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# THE UPV STUDY OF SLAG CONCRETE IN SALINE ENVIRONMENT

**Md. Moinul Islam[1*], Mohammad Rafiqul Islam[2], Amrita Das[3] and Md. Saiful Islam[1]**

[1]Department of Civil Engineering, Chittagong University of Engineering and Technology, Bangladesh.
[2]Department of Civil Engineering, IUBAT, Dhaka, Bangladesh.
[3]Department of Civil Engineering, Southern University, Chittagong, Bangladesh.
[*]moinul91@yahoo.com, rafiq_cuet@yahoo.com, amrita_cuet@yahoo.com, msislam@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 durability characteristics of concrete. The study covers the strength as well as Ultrasonic pulse velocity (UPV) of slag concrete in saline water over a period of 12 months. Four different types of slag concrete of cement slag mix 100:0, 85:15, 70:30 and 55:45 have been studied in plain water and saline water of salt concentration 1T, 3T and 5T over the periods of 1, 3, 6 and 12 months. Concrete specimens of 100 mm cubical size were cast and precured for 28 days in plain water before exposure to different saline water. The specimens were taken out periodically and subjected to compressive strength and UPV tests. Slag concrete of mix 70:30 is found to exhibit around 3% higher UPV and 4% lower strength deterioration as compared to OPC concrete in the same curing environment.

**Keywords:** Compressive strength, Durability, Slag, Saline water, Ultrasonic pulse velocity.

## 1. INTRODUCTION

Concrete is the most commonly used construction materials all over the world since long time ago. Due to rapid development of infrastructures of developing countries, it is expected that in year of 2050, annual consumption of concrete would reach 18 billion tons per year. Typically concrete contains about 15% of cement by mass. So to produce such amount of concrete, 5 billion tons of cement will be necessary [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 $CO_2$ will be added to green house gasses from cement production. It is about 7% of total green house gasses produced globally [2]. Therefore it is clear that concrete should be durable to reduce these negative influences to the environment. When the concrete structures are placed in saline water, it may deteriorate due to the corrosion of steel bars in concrete caused by the chloride and sulfate ingress form salt present in saline water. The transport properties of the concrete including permeability, diffusion, capillary suction, osmosis and electro migration have also been affected due to presence of saline water [3]. Transport properties affect the durability of concrete because they control the supply of aggressive species such as chloride and sulfates responsible for deterioration.

Chloride ions present in saline water generally attribute to the formation of expansive product named Friedls salt ($3CaO.Al_2O_3.CaCl_2.10H_2O$)(Calcium chloroaluminate). This salt has a property of low to medium expansion. Also the formation of excess calcium chloride, which may leach out, results in increased permeability of concrete [4]. Sulfate ions present in saline water is generally attributed to formation of expansive ettringite ($3CaO.Al_2O_3.3CaSO_4.\ 31H_2O$) (Calcium aluminate sulfate) [5]. Both ettringite and gypsum occupy a greater volume as large as 20% after crystallization in the pores of concrete than the compounds they replace [6]. Thus the crystalline product inducing stresses inside the concrete may result in the surface cracking known as softening type of attack.

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. Slag, a by product 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 manufacturing goes to as far back as 1880 [7]. 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 [8]. Besides it has advantages like low heat of hydration, high chloride, sulfate and acid resistance, better workability, higher ultimate strength etc. 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 and solving disposal problem, making long term durable concrete and reduction of $CO_2$ emission. The generated $Ca(OH)_2$ in the hydration process of Portland cement reacts with the slag particles and improve the microstructure. Traditionally slag cement has been produced by intergrinding cement clinker with slag in tube mills [9].

Ultrasonic pulse velocity method is a non-destructive testing (NDT) method, frequently used to estimate the quality of concrete. This method is typically based on measurement of the propagation of velocity, which is closely related to mechanical properties and more directly, to the modulus of elasticity. The measurement of the ultrasonic compressional wave velocity has been used for a long time to evaluate the setting and hardening of cementitious systems. An advanced process in the area of concrete quality control needs proper surveillance by reliable and as much as possible-objective measurements. A possible solution is the ultrasound technique, where amplitude, velocity and frequency variations depending on the age of the material can be observed during the hardening process. The property of cementitious material is changing from a suspension to a solid during the stiffening process caused by the hydration of the cement-matrix. Among the more advanced techniques, only the UPV technique has been standardized (ASTM C 597-83 "Standard Test Method for Pulse Velocity through Concrete"). This method is used to assess the pulse velocity of mortars and compared them to the destructive method results.

In this study, the effect of slag on the UPV and compressive strength of concrete for different curing environment and periods are investigated. The test data provide the relationship between UPV and compressive strength for different types/mix of concrete. Various slag cement ratios as well as saline water of different concentration have been used to get the idea for optimum mix of slag in making durable concrete. This will also alleviate economic, social and environmental problems caused by slag.

## 2. EXPERIMENTAL PROGRAM

This experimental work was carried out to investigate the effect of slag on characteristics of concrete exposed to saline environment.

### 2.1 Materials Used

**Cement:** ASTM Type-I Ordinary Portland cement (OPC) was used.

**Slag:** Ground granulated blast furnace slag (GGBFS) was used for this study. Chemical compositions of OPC and Slag are given in **Table 1.**

**Aggregates:** The coarse aggregate used was crushed stone with a maximum nominal size of 12.5 mm, having specific gravity 2.70, fineness modulus 6.58 and unit weight 1625 kg/m$^3$; whereas the fine aggregate was river sand, having specific gravity 2.61, fineness modulus 2.51 and unit weight 1495 kg/m$^3$.

### 2.2 Variable Details

In the present investigation, slag has been used as blended admixture. A particular concrete mix ratio of 1:1.5:3 and water/cement ratio of 0.45 were used for making test specimen. Different variables used are listed bellow:

(a) Plain water (PW) and artificial saline water (SW) of three different concentration 1T, 3T and 5T was used as curing water. Saline water is simulated in laboratory by mixing plain water with exact amount and proportion of different chemical compounds of sea water as specified in **Table 2.**

**Table 1: Chemical composition of ordinary Portland cement and slag**

| Chemical Compositions | ASTM Type-I Cement (%) | Slag (%) |
|---|---|---|
| Calcium Oxide, CaO | 64.50 | 41.3 |
| Silicon Dioxide, $SiO_2$ | 20.58 | 32.7 |
| Aluminum Oxide, $Al_2O_3$ | 6.42 | 18.4 |
| Ferric Oxide, $Fe_2O_3$ | 4.53 | 1.3 |
| Magnesium Oxide, MgO | 1.12 | 4.2 |
| Sulfur Trioxide, $SO_3$ | 1.45 | -- |
| Sulfer, S | -- | 1.8 |
| Loss on Ignition | 0.9 | -- |
| Insoluble Residue | 0.5 | -- |

**-- = not measured items**.

**Table 2: Specified salt contents of artificial seawater used in experimental program** [10]

| Salt | Chemical formula | Amount (gm) | Remarks |
|---|---|---|---|
| Sodium chloride | NaCl | 27.2 | These amounts of salts were dissolved in plain water to prepare 1000 gm of seawater of 1T concentration |
| Magnesium chloride | $MgCl_2$ | 3.8 | |
| Magnesium sulfate | $MgSO_4$ | 1.7 | |
| Calcium sulfate | $CaSO_4$ | 1.2 | |
| Potassium sulfate | $K_2SO_4$ | 0.9 | |
| Calcium carbonate | $CaCO_3$ | 0.1 | |
| Magnesium bromide | $MgBr_2$ | 0.1 | |
| **Total** | | **35.00** | |

(b) Four different grades of concrete with cement slag ratios 100:0, 85:15, 70:30 and 55:45 were used.

(c) Four different exposure periods of 1, 3, 6 and 12 months were used for this investigation. The specimens were periodically tested for compressive strength and ultrasonic pulse velocity to assess the effect of slag on characteristics of concrete.

## 2.3 Specimen Preparation and Curing

Around 200 cubical specimens of 100 mm size were prepared for the entire investigation program. All the specimens were precured for 28 days in plain water at 27°C. After that, they were placed in saline water of different concentrations (1T, 3T, 5T) as well as plain water for different exposure periods (1, 3, 6, 12 months).

## 3. RESULT AND DISCUSSIONS

The concrete specimens made from OPC and slag are exposed to plain water and saline water of different concentration for various exposure periods. Plain water cured concrete is considered as datum and used to compare the detrimental effect of salt on concrete specimens.

## 3.1 Compressive Strength

The compressive strengths of OPC and slag concretes exposed to different saline water, have been graphically represented in **Figure 1 and 2**. Also for the ease of comparison, the relative compressive strengths are plotted in **Figure 3**. Compressive strengths corresponding to "0" month curing age represent the 28 days plain water cured strength. 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 strength results are seen to be decreased. In case of plain water curing, for OPC concrete, compressive strength for 1 month exposure period is 25.7 MPa whereas this value for slag concrete of cement slag mix 70:30 is 23.7 MPa. After 12 months curing, the corresponding compressive strength values are 37 MPa and 36.2 MPa 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. Turkmen reported the same result for GGBFS [11]. Test results also show that compressive strength of both OPC and slag concrete is reduced when it is exposed to saline water as compared to plain water curing. After 12 months exposure periods, slag concrete of cement slag mix 70:30 cured under plain water shows a compressive strength of 36.2 MPa, where as the corresponding values are 33.2, 32.4 and 30.1 MPa for the same concrete exposed to saline water of 1T, 3T and 5T concentration. Thus it is also clear that compressive strength is reduced with the increase in seawater concentrations although the nature of variation is not proportional.

Effect of salts present in saline water on the compressive strength of slag concrete can also be explained in terms of relative strength. In case of 1 month curing, reduction of strength with respect to plain water curing is 5.8%, 8.6% and 17.5% for OPC concrete cured in seawater of 1T, 3T and 5T concentration, whereas the corresponding values are 8.6%, 15.2%,21.8% for 85:15 slag concrete, 10.9%, 16.3%, 26.8% for 70:30 slag concrete and 10.5%, 14.4%, 19.5% for 55:45 slag concrete. But after 12 months curing, the strength reduction values are 10.3%, 12.7%, 19.5% for OPC concrete, 13%, 16.5%, 20.3% for 85:15 slag concrete, 8.1%, 10.3%, 16.5% for 70:30 slag concrete and 10.3%, 12.7%, 20.5% for 55:45 slag concrete for same curing condition.

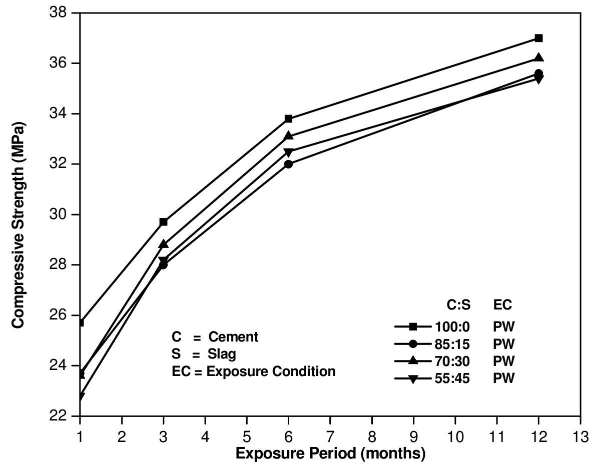


**Fig.1: Compressive strength - Exposure time relation for slag concretes exposed to plain water**

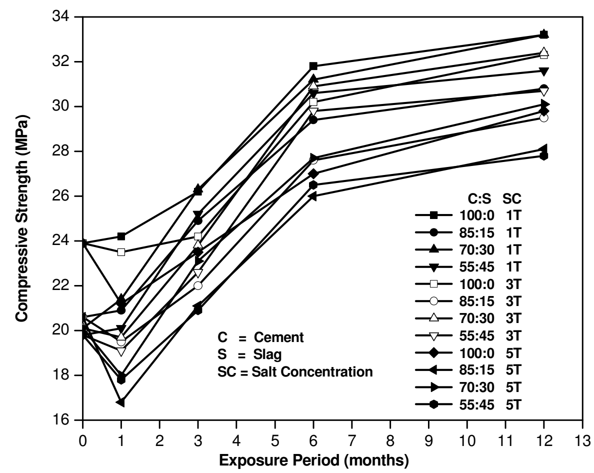


**Fig.2: Compressive strength - Exposure time relation for slag concretes exposed to different saline water**

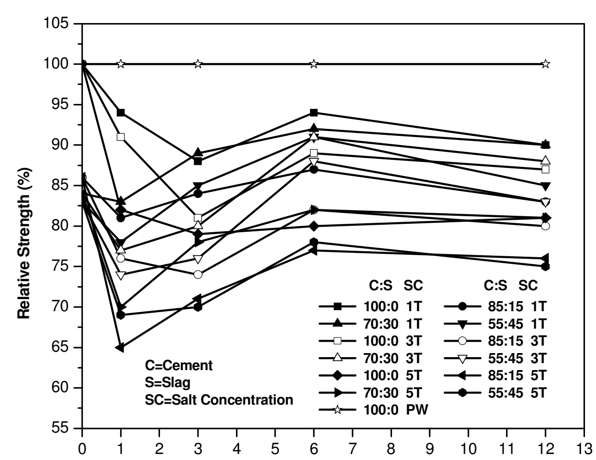


**Fig.3: Relative strength-Exposure time relation for slag concrete exposed to different saline water**

The loss in compressive strengths when compared to 12 months compressive strength of plain water cured OPC concrete, are observed to lie in the range of 10% to 19% for OPC concrete, 13% to 20% for 85:15, 8% to 16% for 70:30 and 10% to 21% for 55:45 slag concrete when exposed to saline water of different concentration. Cause for strength reduction may be due to the formation of expansive compounds when concrete specimens are cured in saline water. Salts present in saline water enter into concrete and reacts with hydrated product of cement and slag, forming ettringite or friedls 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 the above discussion it is clear that slag concrete shows relatively higher resistance against strength deterioration when cured in saline water of different concentration for various curing periods. Among all the concretes, slag concrete made with cement slag mix 70:30 shows the lowest strength deterioration and highest strength development at larger curing periods in any curing condition. This is due to the higher degree of fineness of slag and its optimum amount, which after hydration blocks the pores inside the concrete thereby reducing its permeability. As a result, entrance of saline water 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 higher concrete compressive strength.

### 3.2 Ultrasonic Pulse Velocity

**Figure 4 and 5** shows the relationship between ultrasonic pulse velocity of different slag concretes and exposure periods for different curing environments. From Figure it is evident that in plain water environment, OPC concrete shows higher UPV value than slag concrete. For curing period of 1 month, UPV value for OPC concrete is 3590 m/s in plain water environment, whereas the corresponding values are 3480, 3460 and 3380 m/s for slag concretes of cement slag mix ratio of 85:15, 70:30 and 55:45. At initial ages, differences between UPV values for various concrete are higher but later ages the differences become smaller. After 1 month exposure, the UPV value is 3190 m/s and 3010 m/s for OPC and 70:30 slag concrete cured in saline water of 5T concentration whereas the same value for 6 months curing is 3450 m/s and 3410 m/s respectively. In case of 12 months exposure period it is observed that slag concrete has almost same UPV values as that of OPC concrete for different saline water. At relatively longer curing periods, complete hydration of slag takes place that produce an impermeable concrete, which prevents the easy penetration of salts into the concrete. As a result, the rate of deterioration becomes slower and the corresponding UPV value increases.

From the UPV study, it is clear that for longer exposure period, slag concrete of cement slag mix 70:30 provides better resistance against deterioration. The relatively higher UPV values for this concrete in different environments indicate that this concrete is less affected by saline water.

### 3.3 Relationship between Compressive Strength and UPV

The UPV method, also known as the transit time method, uses a detector to measure the time-of-flight it takes for an ultrasonic pulse to pass through a known thickness of solid material [12]. The UPV can be written as: Vc (x,t) = x/t

Where Vc is the UPV in concrete, *x* is the propagated path length and *t* is the transit time.

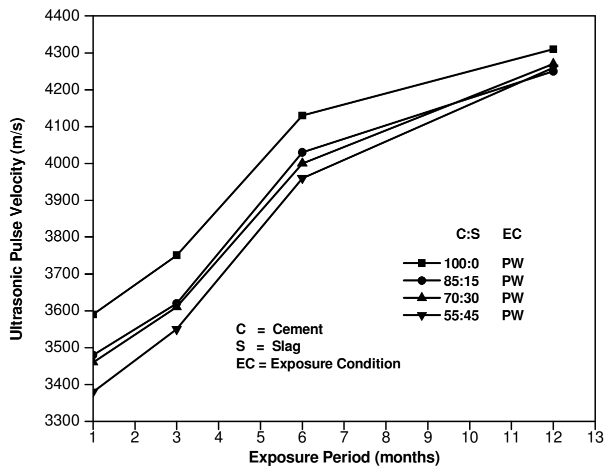


**Fig.4: Ultrasonic pulse velocity - Exposure time relation for slag concretes exposed to plain water**

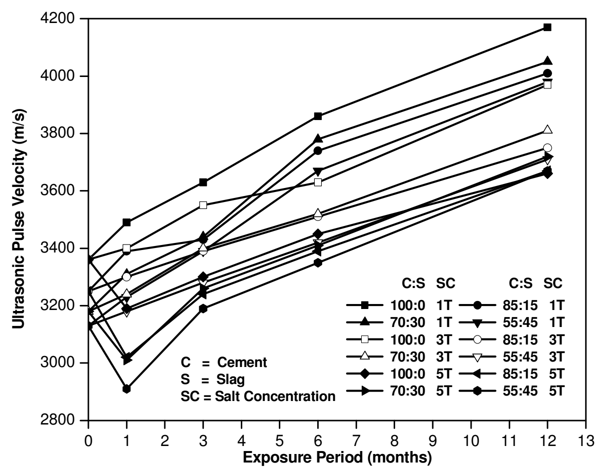


**Fig.5: Ultrasonic pulse velocity - Exposure time relation for slag concretes exposed to different saline water**

Taking into account of the heterogeneous nature of concrete, curing environment and exposure period, the general relationship between UPV and compressive strength is established for all test of concretes found at ages between 1 and 12 months **(Ref. Figure 6)**. On the basis of all the test results i.e. Compressive strength and the corresponding UPV values, the following relation between compressive strength (*f*c' in MPa) and UPV (Vc in m/s) was found:

$$\mathbf{fc' = 3.504\, e^{0.0006Vc}}$$

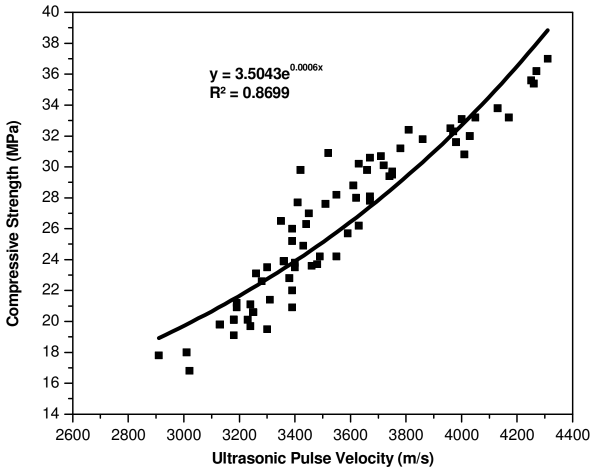


**Fig.6: Relation between Ultrasonic pulse velocity and Compressive strength**

A determination coefficient ($R^2$) of 0.87 indicates a good exponential relationship between UPV and compressive strength. Since $R^2$=0.87, 87% of the variation in the values of compressive strength is accounted for by exponential relationship with UPV.

## 4. CONCLUSIONS

Based on the limited number of test variables and exposure conditions / periods stated above, the following conclusions can be drawn. The study may provide some necessary information related to the use of slag concretes for the construction of marine onshore / offshore reinforced concrete structures:

(1) The partial replacement of cement with slag induced the reduction in compressive strength of concrete at all level of replacement. The gap in the compressive strength was very high at early age but with increasing curing period gap decreased.
(2) Slag concrete shows better resistance against strength deterioration. Among all the concrete, slag concrete of cement slag mix 70:30 shows the least strength deterioration in saline water.
(3) Concrete made with cement slag mix 70:30 shows least deterioration of UPV values for any curing solution which indicates the presence of micro cracks inside 70:30 slag concrete is relatively lower.
(4) A determination coefficient ($R^2$) of 0.87 indicates a good exponential relationship between UPV and compressive strength when all test results are pooled together.

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