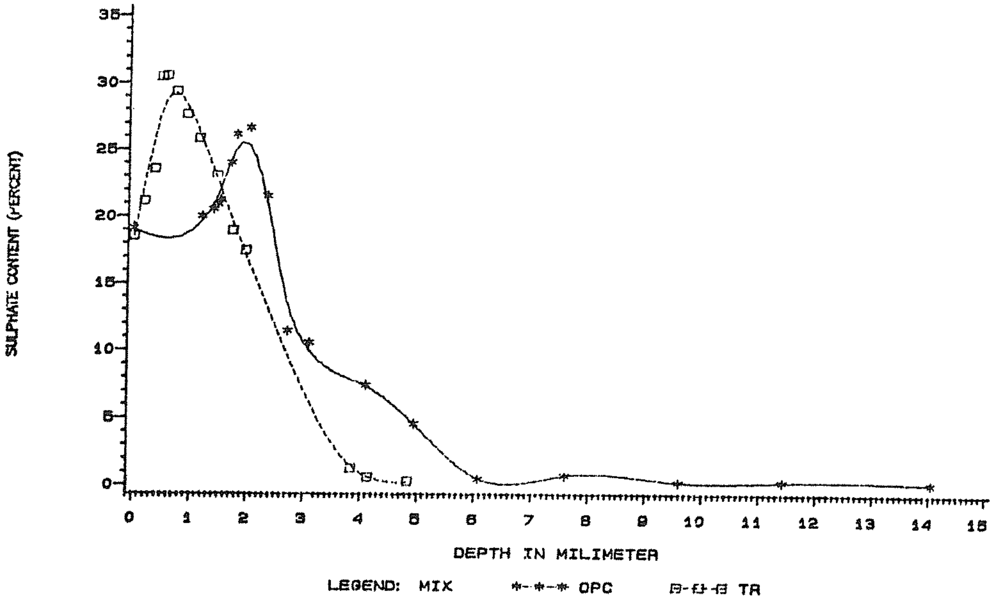

Fig. 9. Sulphate Content at Different Depths

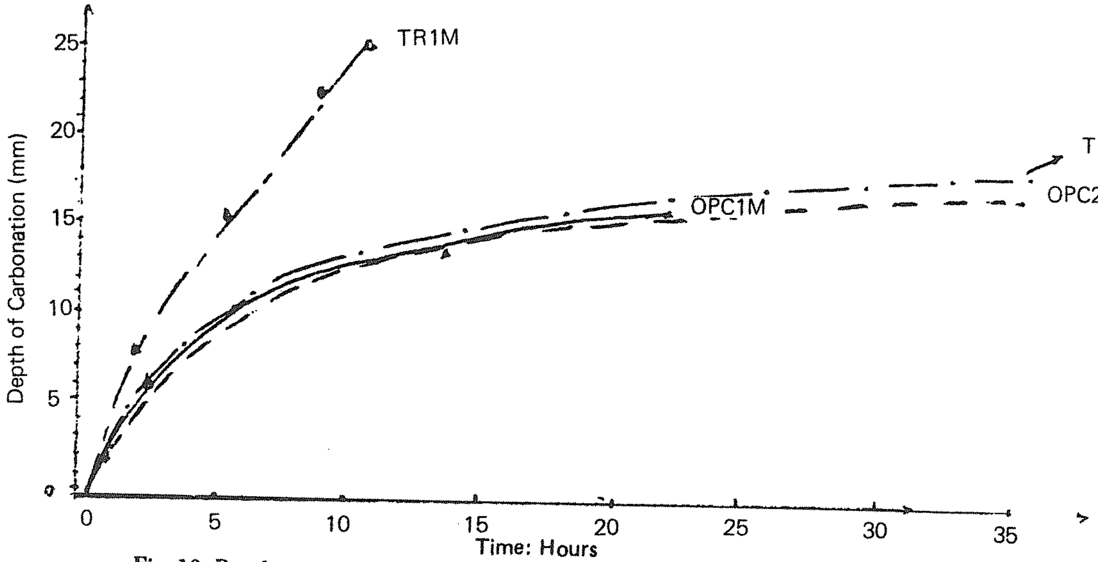

Fig. 10. Depths of Carbonation Time Relation Obtained Under Accelerated Conditions 90% RH, 90% CO_2, 1 At. and 0 days Curing for Mortar Mixes.

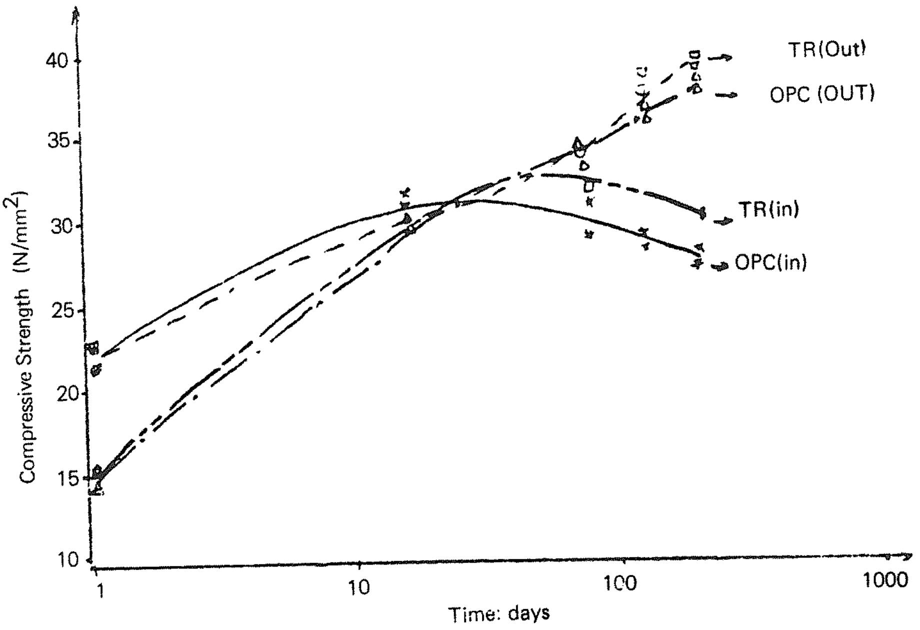

Fig. 7. Compressive Strength at Various Ages for OPC and TR Concrete Mixes Inside and Outside Sulphate Solution.

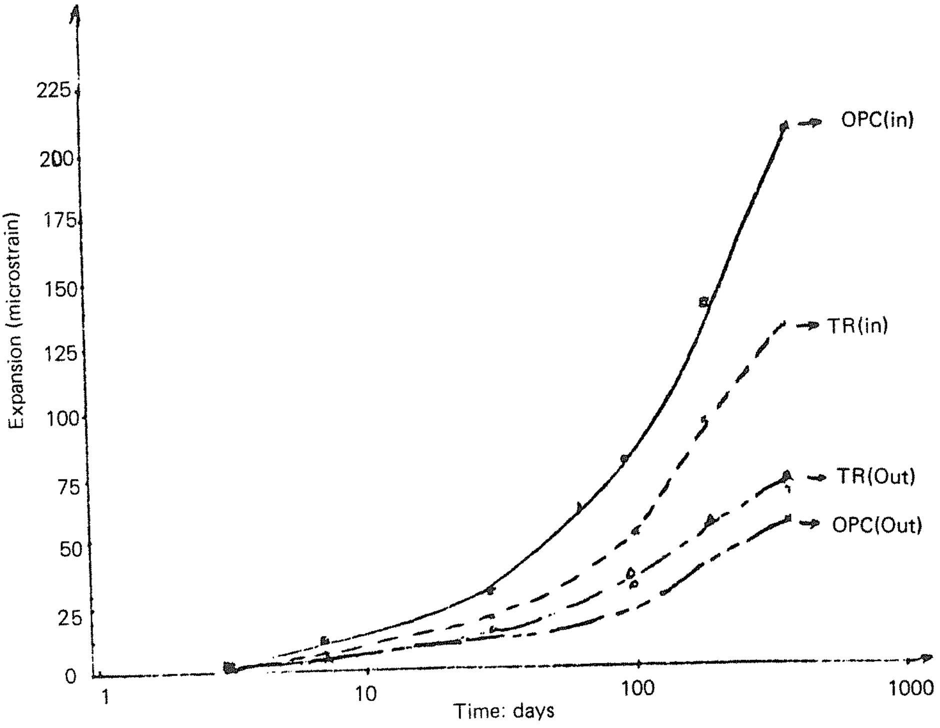

Fig. 8. Expansion at Various Ages for OPC and TR mortar Mixes Inside and Outside Sulphate Solution.

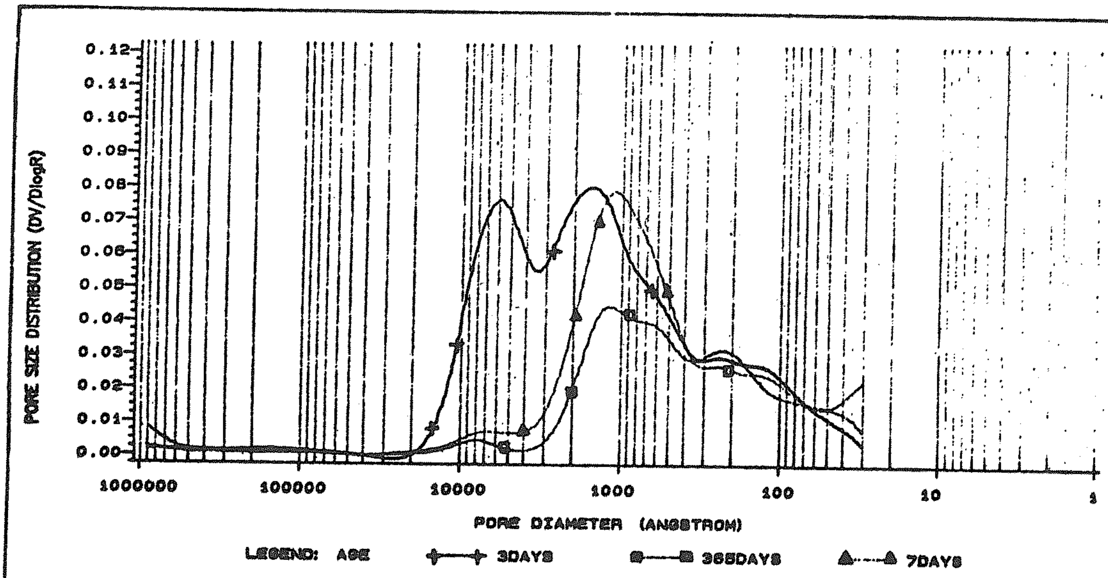

Fig. 5. Derivative Pore Size Distribution for OPC1M Mortar Mix at 3,7 and 365 days

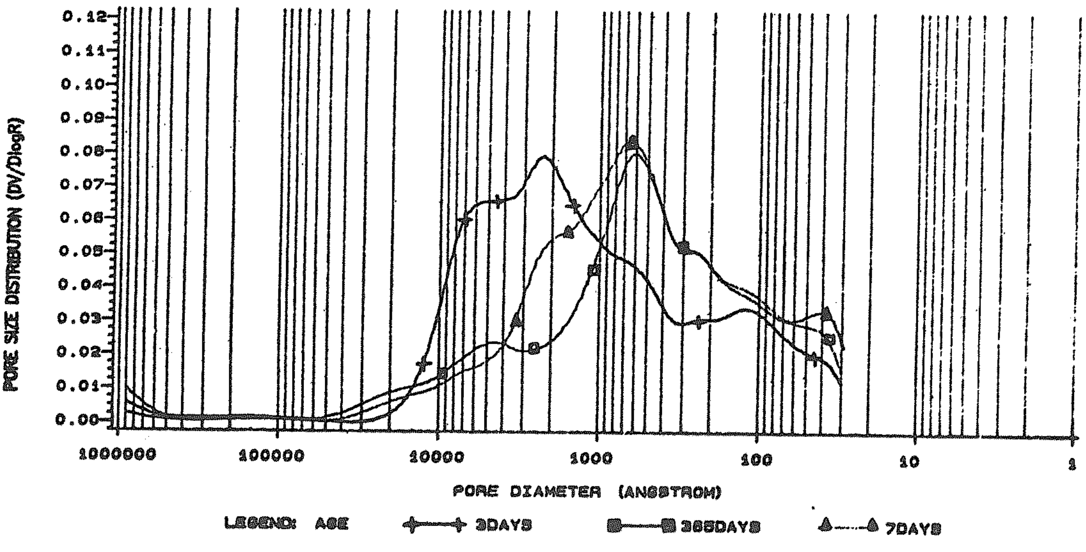

Fig. 6. Derivative Pore Size Distribution for TR1M Mortar Mix at 3,7 and 365 days

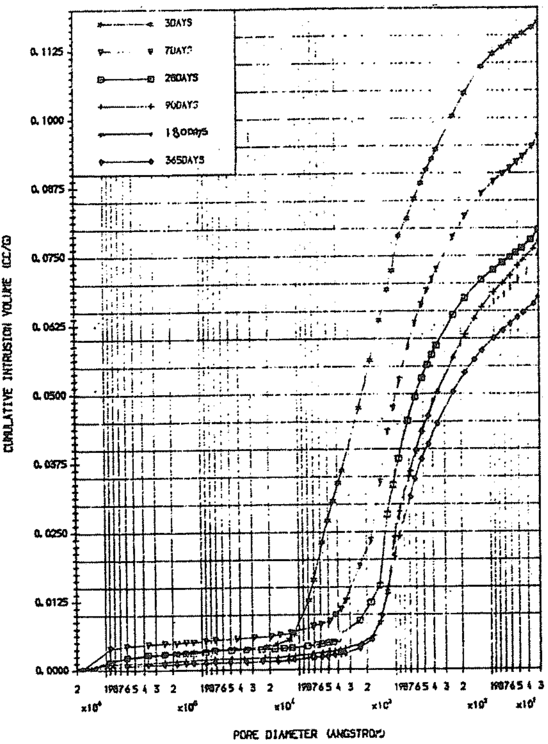

Fig. 1. Cumulative Pore Size Distribution for OPC1M Mortar at Various ages

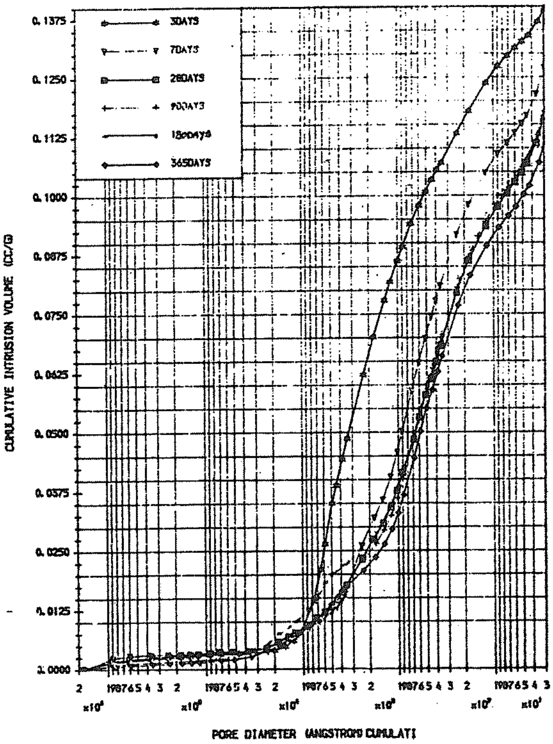

Fig. 2. Cumulative Pore Size Distribution for TR1M Mortar at Various Ages

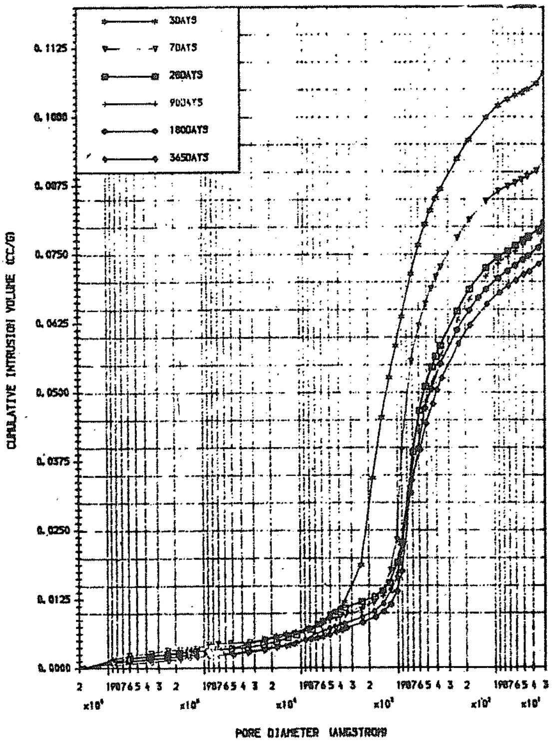

Fig.3. Cumulative Pore Size Distribution for OPC1M Mortar at Various Ages

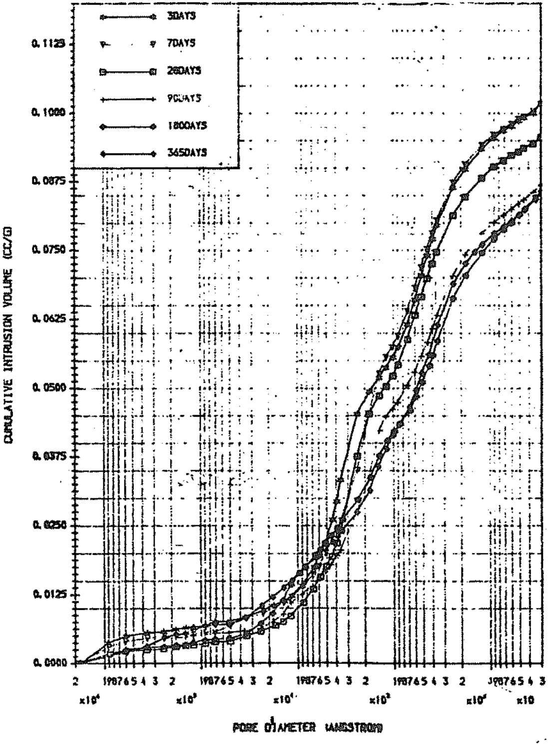

Fig. 4. Cumulative Pore Size Distribution for TR2M Mortar at Various Ages

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Specimen	Oxygen Permeability 10^{-16} m^2					
	3days	7days	28days	90days	180days	365days
OPC1M	5.02	1.77	1.34	0.9	0.53	0.46
TR1M	8.34	4.01	1.6	1.34	1.0	0.93
OPC2M	4.42	1.23	1.06	0.58	0.39	0.32
TR2M	5.08	1.48	1.25	0.52	0.34	0.29

Table 1. Average Oxygen Permeability of Mortar Mixes at Different Ages.

mix	OPC1M	TR1M	OPC2M	TR2M
Effective diffusivities Cm^2/S	22.28×10^{-9}	29.74×10^{-9}	22.51×10^{-9}	22.40×10^{-9}

Table 2: Effective diffusivities of chloride ion in OPC and OPC/TR mortars

t = Time of exposure, months

These models are only applicable to the particular combination of curing and environmental conditions. The equations derived in this part for long term carbonation can be related to the equations derived for accelerated carbonation. As an example for OPC1M mortar having no curing the following expressions have been found under normal and accelerated conditions:

$X_1 = 3.28 \sqrt{t_1}$ accelerated conditions: 50% CO_2, 90% RH, 1 atmosphere

$X_2 = 1.756\sqrt{t_2}$ normal conditions

where X_1 and X_2 are the depth of carbonation in mm, and t_1 and t_2 are the time of carbonation in hours and months respectively. For the same depth of carbonation in both conditions, the relation between t_1 and t_2 is:

$$t_2 \text{ (months)} = 3.5\, t_1 \text{ (hours)}$$

Conclusions

The following conclusions are drawn from the results of this investigation on Portland pozzolan cements containing 20% trass:

For all mortar mixes the porosity decreased with increasing time. The difference in porosity values for mortars between 3 and 7 days was high. Porosity also decreased in all mortar mixes made with superplasticizer due to the reduction in water content. The peaks of the derivative pore size distribution curves shifted to the smaller pore region with time. The size and the shape of peaks between 3 and 7 days were quite different.

Similar to the porosity results there was a dramatic fall in the gas permeability of mortar mixes between 3 and 7 days of age. The permeability reduced as time proceeded due to the pozzolanic reaction which resulted in pore filling process by extra hydration products. In general specimens made with super plasticizer presented lower gas permeability. The penetration of sulphate ions in OPC mortar mixes measured as the amount of sulphate at various depths by XRF was greater than that of OPC/TR mortars. This caused lower strength, higher expansion and severe deterioration in OPC mixes whereas OPC/TR specimens remained unaffected.

The difference between the values of effective diffusivity of chloride ions in OPC and OPC/TR mortar mixes could not be attributed simply to the variations among the pore structures of the mixes. Limited results in the present work showed a good agreement between the gas permeability and effective diffusivity of chloride ions in mortar mixes.

The trends obtained in the accelerated carbonation tests using a simple newly designed apparatus confirmed the trends observed under natural condittions for long periods. The progress of carbonation depended upon the composition of the mix, curing, age and the test conditions, i.e. CO_2 concentration and relative humidity. The poor performance of trass mix exposed to CO_2 was improved by the inclusion of :superplasticizer.. With the limited data in this investigation models were derived relating the depth of carbonation to the porosity and square root of exposure time.

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of trass in improving the durability of mortars when exposed to sulphate solution. The approximate sulphate content of each sample was obtained by converting each XRF trace using a calibration curve and plotted as sulphate content against depth in figure 9. This shows that in both OPC and OPC/TR mortar specimens, the sulphate level increases from a low level at the surface, to a maximum which occurs at a greater depth. The fact that the maximum does not occur at the surface indicate that there is a counter process of sulphate dissolution into the surrounding solution as has been explained by similar results obtained by Cabrera and Plowman.(8) The maximum depth and the position of the peak vary in OPC and OPC/TR mortars. Figure 9 shows that the maximum depth of sulphate penetration in OPC mortar is approximately 6mm while in OPC/TR mortar it falls to 4mm. This also reveals the higher resistance of OPC/TR mortar in sulphate attack than OPC mortar. Visual examination shows severe corner damage and disintegration at 270 days in OPC mortar cubes while no sign of deterioration is observed in OPC/TR mortar cubes after the same period of sulphate exposure.

b) Chloride Diffusion

The values of effective diffusivity of chloride ions in four mortar mixes are given in table 2. The results indicate that the diffusion of chloride ions in mortars is influenced by the addition of pozzolans and superplasticizer. The difference between the effective diffusivity of TR1M and OPC1M mortars can be attributed to the higher W/C ratio and greater total poropsity of TR1M mortar. Examining the pore size distribution curves of the two mortar mixes shown in figures 1 and 2, it is clear that the pore structure of the two mortar specimens are dissimilar. The effective diffusivities of OPC2M and TR2M mortars manufactured with superplasticizer are very close at the age of one year (table 2). This can not be ascribed simply to the total porosity of these mortar mixes. It is therefore the distribution of the pores which is more important in affecting the diffusion rate than total porosity. However, the effective diffusivity of mortar specimens obtained in this investigation can be related to the gas permeability coefficient of them. Comparison of the results in tables 1 and 2 shows a good agreement between the permeability of OPC1M, TR1M, OPC2M and TR2M specimens and their effective diffusivities.

c) Carbonation

Results of the depth of carbonation against time for OPC1M, OPC2M, TR1M and TR2M mortar mixes under various conditions of relative humidity, CO_2 pressure, CO_2 concentration and curing in accelerated test showed higher carbonation for trass mortars. As an example the depth of carbonation time relation is shown in figure 10 for OPC and OPC/TR mortars with and without superplasticizer under accelerated conditions of 90% RH, 90% CO_2, 1 atmosphere pressure and no curing. The trend observed in long term carbonation test was similar to The trend observed in accelerated conditions. After 2 years TR1M mortar specimens having no curing showed 4.8mm carbonation whereas OPC1M mortar specimens carbonated only 2mm under same condition of outdoor storage. Full results of the carbonation tests and the effect of curing, relative humidity, pressure, CO_2 concentration on the depth of carbonation have been published elsewhere (5,9) Based on data obtained in this investigation attempt was made to derive models for the rate of long term carbonation which take into account the porosity of mortar mixes. It is generally recognized that the rate of carbonation is proportional to the square root of exposure time and proportional to the water cement ratio which is related to the porosity. The rate of carbonation of non–superplasticized mixes can be expressed by the following equations:

For OPC1M $x = 4.66\,(P+0.095)\sqrt{t}$ $r = 0.991$

For TR1M mortar $x = 9.62(P-0.03)\sqrt{t}$ $r = 0.985$

where:

x = Average depth of carbonation of 3 faces of mortar cubes, mm

P = porosity of mortar cubes after certain days fog curing and before carbonation sive strength of 50 mm mortar cubes and the expansion of 200 x 50 x 50 mm mortar prisms were determind for specimens immersed in sulphate solution and those left outside. For sulphate content determination X-ray spectrometry technique was used.

Chloride ion diffusion test was carried out according to the technique developed by Page et al.(4) In this method ionic diffusion is measured with a concentration difference between two sides of the sample. One mole/l sodium chloride in lime water was used in one side of the sample and chloride ion was monitored at regular intervals in the saturated lime solution on the other side.

c) Carbonation

Accelerated carbonation test was carried out by using an apparatus designed by author for this purpose. The description of the apparatus has been described elsewhere.(5) Depth of carbonation was measured using a PH indicator (2% solution of phenol phthalene in ethyl-alcohol) The results are the average depth of carbonation measured perpendicularly of three faces of a freshly broken mortar cube using two cubes for each result. Based on data obtained in the long term carbonation attempt was made to derive models for the rate of long term carbonation which take into account the porosity of mortar mixes.

Test Results and Discussion

The experimental pore size distribution curves are presented as the cumulative pore size distribution curves. Figures 1, 2, 3, 4 represent the cumulative pore size distribution at 3, 7, 28, 90. 180 and 365 days for OPC and OPC/TR mortar mixes. It can be seen that the total intruded volume decreases with time in all mortars. In almost all the mortars the difference between the porosities of 3 days and 7 days is high whereas this difference becomes very low between 90 days and 365 days. Figure 2 shows that higher demand of water in TR mix to achieve the same workability as OPC mix has resulted in higher porosity when compared with OPC mortar. However, the total porosity decreases in suoerplasticized mixes due to the reduction in W/C ratio (figure 4). In order to see the effect of time on the pore size distribution of OPC and TR mortar mixes, the derivative distributions of these mixes at 3, 7 and 365 days are plotted in figures 5 and 6. It can be seen that with increasing age, the size and position of peaks are altered considerably. The effect of time of the pore size distribution is more pronounced at early ages.

The results of the average oxygen permeabilities of 5 pressure readings for all specimens at different ages are given in table 1. Each value in this table is the average from at least two specimens. It can be clearly seen that permeability decreases with time. All the specimens undergo a dramatical fall in permeability between 3 and 7 days. In general, specimens associated with (superplasticizer) have shown lower permeability in comparison with normal mortars.

Durability

a) Sulphate Resistance

Result of the tests carried out for determining the compressive strength of OPC and OPC/TR mortars is shown in figure7. The strength of all sulphate cured mortars increases initially upto a maximum value beyond which it decreases. This was also found in investigations carried out by Samanta et al(6) and Richards.(7) It is interesting to note that the use of trass in OPC mortars has increased the resistance of mortars to attack by sulphate solution. The OPC/TR mortar cured in sulphate solution shows higher strength than OPC mortar in the same condition.

Result of the expansion test is also shown in figure 8 as expansion versus time. Very little expansion is observed in OPC and OPC/TR mortar prisms cured at 100% RH and $20^{o}C$ (out of sulphate solution) at the age of 365 days. Comparison of the expansion of OPC and OPC/TR mortar prisms shows that the OPC mix produces a higher expansion rate than the OPC/TR mix. This clearly shows the effect

Durability of mortars and concretes made with OPC and trass

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ABSTRACT

A laboratory study into the durability of OPC and trass-OPC mortars and concerets in presented.

A natural pozzolan of volcanic origin obtained from the Damavand area in Iran and known as "trass" is used to substitute 20% of the OPC content of mortar and concrete. The performance of the material is evaluated by measurements of total porosity, Pore size distribution and permeability in relation to their response to aggressive chloride and sulphate concentrated solution and also Co_2 gas. The carbonation data is used to formulate a performance-time function which is proposed as a model to assess durability of the mortars and concretes.

INTRODUCTION

The performance and durability of concrete structures in aggressive environments are the main subjects of discussion in many international conferences. It is essential to have a durable concrete. Addition of pozzolanic materials to a concrete mix may bring about a considerable improvement in the quality of concrete and its durability. This paper presents the results of laboratory studies of sulphate and chloride attack and carbonation of mortars made with OPC and a natural Pozzolan known as trass.

Materials and Preparation of Specimens

This part has been discussed in the paper regarding the engineering properties of the OPC-trass mortars and concretes (1) and is not repeated again. The same materials and mixes are used for the assessment of durability.

Experimental Details

a) porosity, pore size distribution and Permeability.

Selected samples were analysed using a mercury porosimeter, micromeritics Auto-Pore 9200 to elucidate the changes which occur in the Pore size distribution characteristics with the addition of trass at various times. Gas permeability was used for the assessment of the permeability of mortar mixes. Relationships are developed between pore size distribution and permeability. In this work the permeameter designed for gas permeability test was used for measuring the permeability of small mortar specimens.(2)

b) Chloride and Sulphate Attacks

There are no standard methods of tests for sulphate and chloride resistance of mortars and concretes. In this investigation an accelerated sulphate test was used.(3) The specimens were immersed in 4% Na_2SO_4 solution and the PH of the solution was maintained constant (PH = 6–7) by adding small quantities of 0.1 N sulphuric acid regularly. Compres-