Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2015
(ICMERE2015) 26 – 29 November, 2015, Chittagong, Bangladesh

ICMERE2015-PI-194

PROSPECT OF SLAG IN MAKING STRUCTURAL CONCRETE FOR MARINE ENVIRONMENT

Md. Moinul Islam[1,*] and Md. Saiful Islam[1]

[1-2] Department of Civil Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, Bangladesh
[1,*]moinul91@yahoo.com, [2]msislamcuet@yahoo.com

Abstract*-Ground granulated blast furnace slag (GGBFS), a by-product of the steel manufacturing industry, being used as an effective partial cement replacement material, has already been proven to improve several performance characteristics of concrete in plain water. This paper investigates the performance of slag concrete exposed to artificially made simulated tidal zone marine condition upto the exposure periods of 180 days. Concrete specimens of 100 mm cubical size were cast using OPC with four cement replacement levels (10%, 20%, 30% and 40%) of slag by weight and precured for 28 days in plain water before exposure to seawater environment under submerged (SUB) as well as alternate wetting drying (AWD) condition. The specimens were taken out periodically and subjected to compressive strength and ultrasonic pulse velocity test. After 180 days exposure and for AWD state, the losses in compressive strength as compared to plain water cured specimens of similar age are reported to be around 7% for OPC and 4% for 70:30 slag concrete indicating the better resistance of slag concrete against strength deterioration in marine environment. Slag concrete of mix ratio 70:30 and 28 days precuring is found to be the most effective in resisting the adverse effect of marine environment.*

Keywords: Compressive strength, Durability, Marine environment, Slag, Ultrasonic pulse velocity.

1. INTRODUCTION

Concrete is the most commonly used construction materials all over the world since long time. Typically concrete contains about 15% of cement by mass. Cement production is reported to about 3 billion tons in the year of 2010, expected to around 5 billion tons in the year of 2040 [1]. Generally about one ton of carbon dioxide is generated due to one ton of cement production. So it can be estimated that 5 billion tons of CO2 will be added to green house gasses from cement production in the year of 2050. It is about 7% of total green house gasses produced globally [2]. So concrete should be durable over its entire life span so as to reduce these negative influences to the environment.

Marine environment is not just over the sea, but it could be deemed to be extending over the coast and neighborhood of tidal crecks, backwaters and estuaries [3]. Broadly it covers the area where concrete becomes wet with seawater and wherever the wind will carry salt-water spray, which may be as far as 1 km inland [4]. In the marine environment concrete structures deteriorate mainly due to the corrosion of steel bars in concrete caused by the chloride and sulfate ingress form seawater. Deterioration of concrete due to chloride and sulfate attack is a time-based problem. Both chloride and sulfate induced deterioration of concrete are the subject of main interest for researchers dealing with durability and long-term performance of concrete. The ionic radii of chloride and sulfate ions are 1.81 Å and 2.30 Å respectively [5], whereas the diffusion coefficient for sulfate is 2*10-8 cm2 S-1 and for chloride is 3*10-7 cm2 S-1 [6]. Due to larger diffusion coefficient, chloride ions penetrate at a faster rate than that of sulfate. On the other hand as sulfate holds two negative ions higher than that of chloride (one negative ion), its action on deterioration is more dangerous. Thus both chloride and sulfate penetration may have detrimental effects on concrete exposed to marine environment.

Portland cement substitution by supplementary cementitious materials also called mineral admixtures or mineral additives such as natural pozzolana, slag, coal fly ash, silica fume, rice husk ash and wood fly ash is one of viable alternatives [7]. It is generally agreed that with the proper selection of admixtures, mixture proportioning and curing, supplementary cementitious materials can noticeably improve the durability of concrete [8]. Recently there has been a growing trend for the use of supplementary cementitious materials, whether natural waste or by products, in the production of composite cement because of ecological, economical and diversified product quality reason [9]. Slag, a byproduct of the transformation of iron ore into pig iron in a blast furnace or electric arc furnace, is one of these materials whose use in cement manufacture goes to as far back as 1880 [10]. Since then its use has expanded because it has various advantages over other cementitious materials.

Slag has a relatively constant chemical composition compared to fly ash, silica fume, pozzolanas etc. Besides it has advantages like low heat of hydration, high chloride, sulfate and acid resistance, better workability, higher ultimate strength etc [11]. These properties are beneficial for specialized applications such as hydroelectric dams, large bridges, power stations, metro system, motorways and harbors [12]. Steel making industries are also facing a severe problem to dispose by-products. Therefore utilization of this by products will give several great benefits, such as saving of cements, solving disposal problem, making long term durable concrete and reduction of CO2 emission. The generated Ca(OH)2 in the hydration process of Portland cement reacts with the slag particles and improve the microstructure of concrete.

2. EXPERIMENTAL PROGRAM

The experimental program was planned to study the effect of slag as partial replacement of cement on the strength characteristics of hardened concrete at different curing ages.

2.1 Materials Used

(a) Cement: ASTM Type-I Portland Cement was used as binding material. Chemical compositions of OPC are given in **Table 1**.

(b) Slag: Ground granulated Blast Furnace slag (GGBFS) was used as supplementary cementitious material. Chemical compositions of slag obtained by using X-ray fluorescence study is shown in **Table 1**.

(c) Aggregate: 12.5 mm downgraded crushed stone, with fineness modulus 6.68 and specific gravity 2.69, was used as coarse aggregate. Locally available natural sand passing through 4.75 mm sieve and retained on 0.075 mm sieve with fineness modulus 2.51 and specific gravity 2.64 was used as fine aggregate.

Table 1: Chemical Composition (%) of OPC and Slag

Constituents	Composition	OPC	Slag
Calcium Oxide	CaO	64.18	34.42
Silicon Di-Oxide	SiO_2	20.80	51.49
Aluminum Oxide	Al_2O_3	5.22	31.60
Ferric Oxide	Fe_2O_3	3.15	2.80
Magnesium Oxide	MgO	1.16	0.28
Sulfur Tri-Oxide	SO_3	2.19	0.19
Sodium Oxide	Na_2O	--	0.18
Loss on Ignition	--	1.70	4.2
Insoluble Residue	--	0.6	--

2.2 Mix Design and Sample Preparation

Four different replacement level of cement by slag i.e. cement slag mix ratio (90:10, 80:20, 70:30, 60:40) were used as binding material. Plain concrete specimens i.e. Cement slag mix ratio of 100:0 were also cast as reference concrete. Slag concrete means the concrete made by using cement and slag as cementitious material with sand, stone chips and water. A particular mix ratio of 1:1.5:3 and water/cement ratio of 0.4 was used for making test specimen A total of 300 no's of cubical specimens of 100 mm size from five different types of slag concretes were cast as per ASTM C39. The specimens were demoulded after 24 hours of casting and cured in plain water at 27±2°C. Plain water and artificial seawater of concentration 1T was used as curing water. Artificial seawater was simulated in laboratory by mixing tap water with exact amount and proportion of different sea salt compounds as specified in **Table 2.** Some of the specimens were subjected to alternate wetting-drying cycles (12 hours wetting followed by 12 hours drying) to simulate the tidal marine zone condition.

Table 2: Specified salt contents of artificial seawater used in experimental program [13]

Salt	Amount (gm)	Remarks
Sodium chloride	27.2	These amounts of salts were dissolved in plain water to prepare 1000 gm of seawater of 1T concentration
Magnesium chloride	3.8	
Magnesium sulfate	1.7	
Calcium sulfate	1.2	
Potassium sulfate	0.9	
Calcium carbonate	0.1	
Magnesium bromide	0.1	
Total	**35.00**	

2.3 Test Conducted

(a) Strength tests: Compressive strength of concrete specimens was tested at the ages of 30, 60, 90 and 180 days in accordance with the BS EN 12390-3:2009. Reported compressive strength was taken as the average of three tests results.

(b) Ultrasonic Pulse velocity: After specific exposure period, non-destructive test ultrasonic pulse velocity was performed in accordance with the ASTM C597. Cubical specimens of 100 mm size were required for this test. The average result of three test specimens was taken as the representative data.

3. RESULT AND DISCUSSIONS

3.1 Compressive Strength

The compressive strengths of OPC and slag concretes exposed to different marine environment, have been graphically presented in Fig.1 and Fig.2. Also for the ease of comparison, the relative compressive strengths are plotted in Fig.3 and Fig.4. Compressive strengths corresponding to "0" curing age represent the 28 days plain water cured strength. In case of plain water curing, the specimens for compressive strength were kept in submerged condition only and for seawater curing, both submerged and alternate wetting-drying state of exposure conditions were used. In case of plain water curing, OPC concrete shows higher strength at initial ages than that for slag concrete. But for relatively longer curing periods, the differences between the results are seen to be decreased. In case of plain water curing, for OPC concrete, compressive strength for 30 days exposure period is 34.7 MPa whereas this value for slag concrete of cement slag mix ratio 90:10, 80:20, 70:30, 60:40 are 32.8, 31.6, 30.6, 29.5 MPa respectively. But after 180 days curing, strength values are 42.4 MPa for OPC and 41.1, 40.5, 41.3, 39.7 MPa for slag concrete respectively. This is due to slow hydration rate of slag and for this gain in strength at early age is comparatively lower although after longer curing period; slag concrete attains almost the same strength as that of OPC concrete.

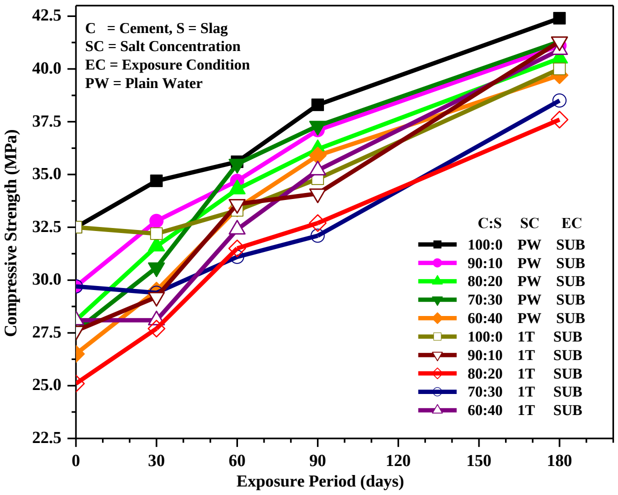

Fig.1: Compressive Strength - Exposure Period Relation for Slag Concrete Exposed to SW

Fig. 1

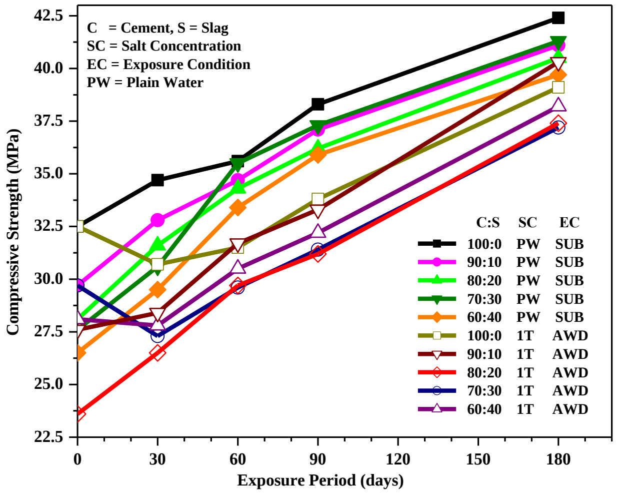

Fig.2: Compressive Strength - Exposure Period Relation for Slag Concrete Exposed to SW

Fig.2

Test results also show that compressive strength of both OPC and slag concrete is reduced when it is exposed to seawater as compared to plain water curing. On the other hand, compressive strength test results of concrete cured in seawater and under submerged condition show relatively higher values than those for alternate wetting-drying (AWD) condition. In case of slag concrete with cement slag mix ratio 80:20 and 70:30 cured in seawater, compressive strength for submerged condition are 28.1, 32.4, 35.2, 40.9 and 29.2, 33.6, 34.1, 41.3 Mpa for 30, 60, 90 and 180 days curing periods respectively; whereas the corresponding values are 27.8, 30.5, 32.2, 38.2 and 28.4, 31.7, 33.3, 40.3 Mpa respectively for alternate wetting-drying condition. This is due to the fact that during wetting cycle, seawater enters into the pore spaces of the concrete and during drying cycles the penetrated salt ions become dried up and react with the cement hydrates that result in the formation of expansive compound and leads to the strength deterioration. Also during drying cycle, moisture inside the concrete may come out form the specimens. As a result normal hydration process is disturbed.

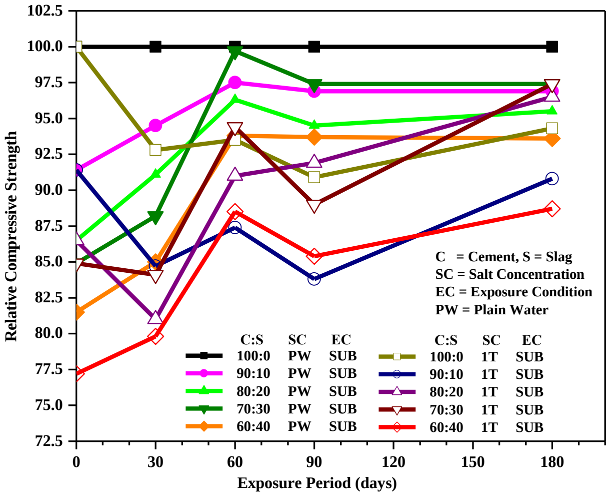

Fig.3: Relative Compressive Strength - Exposure Period Relation for Slag Concrete Exposed to SW

Fig.3

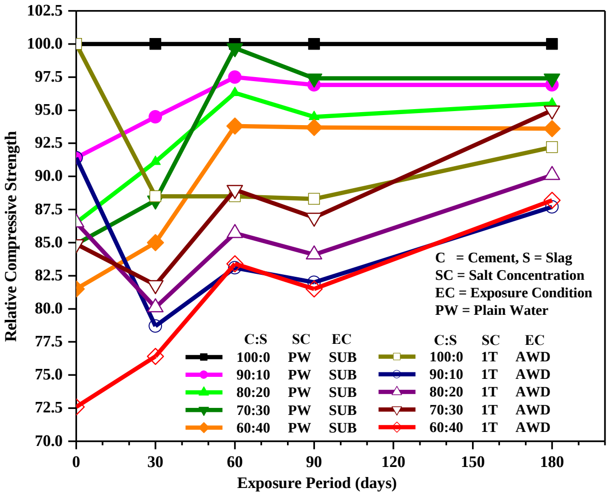

Fig.4: Relative Compressive Strength - Exposure Period Relation for Slag Concrete Exposed to SW

Fig.4

The loss in compressive strengths when compared to 180 days compressive strength of plain water cured OPC concrete, are observed to lie in the range of 6 to 9% for OPC concrete, 10 to 13% for 90:10, 4 to 8% for 80:20, 3 to 5% for 70:30 and 10 to 12% for 60:40 slag concrete when exposed to seawater of different concentration. Cause for strength reduction is the formation of expansive compounds when concrete specimens are cured in seawater. Seawater enters into concrete and reacts with hydrated product of cement and slag, forming ettringite or frields salt. Due to formation of these expansive materials, micro cracks are developed inside the concrete and their subsequent propagation with the progress of hydration weakens the bond between hydrated product and aggregate particles. Ultimate result is the deterioration of concrete and the loss in compressive strength.

From all the above discussion it is clear that slag concrete made with cement slag mix ratio 70:30 shows the highest strength development at larger curing periods in any curing condition. This is due to the higher degree of fineness of slag, which after hydration with the formation of secondary gel blocks the pores inside the concrete thereby reducing its permeability. As a result entrance of seawater in concrete is restricted and the amount of salt ion penetration is thereby reduced. Thus the rate of deterioration is seen to be decreased and ultimately leads to the development of higher concrete compressive strength.

3.2 Ultrasonic Pulse Velocity

Fig.5 and Fig.6 shows the relationship between ultrasonic pulse velocity of slag concretes and exposure periods for different state of exposure.

Fig.4

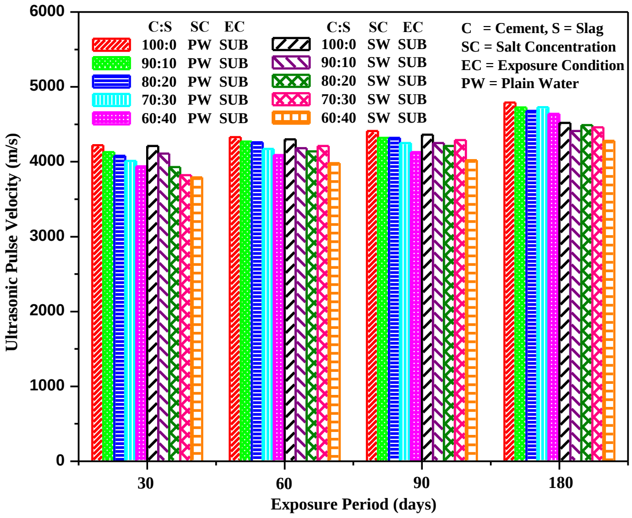

Fig.5: Ultrasonic Pulse Velocity - Exposure Period Relation for Slag Concrete Exposed to SW

Fig.5

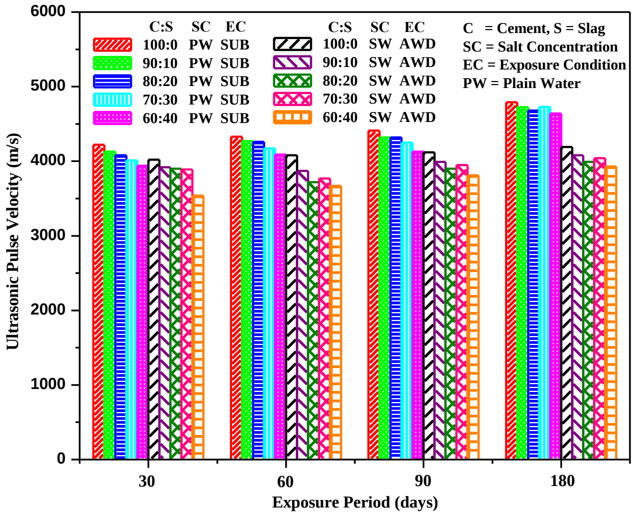

Fig.6: Ultrasonic Pulse Velocity - Exposure Period Relation for Slag Concrete Exposed to SW

Fig.6

From Figure it is evident that in plain water environment, OPC concrete shows higher UPV value than slag concrete. For curing period of 30 days, UPV value for OPC concrete is 4220 m/s in plain water environment, whereas the corresponding values are 4130, 4080, 4010 and 3940 m/s for slag concretes of cement slag mix ratio of 90:10, 80:20, 70:30 and 60:40 respectively. This is because that the hydration rate for OPC concrete is higher than that of slag concrete. At initial ages, differences between these values are higher but later ages the differences become smaller. After 30 days and 180 days of exposure period, the UPV values are 4210 and 4520 m/s respectively for OPC concrete cured under seawater of 1T concentration and submerged condition; whereas the corresponding values for slag concrete of cement slag mix ratio 70:30 and 60:40 are 3820, 3790 m/s for 30 days and 4460, 4280 m/s for 180 days of curing in sea water of 1T concentration respectively. This is due to slow hydration of slag in slag concrete. At relatively longer curing periods, complete hydration of slag takes place that produce an impermeable concrete, which prevents the easy penetration of seawater into the concrete. As a result, the rate of deterioration becomes slower and the corresponding UPV value increases.

It is also observed that UPV values are higher for concrete specimen for submerged condition than that for alternate wetting-drying condition. After 90 days curing, for slag concrete of cement slag mix ratio 90:10, 80:20 and 70:30 cured in seawater of 1T concentration in submerged condition, UPV values are 4250, 4210, 4290 m/s and that for alternate wetting-drying condition are 4080, 3990, 4040 m/s respectively. Actually during wetting condition, sea salts enter inside the concrete and in drying state, it is dried up. Thus the molecules of salts remaining inside the concrete lead to deterioration of concrete and consequently the UPV values decreases. From the UPV study, it is clear that for longer exposure period, slag concrete of cement slag mix ratio of 70:30 provides better resistance against deterioration.

4. CONSLUSIONS:

Based on the results of the investigation conducted on slag concrete made with different level of cement replacement by slag as mentioned and cured up to 180 days in marine environment, the following conclusions can be drawn:

(1) At the initial age of curing, strength gaining rate for slag concrete specimens is relatively lower as compared to corresponding OPC concrete for both plain water and sea water curing.

(2) Compressive strength of concretes specimens is observed to be decreased with time when exposed to sea water.

(3) Concrete specimens exposed to AWD state in sea water exhibited lower compressive strength as well as Ultrasonic Pulse Velocity compared to SUB state of curing.

(4) Slag concrete made by mixing 30% of slag, exhibited the best results with respect to compressive strength.

(5) Slag concrete with 30% cement replacement showed relatively lower reduction of UPV as compared to OPC concrete. This UPV values support the compression strength results of concrete exposed to sea water.

(6) Use of slag as partial replacement of cement can markedly reduces the cost of cement production which otherwise been dumped making environmental hazard.

7. REFERENCES

[1] M. Taylor, C. Tam, and D. Gielen, “Energy Efficiency and CO_2 Emissions from the Global Cement Industry”, in workshop on *Energy Efficiency and CO_2 Emission Reduction Potentials and Policies in the Cement Industry,* IEA, Paris, 4-5 September 2006.

[2] Mohammed, T. U., Hamada, H., and Yamaji, T., Long-term Durability of Concrete Made with Slag Cements Under Marine Environment, *Report of the Port and Airport research Institute,* Vol-42, No.2, 2006.

[3] Concrete in marine environment, Editorial, *Indian Concrete Journal (IJC),* pp. 357-358, August, 1990.

[4] Geymayr, G. W., Repair of concrete in tropical marine environment, Performance of Concrete in Marine Environment, *ACI Publication*, SP-65, pp. 527-556, August, 1980.

[5] Thangavel K., Balasubramanian T.M. and Rengasamy N.S, ‘Fixing of chloride in concrete using admixtures’, Inian Concrete Journal, Vol. 74, pp. 203-206, 2000.

[6] Tumidajski, P. J., Chan, G. W and Philipose, K. E., An Effective Diffusivity for Sulfate Transport into Concrete, *Cement and Concrete Research,* Vol. 25 No. 6, pp. 1159-1163, 1995.

[7] Naik, T.R., "Use of Industrial By-Product in Cement Based Materials", Proceedings from *Creating with Concrete,* International congress, Concrete technology Unit, University of Dundee, Scotland, Septemner,1999.

[8] Zichao. Wu., and Naik, T.R., Chemically Activated Blended Cement, *ACI materials Journal*, Vol.100, No.5, September-October 2003, pp. 434-440.

[9] S. Parniani, M. W. Hussin and F. R. Mansour, “Compressive strength of high volume slag cement concrete in high temperature curing” *Advanced Materials Research,* Vol.287, pp 793-796, 2011.

[10] A. Dubey, R. Chandak, R.K.Y Adav, “Effect of blast furnace slag powder on compressive strength of concrete” *International Journal of Scientific & Engineering Research*, Vol.3, No.8, August, 2012..

[11] Y. Zandi and V. Akpinar, “An Experimental Study on Separately round and together Grinding Portland Slag Cements Strength Properties” *Research Journal of Recent Sciences,* Vol.1, No.4, pp. 27-40, April, 2012.

[12] Oner, M., Erdogdu, K., and Gunlu, A., "Effect of Components fineness on strength of blast furnace slag cement", *Cement and Concrete Research,* Vol. 33, No., pp. 463-469, April 2003.

[13] Mayers, J. J., Holm, G. H., and Mc Allister, R. F., The Hand Book of Ocean and Underwater Engineering, McGraw-Hill London, pp. 1094, 1969.