached, and allowed to dry overnight. All loose materials clinging to the sides of the cylinders were brushed away. Each concrete cylinder was then cut into three slices. The slices were marked top, middle, and bottom to indicate their original positions. The test equipment for the AASHTO T277- 83 method of chloride permeability test uses a 60Volts DC field. It incorporates in itself two receptacles. One receptacle was filled with 0.3M NaOH solutions to serve as anode, and the other receptacle was filled with 3% NaCl solution to serve as the cathode. On each of the slices, the test was allowed to run for 6hours , and the charge passed, in coulombs, through the specimen was automatically recorded. If within 90minutes, there were at least 3000coulombs, or 6000coulombs in six hours, the test was discontinued to prevent damage to the equipment. The charge for six hours is then linearly interpolated in accordance to AASHTO recommendations. A more detail discussion on this method had been described by Fapohunda (1992).

RESULTS

The charge that passed, in coulombs, in six hours through the specimens is shown in Table 3. The values represent the average of two test runs which did not vary by more than 20% as per AASTHO recommendations. Correlation Table for AASHTO Test interpretation is shown in Appendix A.

Table 3: Charges passed (coulombs) in 6hrs

Mix	W/C	23^{o}C	50^{o}C	70^{o}C
Portland Cement	0.40	4700	12000*	18000*
	0.50	9800	13000*	16000*
Slag Cement	0.40	1300	1500	4300
	0.50	1700	2200	5400

* Extrapolated values.

DISCUSSIONS

From the values given in Table 3, it can be seen that for all the concrete mixes, increased curing temperature brings about increased in the amount of charge that passed through the specimen, irrespective of the water-cement ratios. This means increased reduction in ability to resist chloride penetration. That is, high temperature curing results in more porous concrete. It can also be seen that, chloride penetration measured by the amount of charge passed increased with curing temperature for all the mixes At any given temperature, the slag concrete performed better than Portland cement concrete. This result is consistent with earlier results obtained by Smith (2001). The reason being the fact that the presence of Slag brings about reduction in the amount of available calcium hydroxide, by reacting with it, to form additional calcium silicate hydrate (CSH), making the concrete chemically stable and with a finer pore structure relative to ordinary Portland cement concrete. The fine pore structure limit the ability of chlorides to diffuse through the slag concrete. Also increasing the water-cement ratios from 0.40 to 0.50 brought about increased in chloride penetration. This in line with the data in Table 1 in which longer periods are required to reach 70% degree of hydration for paste with lower water-cement ratios. A longer period of hydration will allow more time for the products of hydration to diffuse uniformly through the matrix (Verbeck and Helmuth, 1968), so that a relatively fine and dense matrix results. This again suggested that higher water-cement ratios resulted in porous concrete. The higher the water-cement ratios, the higher the permeability. This can be adduced to the presence of more capillary pores (Neville, 1995), which the presence of more water encourages.

CONCLUSIONS AND RECCOMMENDATIONS

From the results of this work, the following conclusions are made:

1) At equal degree of hydration the resistance to chloride penetration of Portland cement concrete and slag concrete is reduced by curing at higher temperature
2) A concrete containing 30% slag cured at 70^{o}C is less permeable to chloride ingress than Portland cement concrete cured at 23^{o}C, with same water-cement ratio and degree of hydration.

3) Increased water-cement ratios results in increased permeability to chlorides, other conditions being equal
4) The use of slag as partial replacement for Portland cement results in improved resistance to chloride penetration for concrete cured at 23°C, 50°C, and 70°C.
5) Although usage of slag as replacement for Portland cement in concrete production is effective in preventing chloride penetration, it is not to be used as an indicator service life in a saline environment, which is a function of many factors including chloride penetration resistivity. It simply indicates the relative ease with which chloride ions can migrate through different concrete, and need to control the curing process if durability is to be achieved. Also more research would have to be done to determine the optimum dosage level

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APPENDIX A: AASHTO Correlation Table

Charge Passed (Coulombs)	Chloride Permeability	Concrete Type
> 4000	High	High w/c ratio (> 0.6) Conventional PCC*
2000 – 4000	Moderate	Moderate w/c ratio (0.40 - 0.50) Conventional PCC*
1000 – 2000	Low	Low w/c ratio (0.40) Conventional PCC*
100 – 1000	Very Low	Latex-modified concrete, Internally sealed concrete
< 100	Negligible	Polymer impregnated concrete polymer concrete

**Portland cement concrete*