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SORPTIVITY OF FLY ASH CONCRETES

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ABSTRACT

A factorial experiment was designed to measure the sorptivity of cement and fly ash concretes in order to compare the durability of fly ash concrete against the cement concrete. Sorptivity measurements based on the capillary movement of water was made on three grades of cement concrete and six grades of fly ash mixes. The effect of curing was also studied by treating the samples in two curing conditions. A functional relationship of sorptivity against the strength, curing condition and fly ash content has been presented.

The results were useful to analyse the factors influencing the durability of cement and fly ash concretes and to explain why some of the previously reported findings were contradictary. Curing conditions have been found to be the most important factor that affected the durability properties of fly ash concrete. When proper curing was provided, a mix with 40% fly ash was found to reduce the sorptivity by 37%. Under inadequate curing the sorptivity was found to increase by 60%. The influence of curing on cement concrete was found to be of much less importance.

Introduction

Normally, the quality of a concrete is judged by the compressive strength of adequately cured samples at a given age. This practice was popular because, the strength of a concrete could be measured without undue difficulty when compared to that of measuring other parameters. However, the strength of a concrete was not found to be the appropriate parameter for assessing the durability of concretes. It has been demonstrated (1) that the concrete of a known strength produced by different compositions had different performance characteristics. The porestructure and alkalinity of the cover concrete were found to be the most important properties that affected the durability of a concrete. These are measured by the sorptivity and carbonation respectively. As the carbonation is irrelevent for concretes with zero sorptivity, the measurement of sorptivity assumes the primary importance in durability assessment of concretes.

Experimental Details

Materials. The materials used were 20 and 10 mm maximum size crushed gravel, river sand, Type A normal portland cement (similar to ASTM type 1) and a bituminous fly ash (ASTM Class F).

Test Details. Dhir et al (2) detailed a number of methods available, to study the water transport into the concrete. Hall (3) reviewed various methods for measurement of water penetration into concrete and suggested that the data of cumulative absorption of water observed over a reasonable period of time was more precise when compared to single point measurements. In this experiment the sorptivity was measured by a method similar to that suggested by Kelham (4) and the observations were recorded automatically to get the cumulative absorption over a period of one or two days. The period was so chosen as to complete the experimental work in a reasonable time and to reduce the errors of repeat measurements on samples. Because of this requirement, the thickness of the samples cast was reduced to 25mm instead of the 50mm suggested by Kelham (4). The samples were cast to the required thickness of 25mm rather than cutting them to the appropriate thickness. It was felt that casting the samples to the required thickness increased the accuracy of tests, as this helped to reduce the possible errors due to cracking while cutting the samples from test cylinders. Besides, the water absorption at the finished surface of a concrete was thought to be more realistic as it related to the conditions of a structural member. McCarter (5) observed noticeable difference in absorption characteristics between top, bottom and cut surfaces of samples. For consistency, the top surface of the finished concrete sample was always used for measuring absorption in this experiment.

Conditioning of Samples. The samples from different curing environments needed conditioning to bring all the specimen to identical test conditions. Dhir and Byars (6) reported that the samples dried in an oven at 105°C to a constant weight over a 24 hour period gave realistic results. The British Standards 1881 (7) also recommends similar treatment for conditioning of samples. The ASTM absorption test (8) stipulates a drying temperature of 100 to 110°C. The sorptivity values were also found to depend on the temperature used to condition the samples. Hall and Yau (9) found that the samples conditioned at 40°C had lower sorptivity than those conditioned at 105°C. For this experiment, all the samples were conditioned at 105°C, by drying them overnight in an oven as recommended by ASTM and British Standards.

Mix Details. Three grades of portland cement concrete having water cement ratios of 0.53, 0.62 and 0.88 were chosen for this experiment. These mixes are hereafter referred to as mixes M1, M2 and M3 respectively. Each grade of concrete was then redesigned to two levels of fly ash replacement at 20 and 40% by weight, resulting in a total of 9 mixes. The mix details and some characteristics of fresh concrete are detailed in Table 1. Eventhough the slumps of the mixes M1-20 and M3-40 were outside the target values, the conclusions would not be affected by this variation. The samples cast were 200 × 100mm cylinders for compressive strength test and and 100 × 25mm discs for absorption test. The samples were demoulded 24 hours after casting and subjected to standard fog curing at 23°C ± 2°C and a relative humidity of 95 ± 3% for seven days. Nine cylinders and six discs were then transferred to a controlled environment room which had the same temperature as the fog room

TABLE 1
Mix Details

Mix	Coarse Aggr. (kg/m^3)	Sand (kg/m^3)	Cement (kg/m^3)	Fly Ash (kg/m^3)	Water (kg/m^3)	Slump (mm)
M1-00	1151	621	390	0	205	65
M2-00	1237	666	297	0	185	85
M3-00	1295	698	204	0	180	60
M1-20	1151	621	311	78	197	150
M2-20	1232	664	236	60	182	45
M3-20	1278	689	161	40	187	25
M1-40	1164	627	236	158	180	90
M2-40	1230	662	177	119	177	60
M3-40	1287	694	121	81	177	10

but at a relative humidity of 50 ± 3%. This curing condition is hereafter referred to as "drying." Three cylinders from each curing condition were tested for compressive strength and two discs were tested for water absorption. The results for the compressive strengths are given in Table 2.

Results and Discussion

Variation of Strength. The variation of strength with curing and addition of fly ash for mixes M1, M2 and M3 is given in the Table 2. It is evident from the results that fly ash replacemets of 20% did not have a significant impact on the long term strength of fog cured mixes. The results from the fog cured samples showed that the rate of loss of strength was

TABLE 2
Compressive Strength (MPa)

Mix	Age of Concrete (days)					
	28		91		180	
	fog	dry	fog	dry	fog	dry
M1-00	49.9	45.1	58.8	51.6	61.2	51.9
M2-00	33.1	31.1	40.2	37.0	42.6	34.3
M3-00	18.9	15.4	21.0	18.6	20.8	16.9
M1-20	36.2	32.1	44.0	40.2	53.9	41.1
M2-20	25.2	22.4	33.1	26.6	42.4	27.4
M3-20	13.6	11.3	17.2	14.0	22.0	13.5
M1-40	20.4	16.7	28.3	21.5	35.8	20.9
M2-40	19.2	16.6	27.5	20.8	35.5	19.6
M3-40	10.3	7.5	13.1	9.5	18.1	9.2

TABLE 3
Sorptivity (mm/hr$^{1/2}$)

	Age of Concrete (days)					
	28		91		180	
Mix	fog	dry	fog	dry	fog	dry
M1-00	10.4	12.1	10.1	10.6	10.5	10.9
M2-00	10.5	12.8	9.70	11.3	11.4	12.1
M3-00	12.0	14.1	10.4	13.2	12.2	15.2
M1-20	11.0	15.3	9.00	11.7	8.00	12.4
M2-20	11.6	15.6	10.0	14.0	10.2	17.1
M3-20	13.4	15.9	9.70	16.9	9.60	18.2
M1-40	8.50	13.3	5.90	16.7	8.90	18.0
M2-40	9.60	18.9	8.00	17.0	9.30	22.0
M3-40	11.4	17.2	7.90	22.2	9.40	21.5

higher for richer mixes. Under "drying," there was no noticeable increase in strength after 91 days and the strength development pattern did not depend on the grade of the mix.

Curing, Age and Sorptivity. The measured sorptivity are given in Table 3. As expected, the concrete under "drying" had higher sorptivity than those cured in fog room. It could be argued that this was due to the improvement in strength of the fog cured samples. A correct picture could be obtained by comparing the increase in strength due to fog curing over

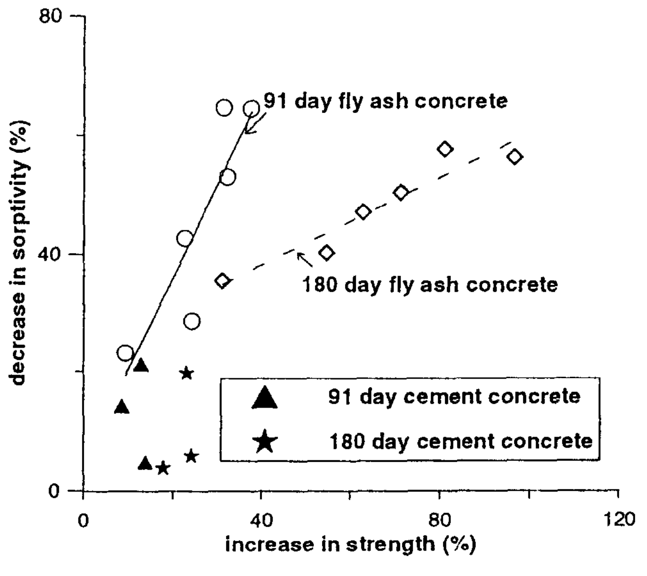

FIG. 1.
Change in sorptivity with change in cured strength.

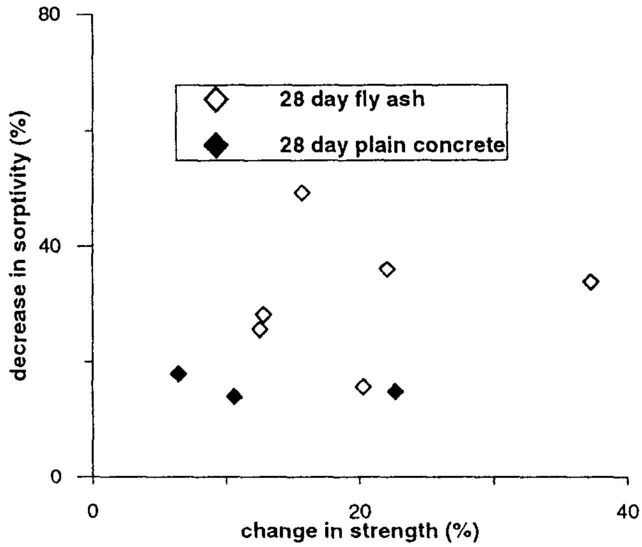

FIG. 2.
Change in sorptivity with change in cured strength.

dry samples and the corresponding changes in sorptivity. These are given in FIGS. 1 and 2. The results are separately analysed for each age of concrete. The increase in strength is calculated as the difference in fog cured and "drying" strengths divided by "drying" strength and the decrease in sorptivity is calculated as the difference between "drying" and fog cured values divided by the "drying" sorptivity. As shown in FIG. 2, there was no direct relationship between the change in strength and sorptivity at 28 days. However, for fly ash concretes at later ages, a direct relationship between the change in strength and sorptivity was found to exist. This is shown in FIG. 1.

The increase in sorptivity for samples of the cement concrete under "drying" was 19% at 28 days, 17% at 91 days and 12% at 180 days. Thus, the difference between sorptivity decreased with age. But the results of the fly ash concrete showed that the difference in sorptivity increased with age. The increase in sorptivity for 20% fly ash concrete was 30, 48 and 72% at 28, 91 and 180 days respectively. The corresponding values for 40% fly ash was 67, 156 and 123%. The results indicated that inadequate curing was more harmful to fly ash concrete than cement concrete. The sorptivity increased with the fly ash content and also with the age.

Strength and Sorptivity. The analysis of strength changes with curing indicated that the sorptivity variation was proportional to the change in strength for fly ash mixes and no such relationship existed for the cement concrete. The relationship of absolute strength and sorptivity is of interest in determining if the quality of a concrete could be assessed when the strength is known. The variation of sorptivity with strength is plotted in FIGS. 3, 4 and 5. These figures were intended only to demonstrate the underlying trend and therefore some of the points which were statistically outliers were not plotted to improve clarity. These curves indicate that sorptivity could be linked with strength irrespective of the age

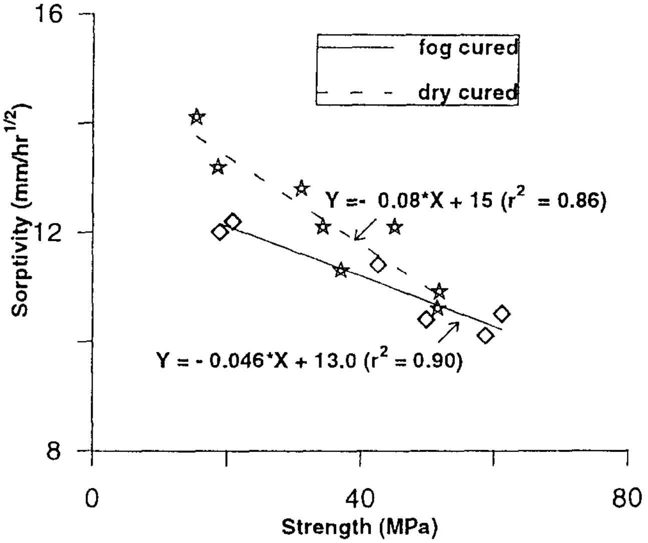

FIG. 3.
Variation of sorptivity with strength (cement concrete).

of the concrete. The change in strength with age is associated with corresponding change in sorptivity of the concrete. Eventhough the strength of a concrete could be used as a measure of its durability at all ages, the results depended on the method of proportioning adopted. The graphs for cement concrete and fly ash concretes were therefore drawn separately. The regression functions of the variables are also given in the graph. It may be observed that for cement concrete the regression line had a slope of 0.046 for fog cured samples. When 20% fly ash was added to the mix, the slope of the curves increased three fold to 0.13. At 40% the change in sorptivity with strength was much steeper and had a slope of 0.26. Similar results hold good for the concrete under "drying" as well. The sorptivity of the samples under "drying" was, in general, 50% more than that of the corresponding fog cured concrete. Patel et al (10) reported that replacing 30% of portland cement with fly ash at a constant water/solid ratio of 0.59 had little effect on the porosity and diffusion characteristics of the concrete at 163 days. The results from this study did not support such a conclusion as the mix M2 had a water/solid ratio similar to that reported by Patel et al. Besides, the results of this study was independent of the water/solid ratio.

Effect of Fly Ash Addition on Sorptivity. As seen from Table 3 the sorptivity of the hardened concrete changed with the addition fly ash. The changes in the sorptivity was maximum for the mixes which had a fly ash content of 40%. This observation does not prove that the sorptivity of fly ash mixes are always higher than that of the cement concrete mixes. In these experiments the cement has been replaced by fly ash of equal weight which resulted in a reduction of strength of the fly ash mixes. The comparison would be appropriate only when cement and fly ash mixes of similar strengths are considered. This is illustrated in FIG. 6 where cement and

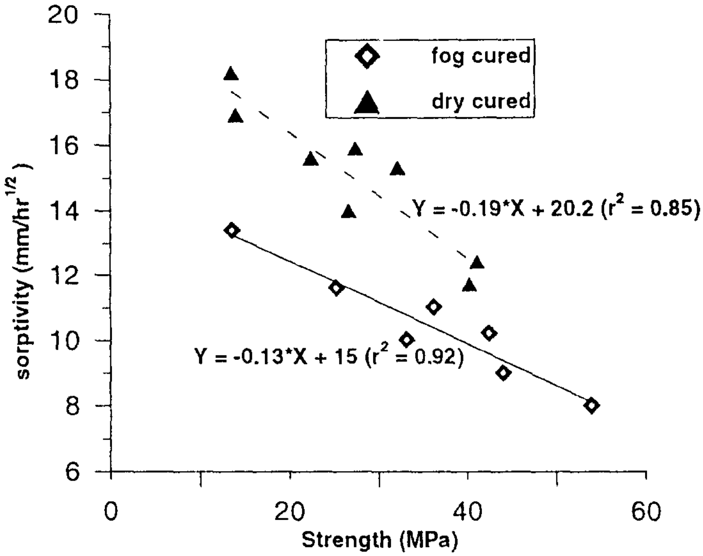

FIG. 4.
Variation of sorptivity with strength (20% Fly Ash).

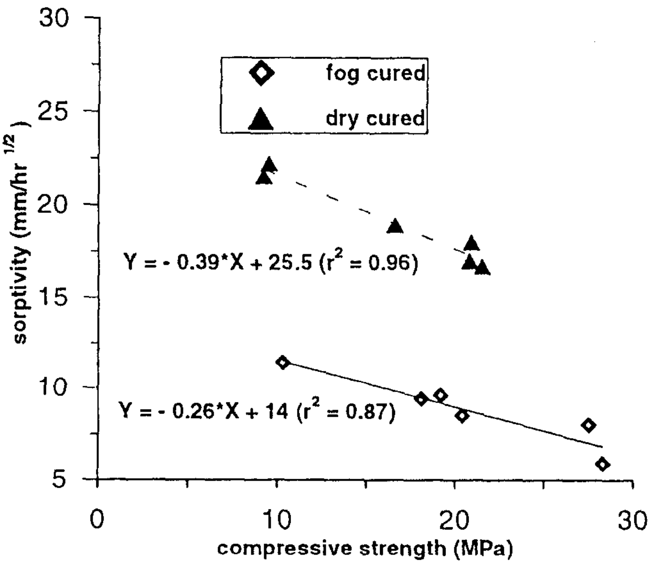

FIG. 5.
Variation of sorptivity with strength (40% Fly Ash).

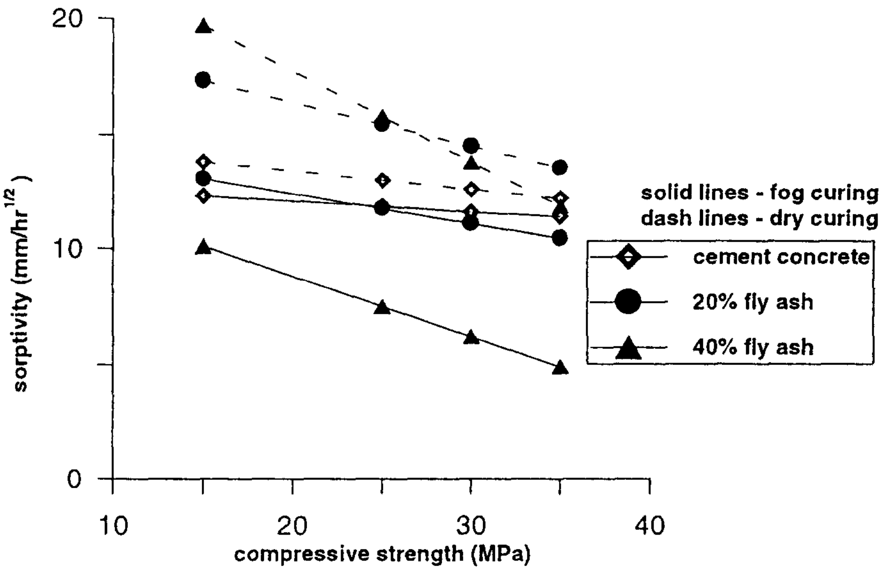

FIG. 6.
Sorptivity of cement and fly ash concretes (identical strength).

fly ash concretes having identical compressive strengths in the range of 15 to 35 MPa had been considered. As stated earlier, the sorptivity was found to be higher under "drying" conditions. The important feature was, for cement concrete the difference in sorptivity between "drying" and fog curing was not significantly different for the range of strengths considered. Also, the addition of fly ash up to 20% did not change the sorptivity characteristics substantially. But, for high fly ash concretes, the sorptivity was lower than the cement concrete of identical strength. On an average, the sorptivity of properly cured concrete only ash was found to be 37% lower than that of cement concrete. But, under "drying," the sorptivity increased by an average of 22%. For fly ash replacements of 20%, there was no noticeable difference between fog cured fly ash and cement concretes. For the samples under "drying," the increase in sorptivity was 19%. Thus, inadequate curing for a 20% fly ash concrete resulted in an increase of 20% in sorptivity. The corresponding value for 40% fly ash concrete was 60%.

Binder Content and Sorptivity. The sorptivity changed with the total binder content of the mixes as shown in Tables 1 and 3. Since the mixes were designed to have the same binder content, as fly ash was used as replacement for cement, the sorptivity of the concrete should not be significantly different for all the mixes if the binder material did not affect it. As can be seen from the Table 3, the sorptivity results were different between mixes. It was not possible to find a reasonable fit of the results with the total binder content, even when the analysis was done separately for the two curing conditions. Therefore, it was concluded that the sorptivity cannot be related with the total binder content of the concrete mixes as the variation could not be fitted to a regression model.

Conclusion

The addition of fly ash to a concrete influenced the sorptivity of the hardened concrete which strongly depended on the curing condition provided. When fog cured concretes of identical strengths were considered, the sorptivity of the fly ash concrete was found to be lower than that of cement concrete. Under "drying," the fly ash concrete had higher sorptivity than cement concrete.

For a given proportioning adopted, the compressive strength of the concrete cylinders was found to be a good indicator of its durability.

The increase in sorptivity of the samples of the cement concrete under "drying" reduced with the age. But the results of the fly ash concrete showed an increase with age. This indicated that the lack of curing was more damaging to the durability of fly ash concrete than cement concrete.

The change in sorptivity for a given strength difference was much higher for fly ash concrete when compared to the cement concrete. This gradient was found to increase with the fly ash content of the mix and its age.

No direct relationship was found to exist between sorptivity and total binder content of the concrete, eventhough the sorptivity changed with binder content.

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