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Drying Shrinkage Study of Blended Cement and OPC Composites in Marine Condition

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Abstract: *The paper presents laboratory investigations on drying shrinkage of concrete made from three different types of cements namely 53 grade Ordinary Portland Cement (53 grade OPC), two types of blended cement namely Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) both are factory blended; for both normal and artificial sea water conditions. An attempt has been made to compare the drying shrinkage of hardened concrete made from above mentioned three types of cements for M30 grade of concrete mix with W/C of 0.45 conducted in accordance with BIS specifications. From the results of the investigation it can be concluded that the performance of blended cement concrete is better when compared to OPC concrete.*
Keywords: *Artificial sea water, Blended cement composites, Drying shrinkage, Marine environment,*

I. Introduction

Shrinkage is a common phenomenon generally encountered in almost all cementitious products due to contraction of total mass upon loss of moisture. Hence, the durability and service life of a marine structure is dependent on the adequacy of design and judicious choice of the constituent materials of concrete [1]. The behaviour of concrete structutres in marine environment has shown that the main cause of distress is reinforcement corrosion due to chloride attack. It is a worldwide problem with serious economic consequences and is now one of the main research areas in concrete stuctures [2].

For the past few years the use of mineral admixtures as cement replacement material has gained importance due to the improved performance characteristics of concrete achieved and the economy obtained in the production of cement or concrete. Addition of mineral admixtures with cement reduces the water demand which in turn reduces the shrinkage [1].

The prediction of delayed strains is of crucial importance for durability and long-term serviceability of concrete structures. These delayed strains cause cracking, loss of prestress and redistribution of stresses. In this study, the drying shrinkage component of delayed strains is considered in order to quantify its interaction with cracking for an aged concrete. Indeed, drying shrinkage leads to a strong structural effect since the drying process, which is the driving mechanism of shrinkage, occurs in an inhomogeneous manner. Self-equilibrated stresses raise within the concrete specimen and cause its cracking [3].

Drying shrinkage, which may lead to inevitable cracking in many concrete structures, can be defined as the volumetric change owing to the drying of concrete. This change in volume of the concrete is related to the volume of water lost. The loss of free water which occurs first may induce shrinkage. As the drying process of the concrete continues, the adsorbed water held by hydrostatic tension in the small capillaries is reduced significantly. The loss of the water (free water and adsorbed water) may lead to tensile stresses, which force concrete to shrink causing cracks that can adversely affect the structural performances, such as durability and serviceability, if not appropriately considered in the design stage [4].

Salt water is the product of the sea. The primary chemical constituents of seawater are the ions of chloride, sodium, magnesium, calcium and potassium. It evident that sodium chloride is by far the predominant salt component of seawater. [5].

II. Research Significance

Marine environment is considered to be the most severe and destructive natural environment. The structures in coastal region are exposed to severe marine environment. In this context the present investigation has been taken up for durability study to ascertain the type of cement that is less susceptible to deterioration under marine environment. This will help us in deciding the type of cement which is best suited for coastal regions.

III. Research Objectives

The main objective of the present research is to study drying shrinkage of concrete made of three types of cement i. e., 53 grade OPC, PPC, PSC. The investigation was carried out for M30grade of concrete mix with W/C ratio 0.45.

IV. Experimental Programme

The experimental programme was divided into the following for phases.

- Test on Cement and other ingredient materials
- Test on workability of concrete
- Preparation of Artificial Sea water
- Drying Shrinkage test on hardened concrete

V. Materials Used

Cement: 53 grade OPC confirming to IS 12269: 1987 [6], PPC confirming to IS 1489 (Part 1) [7] and PSC confirming to IS 455: 1989 [8] were used throughout the investigation.

The various Physical properties of cements were determined in accordance with BIS specifications and the results are tabulated in Table 1.

Table 1: Physical properties and compressive strength of Cements

Properties		**Test Results**			**Requirements as per Indian Codes**
		53 grade OPC	**PPC**	**PSC**	
Specific Gravity		3.15	2.98	3.04	---
Standard Consistency, %		30.00	31.50	31.00	---
Initial Setting Time, minute		95	125	110	Not less than 30
Final Setting Time, minute		180	230	215	Not more than 600
Compressive strength, Mpa	3 days	30.00	24.32	23.41	Not less than 27 (53 grade OPC) Not less than 16 (PPC and PSC)
	7 days	42.16	37.51	35.12	Not less than 37 Mpa (53 grade OPC) Not less than 22 (PPC and PSC)
	28 days	58.13	55.23	53.56	Not less than 53 Mpa (53 grade OPC) Not less than 33 (PPC and PSC)

PPC: Fly ash addition is 25% as furnished by the manufacturer.
PSC: GGBS addition is 40% as furnished by the manufacture.

Aggregates: Locally available river sand of specific gravity 2.65 and fineness modulus 3.59 confirming to zone II and crushed quarried granite stones of specific gravity 2.68 and fineness modulus 7.51 of maximum size 20mm were used as fine and coarse aggregate respectively in all concrete mixes throughout the investigation.

WATER: Normal tap water available in laboratory (for mixing and curing), Artificial sea water confirming to ASTM D1141-98 (2003) (for immersion).

VI. Specimen Details And Designation Of Concrete Mix

The specimens of size150mm x 75mm x 75 mm were cast. The specimen were designated as A, B and C for the concrete prepared from 53 grade OPC, PPC and PSC respectively. Further they are designated as AN1, AN2, AN3, AN4, BN1, BN2, BN3, BN4, CN1, CN2, CN3, CN4 and AS1, AS2, AS3, AS4, BS1, BS2, BS3, BS4, CS1, CS2, CS3, CS4 for concrete made from 53 grade OPC, PPC and PSC immersed in normal water and artificial sea water for 45, 90, 180 and 365 days respectively.

VII. Tests On Fresh Concrete

On fresh concrete tests related to workability measures such as slump, compaction factor and vee-bee tests were conducted in accordance with BIS specifications and the results are tabulated in Table 2.

Table 2: Results of workability tests

Type of Concrete	**Designation**	**Water/ cement ratio**	**Slump value (mm)**	**Compaction factor**	**Vee-Bee degrees (sec)**
53 grade OPC	A	0.45	78	0.89	16
PPC	B	0.45	83	0.91	14
PSC	C	0.45	88	0.92	12

VIII. Preparation Of Artificial Sea Water

Artificial sea water was prepared at laboratory conditions as per ASTM D1141 – 98 (Reapproved 2003) [9]. The preparation involves arrangement of stock solutions, each relatively concentrated but stable in storage. For preparation, aliquots of the two stock solutions with added salt are combined in larger volume.

- Preparation of stock solution No. 1: Dissolve the indicated amounts of the following salts in water and dilute to a volume of 7.0 L. Store the solution in a well stopper glass container.

Compound	**Quantity**
$MgCl_2.6H_2O$	3889.0 g (555.6 g/L)
$CaCl_2$ (anhydrous)	405.6 g (57.9 g/L)
$SrCl_26H_2O$	14.8 g (2.1 g/L

- Preparation of stock solution No. 2: Dissolve the indicated amounts of the following salts in water and dilute to a total volume of 7.0 L or a convenient volume. Store in well stopper amber glass containers.

Compound	**Quantity**
KCl	486.2 g (69.5 g/L)
$NaHCO_3$	140.7 g (20.1 g/L)
KBr	70.4 g (10.0 g/L)
H_3BO_3	19.0 g (2.7 g/L)
NaF	2.1 g (0.3 g/L)

- Preparation of Artificial sea water: To prepare 10.0 L of artificial sea water, dissolve 245.34 g of sodium chloride and 40.94 g of anhydrous sodium sulphate in 8 to 9.0 L of water. Add 200 ml of Stock Solution No. 1 slowly with vigorous stirring and then 100 ml of Stock Solution No. 2. Dilute to 10.0

- Adjust the pH to 8.2 with 0.1 N sodium hydroxide solution. Only a few milliliters of NaOH solution is required. The artificially prepared sea water will have the composition shown in the Table 2.

IX. Tests On Artificial Sea Water

Tests on water were conducted to determine the chemical characteristics. A comparison of concentration of chemical compound content in artificially prepared sea water and as per the ASTM D1141-98 (2003) standards are tabulated in Table 3. Chloride and sodium ion concentration of normal tap water and artificial sea water are tabulated in Table 4.

Table 3: Concentration of chemical compound contents

Compound	**Concentration (g/L)**	
	Artificial Sea Water prepared in lab.	**Requirements as per ASTM D1141-98 (2003)**
NaCl	24.22	24.53
$MgCl_2$	5.00	5.20
Na_2SO_4	3.99	4.09
$CaCl_2$	1.10	1.16
KCl	0.701	0.695
NaCl	24.22	24.53
$NaHCO_3$	0.186	0.201
KBr	0.080	0.101
H_3BO_3	0.019	0.027
$SrCl_2$	0.020	0.025
NaF	0.009	0.003

Table 4: Na and Cl concentration in mg/L.

Type of Water	**pH**	**Na^+**	**Cl^-**
Normal water	7.72	19	76.76
Artificial sea water	8.24	10043	15113

X. Exposure Condition

The specimens were cast and cured using normal water for 28 days. Then the specimens were immersed in artificial sea water prepared according to ASTM: D 1441 – 1998 (Reapproved 2003) for the required age group. However, some specimens were remain immersed in normal water for comparison.

XI. Concrete Mix Proportioning

The important criteria kept in view while proportioning concrete mixes are strength, durability and workability of concrete. IS 10262 (2009) [10] method was employed for concrete mix design. The mix proportioning parameters and mix proportions are presented in Table 5(a) and 5(b) respectively.

Table 5(a): Mix proportioning parameters

No.	Parameters	Description
1	Grade of concrete	M30
2	Type and shape of concrete	Granite, angular
3	Maximum size of aggregate, mm	20
4	Characteristic compressive strength at 28 days, Mpa	30
5	Degree of workability	Corresponding to a compaction factor of 0.85
6	Exposure condition	Severe
7	Degree of quality control	Good
8	Target mean strength, Mpa	38.25
9	Water-cement ratio	0.45

Table 5(b): Mix proportions of M30 grade concrete

No.	Type of concrete	Designation	W/C:C:FA:CA
1	53 grade OPC Concrete	A	0.45:1:1.55:2.67
2	PPC Concrete	B	0.45:1:1.52:2.62
3	PSC Concrete	C	0.45:1:1.54:2.64

XII. Drying Shrinkage Test

Shrinkage is seemingly a simple phenomenon of contraction of concrete upon loss of water. Strictly speaking, shrinkage is a three dimensional deformation, but it is usually expressed as a linear strain.

Drying shrinkage is defined as the time dependent volume reduction due to loss of water at constant temperature and humidity. This test was carried out in accordance with ASTM C 157.

The drying shrinkage is calculated as the difference between the original wet measurement and dry measurement expressed as a percentage of the dry length. The results are tabulated in Table 6 and variations with time (days) are shown in Fig. 1-3.

Table 6: Drying Shrinkage of concrete

Type of Concrete	Drying Shrinkage of Concrete (%)	Type of Concrete	Drying Shrinkage of Concrete (%)
AN1	0.014	AS1	0.020
AN2	0.033	AS2	0.042
AN3	0.067	AS3	0.074
AN4	0.023	AS4	0.036
BN1	0.012	BS1	0.014
BN2	0.026	BS2	0.028
BN3	0.059	BS3	0.063
BN4	0.028	BS4	0.030
CN1	0.010	CS1	0.010
CN2	0.022	CS2	0.026
CN3	0.045	CS3	0.047
CN4	0.020	CS4	0.023

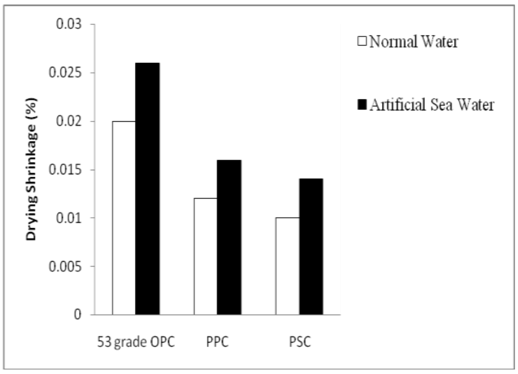

Fig. 1: Drying Shrinkage at 45 days

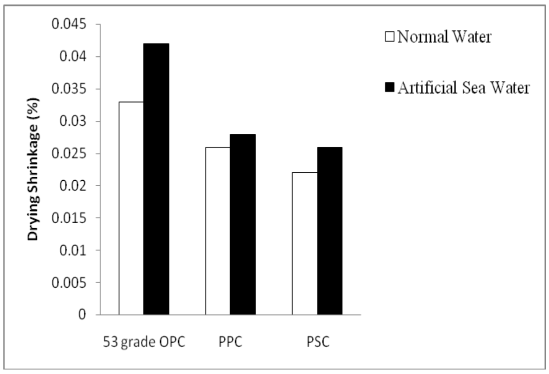

Fig 2: Drying Shrinkage at 90 days

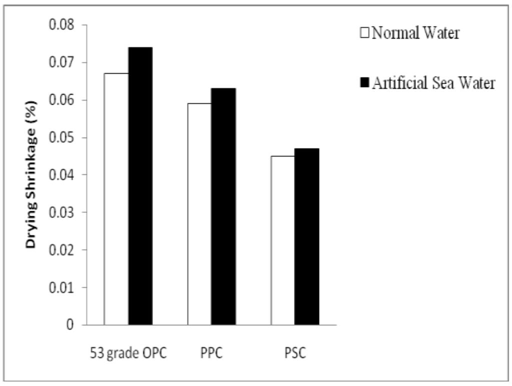

Fig. 3: Drying Shrinkage at 180 days

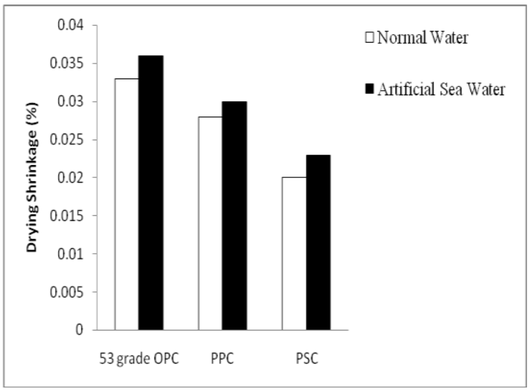

Fig 4: Drying Shrinkage at 365 days

XIII. Results And Discussions

Setting time of Cement

The final setting time of blended cements both PPC and PSC generally gets delayed. This may be attributed to the slow pozzolanic reaction. This delayed setting time can be of benefit during concreting, especially in hot weather concreting.

Workability of Concrete

From the results of workability tests, it is observed that the workability of blended cement concrete, both PPC and PSC concretes is better than the 53 grade OPC concrete. Even though there is not much of difference in workability of concrete the concrete mixes made with PPC and PSC were more cohesive than concrete mix made with 53 grade OPC.

Drying Shrinkage

It is evident from the studies that the performance of PSC and PPC concretes are better than that of the 53 grade OPC concrete.

XIV. Conclusions

From the results, it has been observed that the setting time of blended cements (PPC and PSC) gets delayed. This may be attributed to the slow pozzolanic reaction due to the presence of supplementary cementitious materials.

From the results of workability tests it is evident that the workability performance of blended cements both PPC and PSC is better than 53 grade concrete. Concrete made with blended cement show improved workability. This is due to the increased fineness of supplementary cementitious materials (SCMs) in the blended cements. The SCM particles act as ball bearings for moving the ingredients.

The drying shrinkage of PSC concrete is least followed by PPC and OPC concrete. This trend is due to the fact that mineral admixtures present in blended cement reduce the water requirement of concrete without affecting its properties thus reducing the drying shrinkage. As a result the development of shrinkage cracks may be minimal.

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