Pergamon

Cement and Concrete Research, Vol. 25, No. 1, pp. 1-8, 1995
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0008-8846/95 $9.50+.00

0008-8846(94)00105-7

SULFATE ATTACK ON CONCRETE IN SIMULATED CAST-IN-SITU AND PRECAST SITUATIONS

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(Communicated by A.K. Chatterjee)
(Received March 16, 1994)

ABSTRACT

This paper presents the results of an experimental investigation in which the effect of sulfates on the strength of concrete under conditions simulating cast-in-situ and precast situations, is carried out. A range of sulfate concentrations and exposure durations are adopted and the strength loss in concrete due to the sulfate attack is experimentally determined. The results indicate that the use of precasting in place of casting-in-situ is preferable, in situations exposed to sulfate environments.

1. Introduction

Most concrete structures in service are subjected to aggressive environmental influences which affect durability. Durability in turn affects structural safety, economy, serviceability and maintenance.

Among all chemicals, sulfates are the most important from the point of view of action on structural concrete. Many naturally occuring soils and ground waters contain sulfates which lead to deterioration of structures(1,2). Other situations, where sulfates can attack concrete are sea water, industrial effluents, fertilizer application, acid rain water etc. (1,2). In aqueous environments, the sulfate ions gradually find their way into the interior of concrete and many complex physical and chemical changes begin to take place. The strong sulfate attack considerably influences the mechanical strength of concrete (3-7).

The sulfate resistance of concrete can be improved by using sulfate resisting construction materials and by controlling sulfate permeability into concrete. The sulfate permeation may be controlled by increasing compactness, increasing cover, proper curing, surface treatments and use of precast members. Among the various methods of sulfate resistance, the use of precast members in sulfate environments has not received due attention in literature and in codes of practice.

The effective exposure history of precast and cast-in-situ concretes is characteristically different under identical environmental conditions. Consider as an example, a concrete structure which is exposed naturally to aggressive chemicals. If the structure is cast-in-situ, the concrete is exposed to the aggressive environment from the very early stages, that is even in the fresh state. If, however, the structure is made of precast elements and erected at site, the hardened concrete will be exposed to aggressive environments in a mature state.

Thus it is of significant practical interest to study the comparative behaviour of concrete in precast and cast-in-situ conditions when exposed to sulfate environments.

2. Experimental Programme

Normally if the sulfate concentration is less than about 150 ppm there will not be any significant attack (2,8,9). If the sulfate concentration is more than about 6000 ppm usually surface coatings are applied on concrete (8). In most practical situations, concentrations in natural ground waters and soils are up to the order of 1000 ppm (10), while those of industrial effluents are more. Thus the range of practical importance of the sulfate concentrations are between 150 and 6000 ppm, when the attack on unprotected concrete is studied.

A realistic study of sulfate attack is possible only by long term tests. In the case of low sulfate concentrations less than 1000 ppm, measurable deterioration of the material may need exposure to very long duration, which is often difficult to carry out. In such cases, accelerated tests adopting higher sulfate concentrations (10) will be of value where the focus is on the comparative behaviour and response of concretes cured under different conditions.

Usually in situations where moderate sulfate environments are anticipated, relatively richer mixes with ordinary portland cement and water-cement ratio equal to 0.5 are adopted (2,8,9).

Among the different sulfates, alkali sulfates and calcium sulfates are the most common sources of sulfate ions in soils and ground water (1,2).

The above factors are kept in mind in planning the experimental programme, the details of which are given in the following :

In this investigation locally available river sand as fine aggregate and natural gravel of maximum size 20 mm as coarse aggregate, were used in making three concrete mixes which are denoted by A,B and C. Ordinary portland cement was used throughout the investigation. The details of concrete mixes are given in Table 1.

TABLE 1

Details of Concrete Mixes

Mix	Mix ratio (by weight)					Water-Cement ratio
	Cement	:	Fine aggregate	:	Coarse aggregate	
A	1	:	2	:	4	0.5
B	1	:	1.5	:	3	0.5
C	1	:	1	:	2	0.5

Fifteen centimeter concrete cubes were cast and an attempt has been made to simulate conditions that reflect the situations of cast-in-situ and precast concreting situations. Depending upon the ingradients used in mixing and the curing conditions, the concrete cubes were divided into three groups denoted by X,Y and Z, as given in Table 2 below.

TABLE 2

Mixing and Curing Conditions

Designation	Water used for mixing	Water used for curing	Remarks
X	Ordinary water	Ordinary Water	Controlled concrete cubes
Y	Sodium sulfate solutions having sulfate (SO_4^{--}) concentrations of 500,2000 and 5000 ppm	Sodium sulfate solutions having sulfate (SO_4^{--}) concentrations the same as those used for mixing	Concrete cubes reflecting cast-in-situ situations
Z	Ordinary water	Initially cured in ordinary water for 28 days, and subsequently cured with sodium sulfate solutions having sulfate (SO_4^{--}) concentrations of 500, 2000 and 5000 ppm	Concrete cubes reflecting precast situations

The compressive strengths in all the cases were determined as per the standard procedure after 28,58,88 and 118 days of casting.

3. Results and Discussion

The variation of concrete strength with age in fresh water is shown in Figure 1. Figures 2-4 show the percentage reduction in compressive strength of concrete mixed and cured in sulfate solutions of different concentrations. Figures 5-7 show the percentage reduction in compressive strength of concrete mix with ordinary water and cured in ordinary water for 28 days before exposure to sulfate attack.

The percentage loss in strength is given by

$$\text{Percentage loss} = \left(1 - \frac{\sigma_R}{\sigma}\right) \times 100 \qquad \ldots (1)$$

where

σ_R = strength after exposure to sulfate environment for a period of T, and

σ = strength of concrete in the absence of sulfate environment after time T, where T is the curing period in days.

It can be seen from Figures 2-7 that reduction in compressive strength takes places due to sulfate attack. The percentage loss in compressive strength increases with sulfate concentration and also with the period of exposure. From Figures 2-7 it can also be seen that a concrete with higher strength has less percentage reduction in strength when exposed to sulfate attack.

The possible reasons for the observed behaviour of concretes under sulfate attack are as given in the following :

Sulfate attack on concrete is a complex process. When a cement concrete matrix is placed in a sulfate environment, the sulfate attack

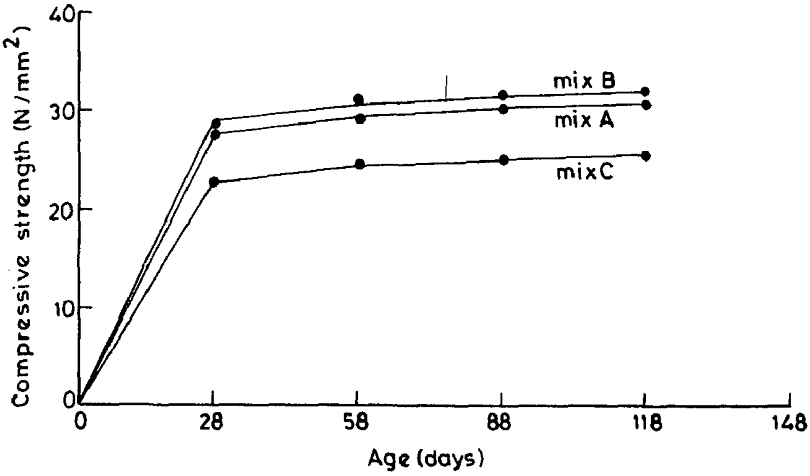

FIG. 1

Variation of concrete strength with age in fresh water

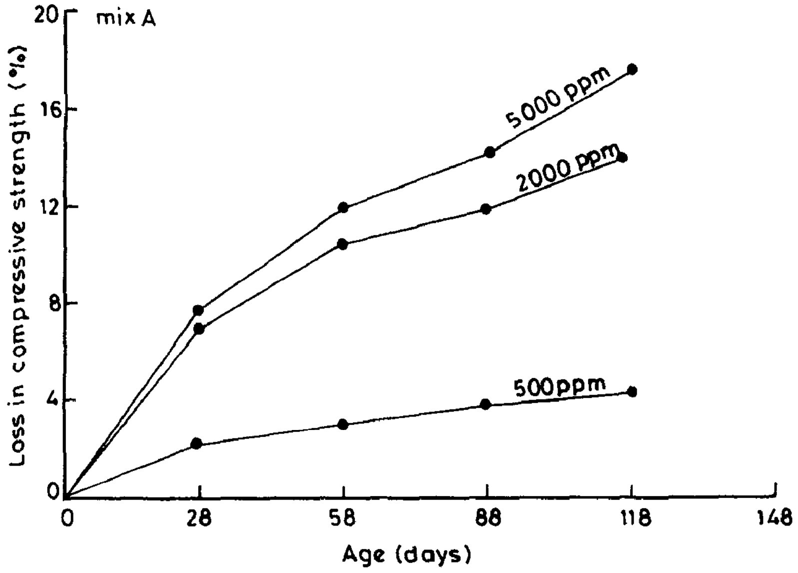

FIG. 2

Effect of sulfate solutions on strength of group Y concrete specimens

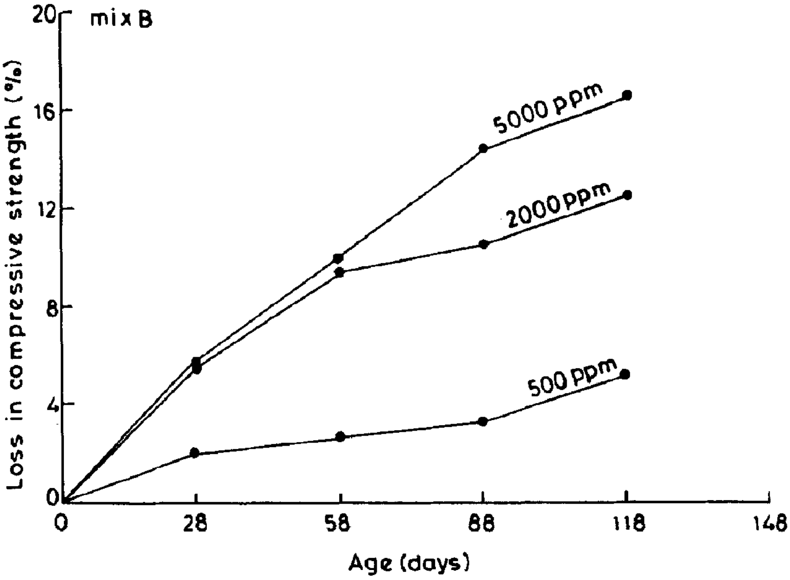

FIG. 3

Effect of sulfate solutions on strength of group Y concrete specimens

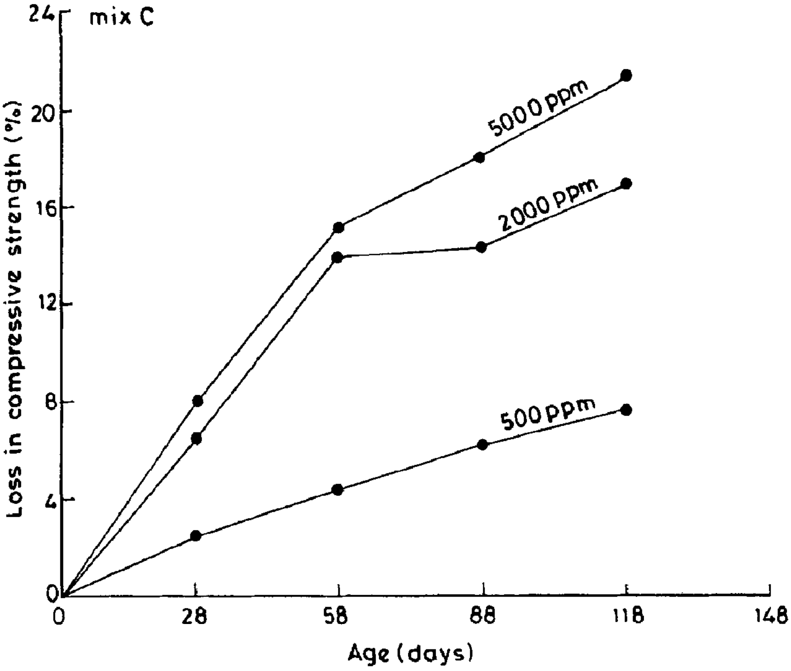

FIG. 4

Effect of sulfate solutions on strength of group Y concrete specimens takes place as a sequence of three sub-processes (11-19).

(a) The first process, which is controlled by the permeability of the cement concrete matrix, is the diffusion of sulfate ions into the pores of the matrix. It is the pore water that is responsible for reaction between the constituents of cement and concrete with aggressive sulfate ions.

(b) The second process is the reaction in-between environmental sulfate ions and crystalline calcium hydroxide present in the hydrated cement to yield crystalline gypsum, given by equation 2.

$$2\,Na^+ + SO_4^{--} + Ca(OH)_2 + 2H_2O \longrightarrow 2\,Na^+ + OH^- + CaSO_4.2H_2O \quad \ldots (2)$$

(c) Finally, in the third process, sulfate ions react with hydrated

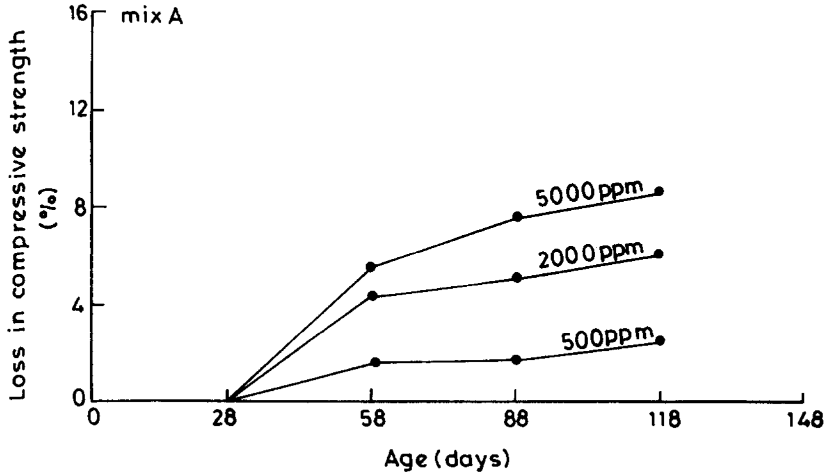

FIG. 5

Effect of sulfate solutions on strength of group Z concrete specimens

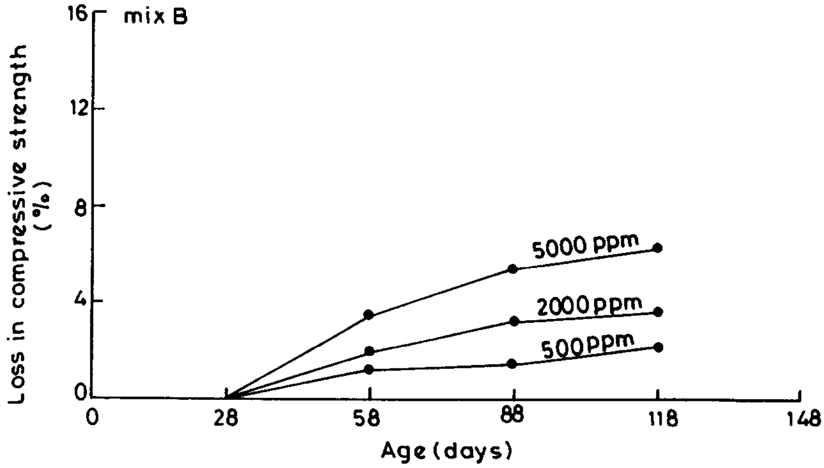

FIG. 6

Effect of sulfate solutions on strength of group Z concrete specimens aluminates to form ettringite. The relations can be given in the abbreviated form as follows :

$$C_3A.\ C\bar{S}.\ H_{18} + 2N\bar{S} + 2CH + 14H \longrightarrow C_3A.\ 3C\bar{S}.\ H_{32} + 2NH \qquad \ldots (3)$$

$$C_3A.\ CH.\ H_{18} + 3N\bar{S} + 2CH + 14H \longrightarrow C_3A.\ 3C\bar{S}.\ H_{32} + 3NH \qquad \ldots (4)$$

The gradual removal of calcium hydroxide and hydrated aluminates and their respective replacement with calcium sulfate and ettringite results in expansion and consequent loss in strength of concrete.

The rate of deterioration of concrete in sulfate environments is dependent on its total porosity. The porosity of concrete $\epsilon(t)$ decreases with time due to the process of cement hydration and of carbonation (20) and is given by

$$\epsilon(t) = \epsilon_o - \triangle\epsilon_H(t) - \triangle\epsilon_c \qquad \ldots (5)$$

where

ϵ_o = porosity of fresh concrete,

$\triangle\epsilon_H(t)$ = reduction in porosity due to hydration, and

$\triangle\epsilon_c$ = reduction in porosity due to carbonation.

The initial value of porosity ϵ_o is the sum of the volume fractions of mixing water and the entrapped air.

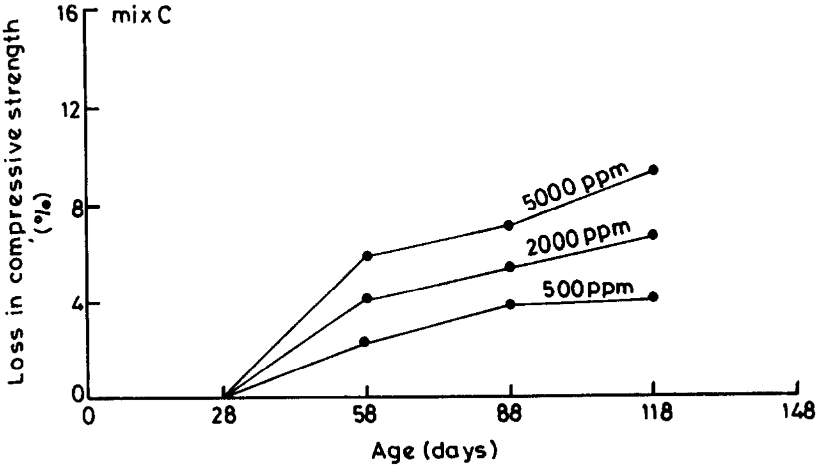

FIG. 7

Effect of sulfate solutions on strength of group Z concrete specimens

If a structure is made of precast elements and erected at site, then the hardened concrete will be subjected to sulfate 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 sulfate attack will be less in structures made of precast concrete members.

The above fact is found true from the present experimental results obtained under simulated conditions. From Figures 2-4 and Figures 5-7, it can be seen that for the same mix and water-cement ratio, percentage reduction in strength of concrete exposed to sulfate environments after 28 days of casting and curing in ordinary water is less. In most of the cases, the losses have been reduced by even more than 50 percent. The stronger the concretes, the lesser the permeability and hence the lesser the reduction in strength due to permeability.

The use of precast concrete elements in structures will not only provide a means for quality production but also reduces sulfate attack appreciably.

5. Conclusions

Based upon the results of experimental study reported in this paper, the following conclusions can be drawn.

1. The effect of sulfate environment on concrete is to decrease its compressive strength and this loss increases as a function of sulfate concentration and also age of exposure.
2. A concrete mix having higher value of strength shows less percentage loss in strength when exposed to sulfate attack.
3. The use of precast members in place of cast-in-situ members will reduce the effect of sulfate solutions on concrete structures considerably.

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