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Influence of water quality on the strength of plain and blended cement concretes in marine environments

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Abstract

This paper reports on the results of an experimental investigation carried out to study the effects of the quality of mixing water and initial curing on the strength of concrete exposed to seawater attack. An attempt has been made to consider a set of combinations with mixing water and initial curing conditions such that they reflect the situations of simulated cast-in-situ and precast conditions of concreting in marine environments. The effects of the quality of mixing water and initial curing on the strength of concrete in marine environments were investigated by considering different levels of fly ash replacement and cement type. Concrete specimens made with plain cements, Type I, II, and V, and blended cements made with fly ash were exposed to marine environments for a period of 1 year. The performance of these cements in concrete was evaluated by reduction in compressive strength. Results of this study showed that the use of precasting in place of casting-in-situ mitigates the effect of marine environments on concrete specimens considerably.

Keywords: Durability; Sulfate attack; Blended cement; Precast units

1. Introduction

The chemical deterioration of concrete in marine environments has been a topic of interest to concrete technologists in the last few decades. The concomitant presence of sulfate and chloride ions in marine environments causes deterioration of reinforced concrete structures and reinforcement corrosion. The reaction of the concrete with the sulfate ions in marine environments is similar to that of sulfate ions in non-marine environments, but the effects are different due to the presence of chloride ions in the former [1,2]. The effect of the conjoint presence of chlorides and sulfates on the sulfate resistance of hydrated Portland cements is inconclusive and highly debated [2]. The sulfate attack in marine environment gives rise to expansive ettringite, gypsum, and brucite and sometimes is associated with calcite formation [3–6].

The sulfate resistance of concrete structures in marine environments can be improved by using sulfate-resisting construction materials and by controlling sulfate permeation into concrete. The principal methods available to prevent sulfate attack using sulfate-resisting construction materials are changing Type I to Type II or Type V cement and introducing pozzolana such as fly ash, blast furnace slag in concrete [2,7–20]. Typically, Type I cement contains between 8% and 12% C_3A, as defined by ASTM C 150, whereas Type II cement contains less than 8% C_3A and Type V cement less than 5% C_3A. The sulfate permeation may be controlled by: increasing compactness, low water–cement ratio, properly designed and constructed joints, proper curing, surface treatment, and use of precast concrete in place of cast-in-situ concrete [1,12,15,21–23].

Recently, several researchers [7,15,19,24–26] have showed that limitation on C_3A content is not the ultimate answer to the problem of sulfate attack. The use of blended cement made with fly ash, silica fume, and blast furnace slag is therefore recommended [2,4,18,20] in sulfate environments. In addition, recent studies [2,26] have shown that blended cement concrete has an increased resistance to chloride penetration in structures exposed to seawater.

Among the various methods of controlling sulfate permeation, the use of precasting in place of casting-in-situ in sulfate environments has not received due attention in literature and codes of practice. The earlier study [23] points

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out the relative superiority of precasting in place of casting-in-situ in sulfate environments. In this study [23], the comparative behavior of concrete made with plain Type I cement and exposed to sulfate attack in simulated cast-in-situ and precast conditions was reported.

The effective exposure history of precast and cast-in-situ concrete is characteristically different under identical environmental conditions. Precast elements are extensively used in marine structures. They are more often used because of the ease in construction rather than as a durability measure.

Since blended cements are used universally at present, the evaluation of their performance in seawater environments will provide useful information for their use in such environments. The earlier studies have focused their attention on the merits of cement replacement materials in improving sulfate resistance of concrete in cast-in-situ conditions. A little effort has been made to find out the relative merits of blended cement concrete in precast conditions as compared to the cast-in-situ, in marine environments. Also, the type of cement, Type I, II, or V, to be used in blended cements for precast concrete exposed to sea environments has not been clearly established.

To assess the preceding concerns, plain and blended cement concrete specimens made with different proportions of fly ash were exposed to seawater attack in simulated precast and cast-in-situ conditions. Such a study is of significant practical interest since it incorporates Type I, Type II, and Type V cements.

2. Experimental program

2.1. Materials

ASTM C 150 Type I, Type II, and Type V cements were used in preparing the concrete specimens. Blended cements were prepared by replacing 10%, 20%, and 30% of these cements with ASTM C 618 Class F fly ash. The chemical composition of the cement and fly ash used in this investigation is given in Table 1. Washed river sand of fineness modulus 2.36 and natural gravel of nominal size 20 mm was used as coarse aggregate. Ordinary water used was the normal drinking water from the piped water supply system.

Table 1
Chemical composition of cements and fly ash

Constituent (% by weight)	Type I cement	Type II cement	Type V cement	Fly ash
Calcium oxide	64.4	64.7	65.0	10.1
Silicon oxide	20.8	21.7	21.9	53.2
Aluminium oxide	5.8	4.2	3.2	22.4
Ferric oxide	3.5	3.3	3.9	6.4
Magnesium oxide	1.9	1.9	2.2	2.4
Sulfur trioxide	2.2	2.3	2.5	0.7
Sodium oxide	0.1	0.2	0.3	0.0
Loss on ignition	0.9	0.9	0.8	0.4
Compound composition				
Tricalcium silicate	53.8	58.9	63.9	–
Dicalcium silicate	19.1	17.9	14.7	–
Tricalcium aluminate	9.5	5.6	1.9	–
Tetracalcium aluminoferrite	10.6	10.0	11.9	–

Table 2
Details of concrete mixes

Mix	Cement (kg)	Fly ash (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water–cementitious material ratio
A	1.0	0.0	1.5	3.0	0.4
B	0.9	0.1	1.5	3.0	0.4
C	0.8	0.2	1.5	3.0	0.4
D	0.7	0.3	1.5	3.0	0.4

2.2. Mix proportions and specimen preparation

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. Mix proportions used for investigating effects of marine environments on concrete specimens made with plain cement and blended cement under simulated cast-in-situ and precast situations are given in Table 2.

Concrete cubes of 15 cm were cast and an attempt has been made to simulate conditions of cast-in-situ and precast concreting. Depending upon the ingredients used in mixing and curing conditions, the concrete cubes were divided into three groups denoted by X, Y, and Z, as given in Table 3.

The concrete cubes cured in seawater were kept completely submerged in seawater. However, in the splashing zone, due to wetting and dry effects, the concentrations of salts can be higher than in the bulk seawater.

2.3. Test techniques

The criterion selected for the comparative evaluation of resistance of concrete under simulated precast condi-

Table 3
Mixing and curing conditions

Designation	Water used for mixing	Water used for curing	Remarks
X	Ordinary water	Ordinary water	Controlled concrete cubes
Y	Seawater	Seawater	Concrete cubes reflecting cast-in-situ situations
Z	Ordinary water	Initially cured in ordinary water for 28 days, and subsequently cured with seawater	Concrete cubes reflecting pre-cast situations

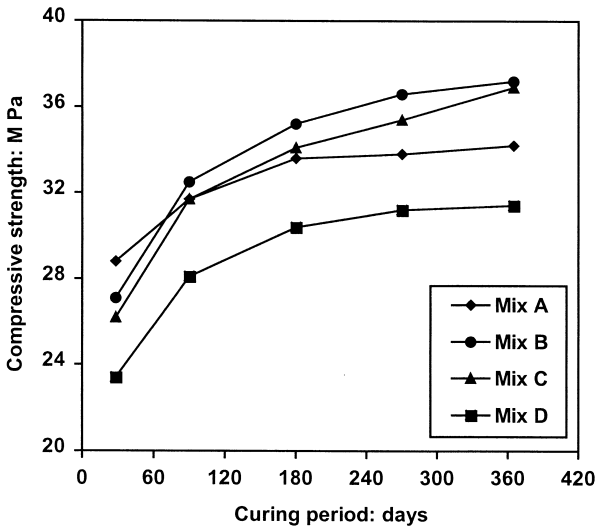

Fig. 1. Strength development in Type I cement concrete specimens of group X.

tions and cast-in-situ, was the extent of strength loss as a result of seawater exposure. The compressive strengths in all the cases were determined as per the standard procedure after 28, 90, 180, 270, and 365 days of casting. The reduction in compressive strength of concrete was denoted by the strength deterioration factor (SDF), which is defined as:

$$SDF = (1 - \sigma_R/\sigma) \times 100$$

where σ_R is the average compressive strength (MPa) of concrete specimens after exposure to marine environments for a period of t days and σ is the average compressive strength (MPa) of concrete specimens in the absence of marine environments after time t, where t is the curing period in days.

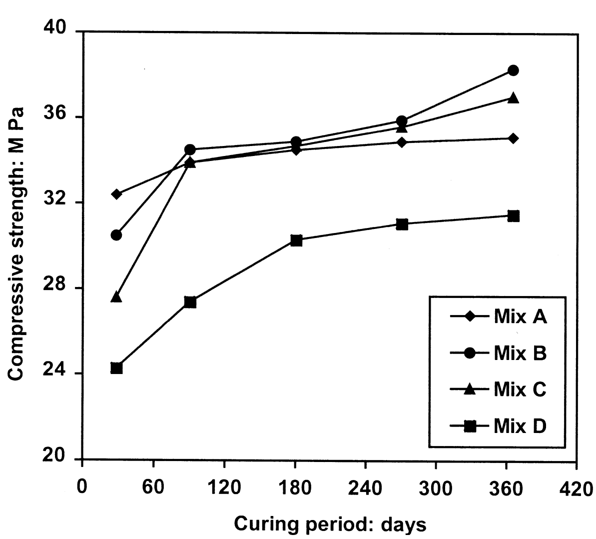

Fig. 2. Strength development in Type II cement concrete specimens of group X.

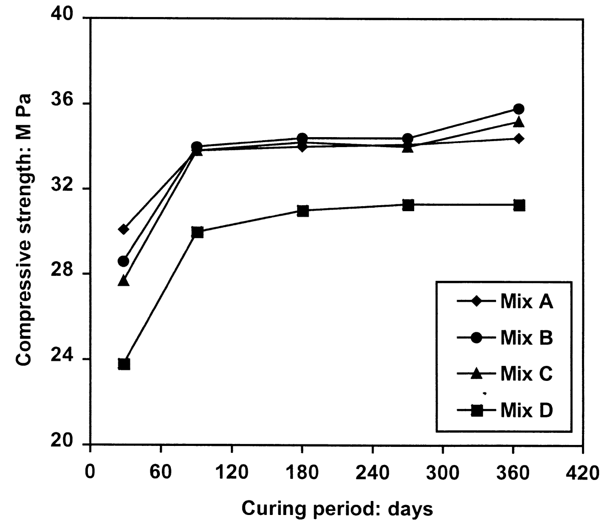

Fig. 3. Strength development in Type V cement concrete specimens of group X.

3. Test results and discussion

The influence of water quality on the strength of plain and blended cement concrete made with Type I, Type II, and Type V cements are reported in this article.

Data on compressive strength development of controlled concrete specimens made with plain and blended cements are shown in Figs. 1–3. These data indicate that all plain cements exhibited somewhat similar strength after 365 days of water curing. After 365 days of curing, compressive strength was observed more in concrete made by blending up to 20% of fly ash with all plain cements.

The reduction in compressive strength represented as SDF in plain and fly ash blended cement concrete specimens exposed to marine environments is plotted in

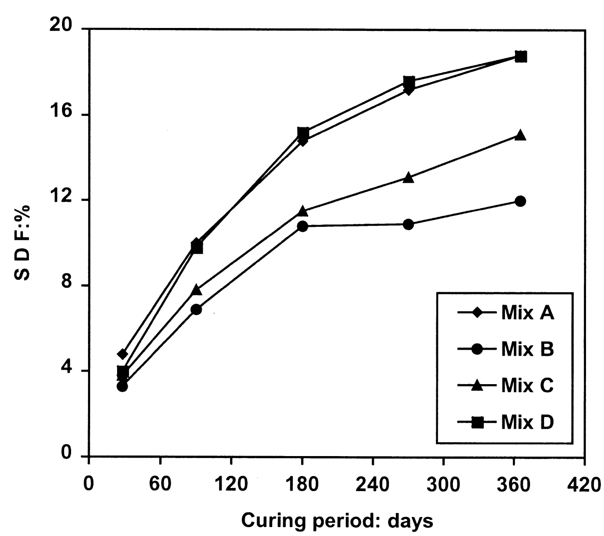

Fig. 4. Reduction in strength in Type I cement concrete specimens of group Y.

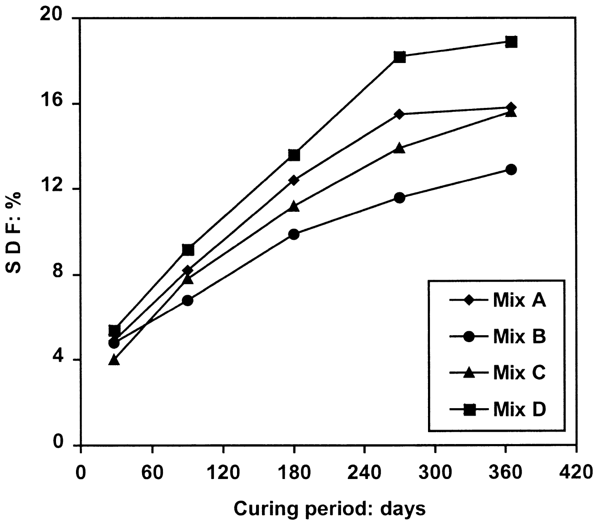

Fig. 5. Reduction in strength in Type II cement concrete specimens of group Y.

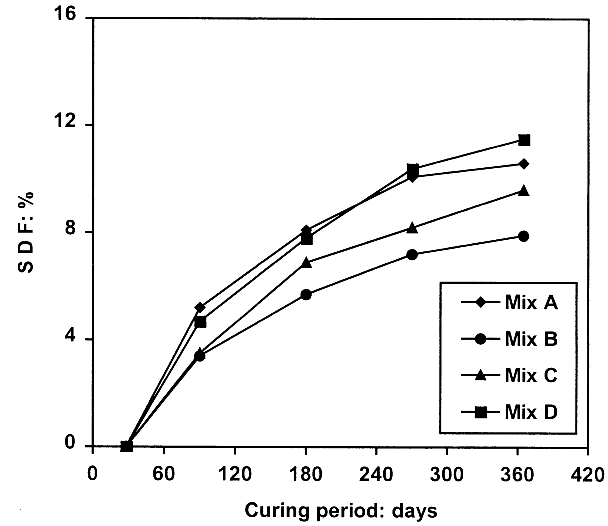

Fig. 7. Reduction in strength in Type I cement concrete specimens of group Z.

Figs. 4–9. Figs. 4–6 show the percentage reduction in compressive strength of concrete mixed and cured in seawater. Figs. 7–9 show the percentage reduction in compressive strength of concrete mixed and initially cured with ordinary water and exposed to seawater attack after 28 days of casting. It is evident from Figs. 4–9 that with the increase in age of concrete, the SDF value goes on increasing.

It can be seen from Figs. 4–6 that concrete made with Type II and Type V plain cements is more resistant to seawater attack as compared to the Type I plain cement. The effect of seawater attack on concrete was studied using fly ash at 0%, 10%, 20%, and 30% replacement for Type I, Type II, and Type V Portland cements. Fig. 4 shows that 10% and 20% blending of fly ash in Type I cement have increased concrete durability against seawater attack considerably. However, the blending of 30% fly ash in cement has not shown any change in the SDF value of concrete as compared to plain cement concrete specimens. The data on SDFs for concrete with Type II cement specimens (Fig. 5) indicate a qualitative trend similar to that observed in Type I cement specimens.

In general, concrete containing lower C_3A Portland cements (Type V cement) showed greater resistance to seawater attack. However, the blending of fly ash in Type V cement concrete decreased the overall resistance of these concretes below that of a standard blended Type I Portland cement concrete. It can also be seen from Figs. 4 and 6 that after 365 days of exposure to marine environments, concrete made with 20% fly ash replacement of Type I cement

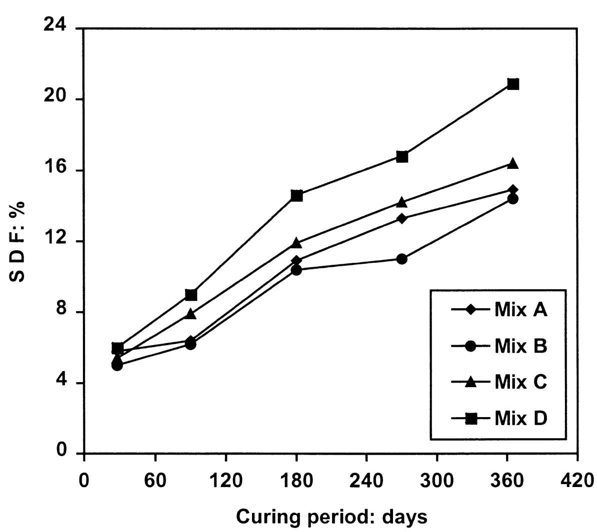

Fig. 6. Reduction in strength in Type V cement concrete specimens of group Y.

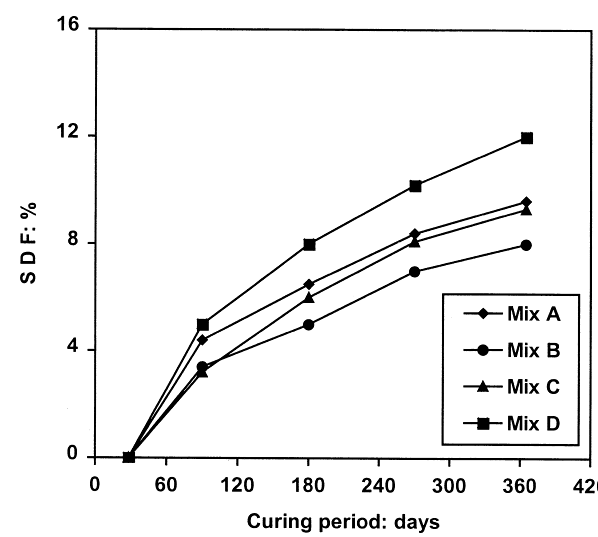

Fig. 8. Reduction in strength in Type II cement concrete specimens of group Z.

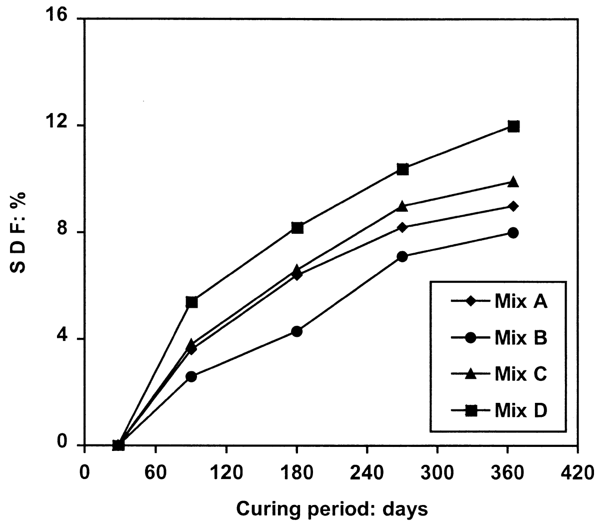

Fig. 9. Reduction in strength in Type V cement concrete specimens of group Z.

performs similar to Type V sulfate resisting cement in terms of improvement in concrete strength.

The rate of deterioration of concrete in marine environments is dependent on its total porosity. The porosity of concrete decreases with time due to the processes of cement hydration and carbonation [27].

If a marine structure is made of precast elements and is erected at site, then the hardened concrete will be subjected to seawater attack at mature state as compared to a structure made of cast-in-situ elements. Since the porosity of concrete reduces with corresponding hardening of concrete, it is expected that the seawater attack will be less in structures made of precast elements.

The above fact was found true from the experimental results obtained under simulated mixing and curing conditions. In Figs. 4–9, it can be seen that the SDF values for all cements exposed to marine environments in simulated precast situation are relatively low compared with cast-in-situ situations. In some of the cases, the losses have been reduced to even more than 40%. The beneficial effect of fly ash blending under simulated precast conditions was observed more in concrete made with low fly ash replacement of Type I, Type II, and Type V cements. Similar to concrete subjected to simulated cast-in-situ conditions, the blending of fly ash in Type I and Type II cements was observed to be more beneficial than the blending in Type V cement in simulated precast conditions of concreting in marine environments, as shown in Figs. 7–9.

Often, there is a concern as to the type of cement to be used with supplementary cementing materials for structures exposed to marine environments. The strength reduction data developed in this investigation, using fly ash blended with Type I, Type II, and Type V cements, indicate no significant difference between these cements in both simulated cast-in-situ and precast conditions. This indicates that Type I cement, which is now recommended [9] to improve corrosion resistance of reinforced cement concrete, is the potential choice for the construction of marine structures with appropriate blending of pozzolana.

It is found from the experimental results that the use of precasting in place of casting-in-situ increases the resistance of concrete against marine environments appreciably. Blending a suitable proportion of fly ash with Portland cements can further reduce the effect of seawater on marine structures.

4. Conclusions

Concrete specimens prepared using plain and blended Type I, Type II, and Type V cements were exposed to marine environments under two different conditions of mixing water and initial curing simulated to reflect the precast and cast-in-situ concreting. The performance of concrete in simulated precast and cast-in-situ conditions was evaluated by reduction in compressive strength. Based upon the results of the experimental study reported in this paper, the following conclusions can be drawn.

1. The effect of marine environments on concrete is to decrease its compressive strength and this loss increases with age of exposure.
2. The blending of fly ash (10% and 20%) in both Type I and Type II cements has increased their resistance against seawater attack.
3. The use of fly ash in combination with Portland cements with very low C_3A content, Type V cement, did not result in a level of resistance equal to or greater than that of Type I or Type II Portland cements in marine environments.
4. The beneficial effect of precasting in marine environments was noticeable in all the three types of plain and blended cements. In some of the cases, the losses have been reduced to even more than 40% in simulated precast situations.
5. The blending of fly ash in Type I cement is observed to be slightly more beneficial than the blending in Type II or Type V cements against marine environments in both simulated precast and cast-in-situ situations.

This indicates that a Type I cement is a potential choice for the construction of marine structures. In view of the high chloride combining capacity of high C_3A Type I cement, a potentially useful approach in the marine environments would be to generally specify the use of a Type I cement modified with a suitable pozzolana. The use of precasting in place of casting-in-situ will further increase the resistance of concrete against marine environments.

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