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Effect of Silpozz and Fly Ash on Strength and Durability Properties of Concrete in Sea Water

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Abstract

This paper investigates the influence of using environmental by-product materials such as Silpozz and Fly Ash (FA) in concrete properties to resist saline water. The mix design is targeted for M30 grade concrete. Five concrete mixtures were designed to have the same degree of workability with water to cementitious material ratio of 0.43. The plain cement concrete samples made 0% replacement of FA and Silpozz with cement. The blended cement concrete samples made with 10% replacement of FA and 10%, 20%, 30%, and 40% replacement of silpozz with cement. Two set of samples (cube, cylinder and prism) have been prepared. One set of sample, after 28 days of Normal Water Curing (NWC) was being immersed in sea water for 7, 28 and 90 days and the other set of samples have been cured in normal water for 7, 28 and 90 days. The studied parameters include the compressive strength, flexural strength and split tensile strength of NWC and Sea Water Curing (SWC) samples after 28 days of NWC for 7, 28, and 90 days curing period. The acid soluble chloride and water soluble chloride contents were measured through the concrete samples of 28 days SWC after 28 days of NWC. The obtained test results indicated that the use of FA and Silpozz in concrete showed significant resistance to chloride penetration up to 10% replacement of FA and 30% replacement of Silpozz with cement. The carbonation depth of concrete samples for 90 days SWC after 28 days of NWC was measured. There is no significant change in depth of carbonation. The percentage increase in compressive strength for blended cement concrete in NWC is better than the samples in SWC after 28 days of NWC.

Keywords: Acid Soluble Chloride, Compressive Strength, Sea Water, Silpozz, Water Soluble Chloride

1. Introduction

The increasing number of concrete structures exhibiting unacceptable levels of deterioration, particularly in the marine environment, has attracted widespread attention in recent years. The durability of reinforced concrete structures in marine environments continues to remain a matter of concern for practicing structural engineers. Large numbers of concrete structures are exposed to sea water either directly or indirectly. For several reasons, effect of sea water on concrete deserves special attention. The coastal and offshore structures are exposed to simultaneous action of a number of physical and chemical deterioration processes. One of the main reasons for deterioration of concrete in the past is that too much emphasis is placed on concrete compressive strength. It is now recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is equally important. Therefore, both strength and durability have to be considered explicitly at the design stage[1]. The durability of concrete is generally regarded as its ability to resist the effects and influences of the environment, while performing its desired function[2]. Sound concrete is an ideal environment for steel, but the increased use of de-icing salts and the increased concentration of carbon dioxide in modern environments principally due to industrial pollution, has resulted in corrosion of the rebar becoming the primary cause of failure of this material[3]. The most damaging effect of seawater on concrete structures arises from the action of chlorides on the steel reinforcement and the

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build up of salts[4]. Some of the researchers have conducted the testing and modelling of chloride penetration into concrete and also used accelerated chloride migration test to study the chloride content in marine concrete[5–7]. The chemical deterioration of concrete subjected to seawater has been a topic of interest to concrete researchers in the last few decades, and the findings have revealed some very important facts, but still it remains to be a dynamic subject for further study and research[8–9]. The present study focuses strength and durability properties such as chloride content and carbonation for plain and blended cement concrete samples in sea water.

2. Experimental Study

Experimental study was carried out using different mixes of concrete mixed and cured in fresh water and sea water after 28 days of NWC in order to test the strength properties such as compressive, flexural and split tensile strength and durability properties such as the acid soluble chloride, water soluble chloride and carbonation depth.

2.1 Materials used and Properties

The material used in the present study is Ordinary Portland Cement (OPC), class F Fly Ash (FA), Silpozz, fine aggregate, coarse aggregate, normal water and sea water. The physical properties of OPC obtained from experimentally and the value specified by IS 8112:1989[10] are presented in Table 1. The sand is used as fine aggregate which is passing through IS 4.75 mm sieve. The size of coarse aggregate is used below 20 mm size. The properties of aggregates obtained experimentally as per IS: 383-1970[11] and the values are presented in Table 2. Sea water is collected from Puri Beach of Bay of Bengal, Konark, Odisha.

Table 2. Properties of aggregates

Specifications	Value obtained experimentally as per IS : 383-1970	
	Coarse aggregates	Fine aggregates
Fineness modulus	7.0	3.03 (Zone-3)
Specific gravity	2.86	2.67
Water absorption (%)	0.2	0.4
Bulk density (kg/m^3)	1424	1568
Abrasion value (%)	34.78	-
Impact value (%)	24	-
Crushing value (%)	23.3	-

SILPOZZ

FLY ASH

Figure 1. Silpozz and Fly Ash sample.

In this work, class F fly ash was supplied by NALCO, Angul, Odisha. Silpozz is used as substitute material of silica fume. Silpozz is very good pozzolana which is manufactured by burning of rice husk in designed furnace in between 600 to 700 degree centigrade. The furnace temperature is controlled by the air volume let inside the furnace. The furnace is also designed not to exceed temperatures above 700 degrees. Silpozz can be used as an admixture in a big way to make special concrete mixes. It is supplied from N. K. Enterprises, Singhania House, Jharsuguda, Odisha. The sample of FA and silpozz which is shown in Figure1 and the physical and chemical properties specified by the supplier is presented in Tables 3-5.

Table 1. Physical properties of Ordinary Portland Cement

Characteristics	Value obtained experimentally	Value specified by IS 8112:1989
Setting Time, (minutes)		
Initial setting time	165	30 (min)
Final setting time	360	600 (max)
Standard Consistency (%)	34	NA
Specific gravity	3.15	3.15
Compressive strength, MPa		
3 days	28 MPa	23 MPa
7 days	42 MPa	33 MPa
(c) 28 days	48 MPa	43 MPa
Fineness (m^2 / kg)	333	225 (min)

Table 3. Physical properties of Fly Ash

Characteristics	Physical properties
Specific gravity	2.12
Plasticity	Non-plastic
Proctor compaction	Maximum
Dry density (gm/cc)	1.2
Optimum moisture content (%)	28.5
Cohesion (kg/cm^2)	Negligible
Compression index	0.18
Permeability (cm/sec)	104.6

Table 4. Physical properties of Silpozz

Characteristics	Average value
Specific surface, m^2/g	15
Oversize percent retained on 45 micron IS sieve	10
Oversize percent retained on 45 micron IS sieve variation from average percent	5
Compressive strength at 7 days as percent of control sample	85
Bulk density	0.23 grams/cc
Physical state	Solid-non-Hazardous
Colour	Grey
LOI	< 6.0%

Table 5. Chemical composition of Fly Ash and Silpozz

Oxides (%)	Chemical composition of silpozz	Chemical composition of FA
SiO_2	88.18	58.13
Al_2O_3	1.61	31.00
Fe_2O_3	0.56	4.10
Carbon	2.67	-
CaO	1.59	0.60
MgO	1.63	0.10
K_2O	1.67	0.90
Na_2O	-	0.05
SO_3	-	0.12
TiO_2	-	1.63
Others	2.09	0.011
Moisture	0.79	-
LOI		2.90

2.2. Mix Proportion and Identifications

Usually, in marine environments, relatively richer mixes with low water to cementitious material ratio are used. This aspect was kept in mind in planning the experimental program. Therefore concrete mixture of M30 is designed as per standard specification of IS 10262-2009[12] to achieve target mean strength 39 MPa. The concrete mix proportion was (1: 1.44: 2.91), W/C 0.43. The concrete mix proportion along with their mix identification was designated according to their replacement ratio as given in Table 6. Workability of fresh concrete was measured by slump test immediately after mixing. It was found that the slump value varied between 25 to 40 mm.

Table 6. Mix proportions and identity for plain and blended cement concrete

Concrete mix proportion	Mix Identity
Contains 100% Cement+0% Fly ash+0% Silpozz	MC100F0S0
Contains 80% Cement+10% Fly ash+10% Silpozz	MC80F10S10
Contains 70% Cement+10% Fly ash+20% Silpozz	MC70F10S20
Contains 60% cement+10% Fly ash+30% Silpozz	MC60F10S30
Contains 50% Cement+10% Fly ash+40% Silpozz	MC50F10S40

3. Experimental Results and Discussions

In this study, cubes of size 150 mm × 150 mm × 150 mm, cylinders of size 100 mm diameter and 200 mm height and prisms of size 100 mm × 100 mm × 500 mm is used as shown in Figure 2. The hardened concrete properties such as compressive strength for cubes, flexural strength for prisms and split tensile strength for cylinders were tested in the laboratory which is shown in Figure 3. The chloride content along with the carbonation depth profile was also measured. The test results are presented along with their graphical plots and discussions. A comparative study of samples in NWC and SWC after 28 days of NWC is presented.

Figure 2. Casting of cubes, cylinders and prisms.

Figure 3. Testing of cube, cylinder and prism.

3.1 Compressive Strength

The compressive strength is measured using cube specimens. The size of the cube specimen is 150 mm × 150 mm × 150 mm. Nine numbers of cubes were cast for each mix and each three cubes were cured in normal water for 7, 28 and 90 days and another nine numbers of cubes were cast in normal water and cured in sea water after 28 days of NWC. Figures 4-5 represent the compressive strength in MPa versus age in days for 10% FA and silpozz based concrete samples in NWC and SWC respectively. Figure 4 indicates that with 10% of FA and up to 20% silpozz, the compressive strength is comparatively more with respect to control specimen at 90 days. It is observed from Figure 5 that the compressive strength of concrete specimens in SWC is almost same up to 28 days and in later age the strength increases in all the specimens. The compressive strength of specimen with 10% replacement of FA and up to 20% silpozz with cement gives higher value as compared with control specimen in later age. The compressive strength of SWC samples is relatively lower as compared to NWC samples.

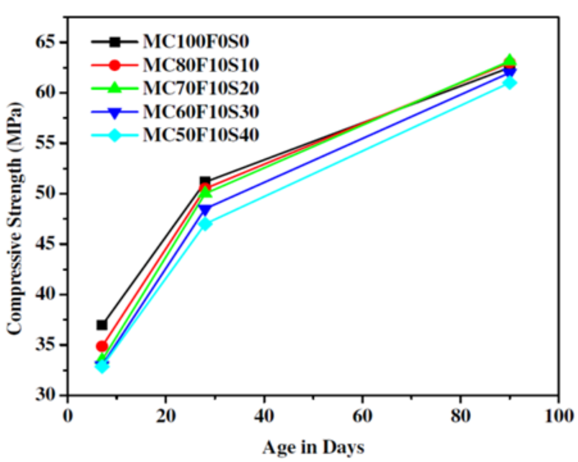

Figure 4. Compressive strength versus age in days (NWC).

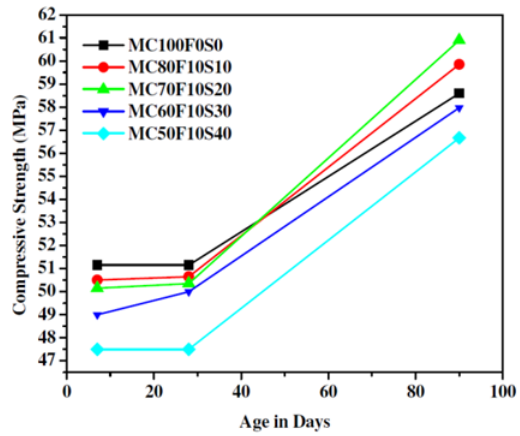

Figure 5. Compressive strength versus age in days (SWC).

3.2 Flexural Strength

The flexural strength is measured using prism specimens of size 100 mm x 100 mm x 500 mm and nine numbers of prisms were cast for each mix and each three prisms were cured in normal water for 7, 28 and 90 days and another nine numbers of prisms were cast in normal water and cured in sea water for 90 days after 28 days of NWC. Figures 6-7 shows the plot between the flexural strength of prisms in MPa and age in days for 10% FA and silpozz based concrete samples in NWC and SWC respectively.

Figure 6 shows that with 10% of FA and upto 30% silpozz, the flexure strength is comparatively more with respect to control specimen at 90 days in NWC samples. Figure 7 represents that with 10% of FA and upto 30% silpozz the flexural strength is more with respect to control specimen at 90 days in SWC samples.

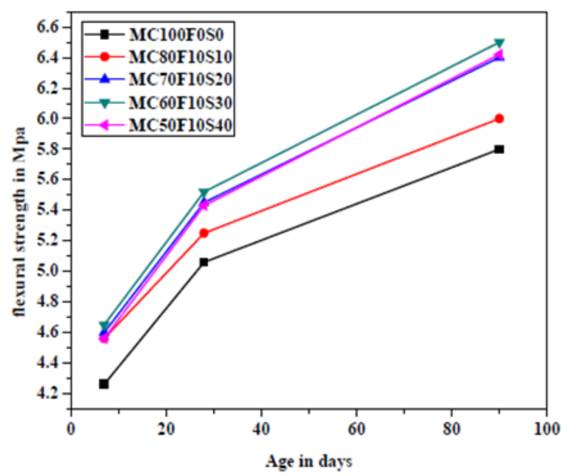

Figure 6. Flexural strength versus age in days (NWC).

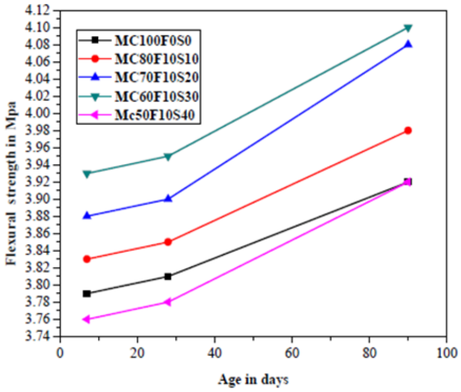

Figure 7. Flexural strength versus age in days (SWC).

3.3 Split Tensile Strength

The split tensile strength is tested for cylindrical samples of size 200 mm length and 100 mm diameter. Nine numbers of cylinders were cast for each mix and each three cylinders were cured in normal water for 7, 28 and 90 days and another nine numbers of cylinders were cast in normal water and cured in sea water after 28 days of NWC. Figures 8-9 shows the plot between the split tensile strength of cylinders in MPa and age in days for 10% FA and silpozz based concrete samples in NWC and SWC respectively. Figure 8 shows that with 10% of FA and upto 30% silpozz, the split tensile strength is comparatively more with respect to control specimen at 90 days in NWC samples. Figure 9 represents that with 10% of FA and upto 30% silpozz the split tensile strength is more with respect to control specimen at 90 days in SWC samples. The samples with 10% FA and 20% silpozz attain relatively same split tensile strength as compared to the above specimen at 90 days of NWC. But SWC sample of same specification with 10% FA and 20% silpozz is relatively less split tensile strength.

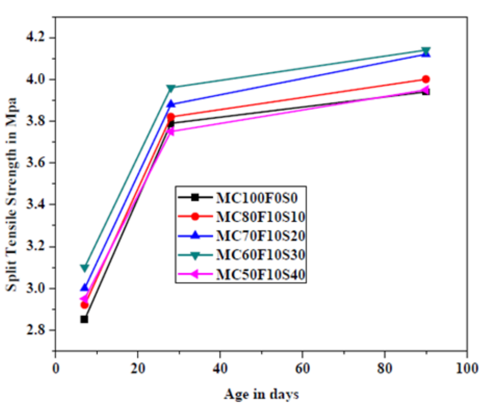

Figure 8. Split tensile strength versus age in days (NWC).

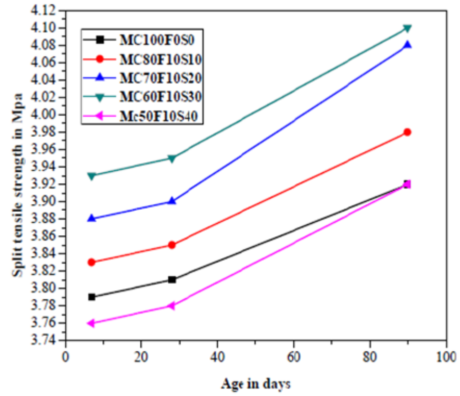

Figure 9. Split tensile strength versus age in days (SWC).

4. Determination of Chloride Content

The chloride content in concrete specimens is determined in form of water soluble chloride and acid soluble chloride as per IS 14959 – 2001 (Part-1)[13]. The water soluble and acid soluble chloride was determined for samples at 28 days of SWC upto 30% replacement of FA with cement and combination of 10% FA with upto 30% replacement of silpozz with cement. Figure 10 shows the graph between water soluble chlorides in mg/kg and types of concrete mix. From Figure 10, it is observed that MC50F10S40 and MC60F10S30 are having low water soluble chloride compared to other specimen. Figure 11 shows the graph between acid soluble chloride in mg/kg and types of concrete mix. It is observed from Figure 11 that the mix MC60F10S30 is having less acid soluble chloride than other specimen. It is found that the addition of silpozz with 10% FA may reduce the porosity of the transition zone between cement paste and aggregate.

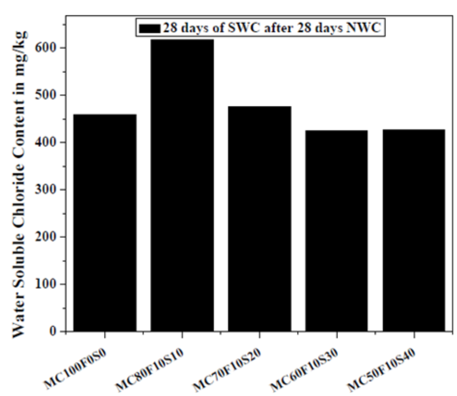

Figure 10. Water soluble chlorides versus types of mix.

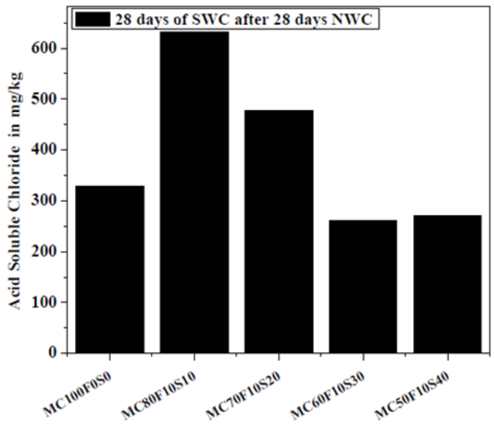

Figure 11. Acid soluble chlorides versus types of mix.

5. Depth of Carbonation

The depth of carbonation was measured for 10% FA and silpozz based samples which were cured for 90 days in sea water after 28 days of NWC. The surface of the cubes were chiselled and dressed properly with wire brush after taking out from sea water. The carbonation depth was determined by means of a phenolphthalein indicator. For each sample, the average carbonation depth of the four measurements is reported. The depth of carbonation versus types of concrete mix is presented in Figure 12. There is no significant change in the depth of carbonation. It is observed from Figure 12 that the samples of 10% FA with 20% silpozz and 10% FA with 30% silpozz have the same depth of carbonation.

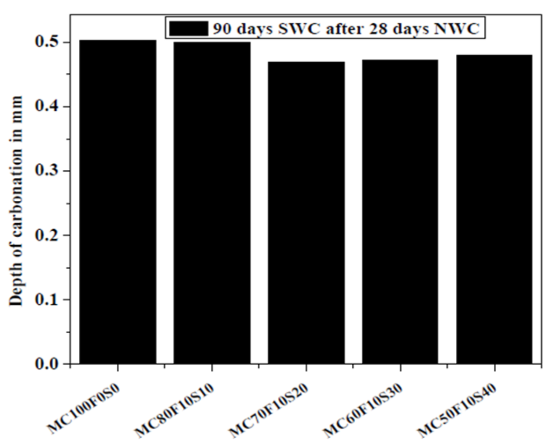

Figure 12. Depth of carbonation versus types of concrete mix.

6. Conclusion

Based on this study, the following conclusions may be drawn

- The percentage reduction in compressive strength is found to be less than 5% for the specimen with 10% FA and upto 20% silpozz on the replacement of cement for SWC samples at 90 days after 28 days of NWC.
- Similarly the percentage reduction in flexural strength and split tensile strength is within 6% for SWC specimens at 90 days after 28 days of NWC.
- There is no significant change in the depth of carbonation during 90 days of SWC after 28 days of NWC.
- It is observed that the sample of 10% FA with 20% silpozz and 10% FA with 30% silpozz have better resistance against carbonation.
- The water soluble chloride and acid soluble chloride in blended cement concrete (MC60F10S30) cured in sea water for 28 days after 28 days of NWC is found less as compared to the control specimen.
- It may be concluded that resistance against all possible forms of deterioration is distinctly improved by using mineral admixtures like FA and silpozz upto certain percentage of replacement of cement.

7. Acknowledgement

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