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Durability Properties of Concrete Influenced By Microfines

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ABSTRACT: *Concretes produced from puzzolona cements and those in which supplementary cementitious materials are added during the production of concrete have shown better durability properties in comparison to concrete made from ordinary Portland cement. This is attributed to improved pore structure, and the effect of secondary hydration. With the availability of natural sand getting reduced, fine aggregates are now made from rocks. In this process particle less than 75microns, called microfines are produced. Quarry dust is mostly wasted as codes limit the percentage of microfines in concrete. This study investigates the effect of partial replacement of cement with quarry dust and a microfine cement made for special uses, on the durability properties of concrete. The percentage replacement of quarry dust is kept constant at 7.5 % by weight of cement, while the percentage replacement of microfine cement is varied from 5 to 20%. The results of this investigation are encouraging and have shown that water absorption, sorptivity and chloride penetration are decreased and acid resistance increases due to such replacements.*

Keywords: *microfines, acid resistance, water absorption, sorptivity, and chloride penetration.*

I. INTRODUCTION

A strong concrete was believed to be a durable concrete few decade's back and concretes were designed for high strength. However, early deterioration of the structures and enhanced costs of maintenance has brought in the realization that concrete needs to be designed for both strength and durability. As the impermeability of the concrete increases, the durability of the concrete is set to increase as most factors which result in faster deterioration are either water borne or air borne. Enhancing the cover of concrete is found to reduce the permeability. Compounds like talc, chalk, fuller's earth have been used by the concrete industry to fill/eliminate the unexpected voids in concrete, making it less permeable [1]. Use of supplementary cementitious materials as partial replacements for cement and also for addition to the concrete during mixing has given enhanced workability, along with high strength and durability. Ordinary Portland cement was the main variety of cement manufactured in India till early 2000s, but in 2011, puzzolonic cement produced was about 68.05% of the total cement manufactured in the country [2].

The availability of river sand as fine aggregates for concreting is on the decrease while the demand for fine aggregates is on the increase. Many governments' state and central have banned or limited the mining of natural river sand on environmental concerns. The concrete industry is dependent upon fine sand manufactured from rocks. In this production process, considerable amount of microfine particles of size less than 75 microns are produced. This material known as quarry dust, stone dust or simply dust has no takers and is mostly used for land filling. The material being inert is considered unsuitable for partial replacement of cement as it would increase the insoluble residue in the cement. However, several researchers have attempted to use this material for partial replacement of cement either in isolation or in combination with other supplementary cementitious materials [3,4,5,6,7]. The result of such research has been encouraging and it is opined by the researchers that this material has to the potential to partially replace cement.

The cement industry manufactures several types of microfine cements for special purposes like grouting, increasing workability, etc., Researchers have used such microfine cements for partial replacement of cement [8,9,10] and have reported encouraging results. The durability aspects of concrete with microfines are sparsely reported. In this paper, the findings of experimental investigations on durability parameters of concretes, wherein, the two microfine materials, stone dust and microfine cement were used in combination to partially replace cement are analyzed and reported.

II. EXPERIMENTAL INVESTIGATION

2.1 Materials

Cement: 43 Grade ordinary Portland cement conforming to IS 8112:2013 [11] is used in this study.

Microfine cement: Microfine cement manufactured by ACC-Alccofine and marketed with the brand name Alccofine 1203 is the microfine cement used in the study.

Quarry dust: Quarry dust passing through 75 micron is collected from a stone quarry bordering Goa-Maharashtra states.

The physical and chemical properties of cement, microfine cement, and quarry dust are detailed in Table 1; in-line with the codal stipulations in IS 8112:2013.

Table 1: Physical and Chemical Properties of cement, quarry dust and microfine cement

Sl No	Property/Constituent	Microfine cement	Quarry dust	Cement	Requirements as per IS 8112:2013
Physical Properties					
1	Fineness (m^2/kg)	1200	140	327	Min 225
2	Bulk Density (kg/m^3)	878	1610	1169	
3	Specific Gravity	2.90	2.77	3.13	
Chemical Properties					
1	Silica (SiO_2, % by mass)	35.6	62.22	21.6	
2	Alumina (Al_2O_3, % by mass)	21.7	15.01	4.8	
3	Ferric Oxide (Fe_2O_3, % by mass)	1.4	8.37	3.9	
4	Calcium Oxide (CaO, % by mass)	33.5	3.52	62.7	
5	Magnesium Oxide (MgO, % by mass)	6.3	4.00	0.9	Max 6.0
6	Total Sulphur content calculated as Sulphuric Anhydride (SO_3)	0.11	0.05	2.5	Max 3.5
7	Chloride content (% by mass)			0.02	Max 0.10
8	Loss of Ignition (% by mass)	0.67	1.71	1.8	Max 5.0
9	Insoluble Residue (% by mass)	0.49	81.40	0.75	Max 4.0

However, the percentage of Insoluble Residue in the quarry dust sample is much higher than the maximum limit of 4.00 % specified by IS 8112:1989, which is expected as quarry dust is an inert material.
Further the XRD images of cement, quarry dust and microfine cement are shown in Figures 1, 2 and 3 respectively

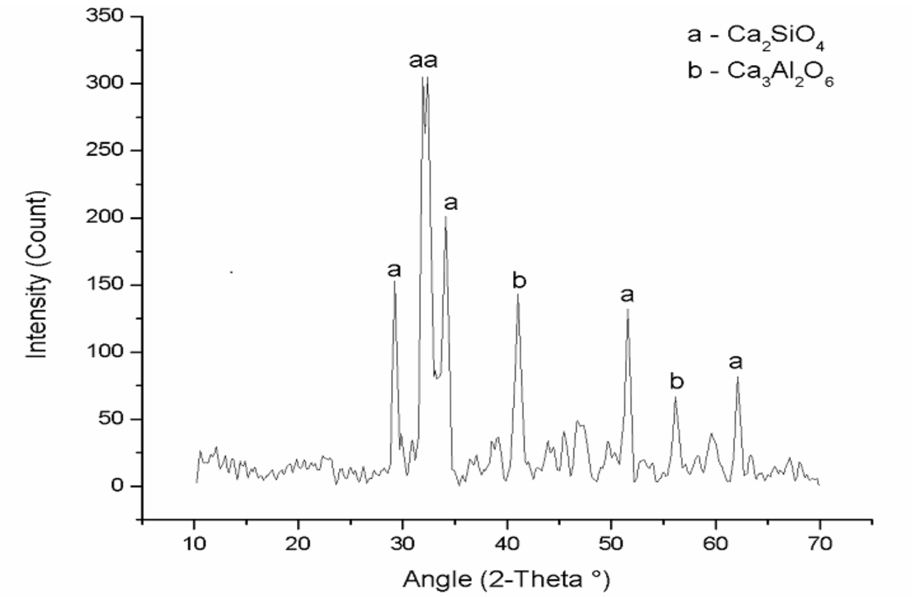

Fig 1: XRD image of cement

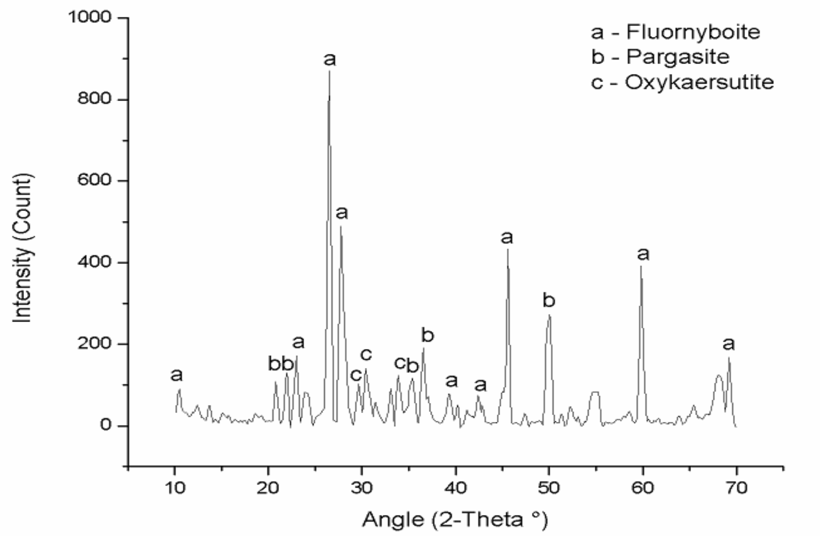

Fig 2: XRD image of Quarry dust

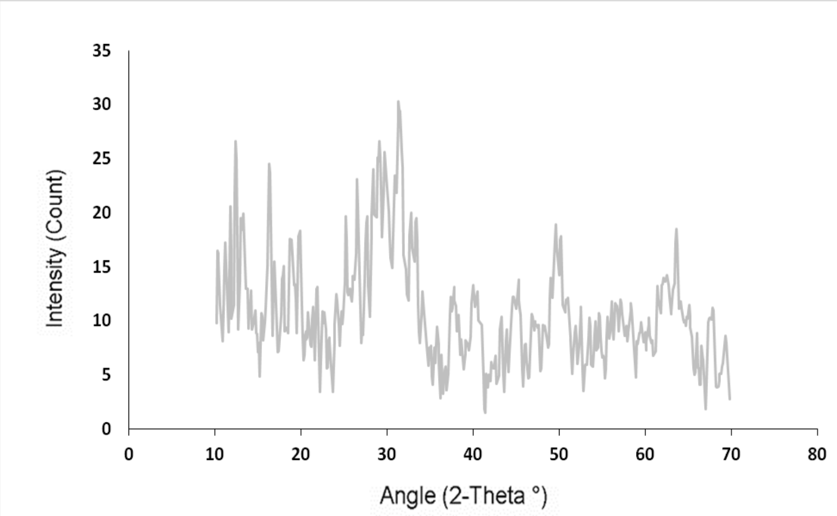

Fig 3: XRD image of Microfine cement

The XRD study of cement in Fig. 1 indicates the presence of mineral phases in the form of Dicalcium silicate (Belite) and Tricalcium aluminate (Aluminate or Celite). The highest intensity peaks of Dicalcium silicate phase is observed in between 30-40 degree whereas couple of peaks of aluminate phase is also observed. The study confirms the presence of crystalline phases.

The XRD analysis of quarry dust in Fig. 2, indicates the formation of Fluornyboite, Pargasite and Oxykaersutite phases. However, the highest intensity peaks were observed for Fluornyboite which is a combination of sodium, potassium calcium and other elements. The minor phases of pragasite and Oxykaersutite are also observed from the XRD analysis.

The XRD analysis of microfine cement in Fig. 3 shows no peaks meaning no crystalline phase are detectable in the microfine cement. Having no crystalline phase and having small particle size indicates that the material has a high degree of reactivity.

Fine aggregates: Locally available river sand of Zone I and Zone IV were used in the study and had a specific gravity of 2.70 and 2.63 respectively.

Admixture: Sulphonated Napthalene Polymer, which gets instantly dispersed in water and is formulated to give water reduction without loss of workability, was the admixture used in the study.

2.2 Specimen Types

In this study cement is partially replaced with quarry dust and special purpose microfine cement. The replacement of quarry dust is kept constant at 7.5%, while microfine cement percentage is varied from 5, 10, 15 and 20%. The specimen types and the binder quantities are given in Table 2.

2.3 Mix Proportions, Casting and Curing

For the purpose of this study, mix design for a target compressive strength of 35 MPa is made as per IS 10262:2009 [12]. One control mix of only cement and four mixes with cement replacements as indicated in Table 2 were prepared.

The specimens were cast using laboratory pan mixer, compacted on vibrating table and were cured in shaded curing tanks.

Table 2: Specimen Type and Binder Quantities

Sl No.	Designation of Specimen	Binders		
		Cement (%)	Microfine cement (%)	Quarry dust (%)
1	**C**	100	-	-
2	**C1**	72.5	20	7.5
3	**C2**	77.5	15	7.5
4	**C3**	82.5	10	7.5
5	**C4**	87.5	5	7.5

2.4 Test Methods

Saturated water absorption test: After 28 days of curing the 70.6 mm cubical concrete specimens were dried in an oven at 110±5^{0}C for not less than 24 hours and until there was no change in mass on two consecutive weightings. After noting down the mass, the specimens were immersed in water for not less than 48 hours and until there was no change in the mass of the specimens on consecutive weightings. This mass was again noted. The difference between the saturated mass and the over dried mass, as a percentage of the oven dried mass indicated the saturated water absorption [13].

Acid resistance test: After 28 days of curing the 100 mm cubical concrete specimens were weighed and immersed in 5% sulfuric acid solutions for 45 and 90 days. Similarly another set of specimens were immersed in 5% hydrochloric acid solutions for 45, 90 days. Thereafter the specimens were removed, cleaned under flowing tap water to remove all loose adhering and the specimens were surface examined. Then the weight and compressive strength of the specimens were determined. The percentage loss of weight, percentage loss of compressive strength and the acid durability factor were determined, both for sulfuric and hydrochloric acid exposures.

Sulfate attack test: The test procedure and testing was similar to Acid resistance test. However, the specimens were immersed in 5% magnesium sulfate solutions for 45 and 90 days.

Sorptivity test: After 28 days of curing the 100 mm cubical concrete specimens were dried in an oven at 110±5^{0}C for not less than 24 hours and until there was no change in mass on two consecutive weightings. The specimens were epoxy coated on the outside, but for two parallel faces. The specimen was there after kept in a tray on wooden pieces such that water could rise from the unpainted bottom surface only vertically. The water level was maintained at 5mm from the bottom of the cubical specimen. The weight of the specimens was recorded at 2, 5, 10, 20,40, 60 minutes, 2, 4, 8 hours and 1, 2, 3, …7 days to measure capacity of the concrete medium to absorb water by capillary action.

Rapid Chloride Permeability Test (RCPT): After 28 days of curing, the 100 mm dia, 200 mm height cylindrical specimens are cut using diamond dressed coring bit to three samples of 100 mm dia and 50 mm height. The curved surface is coated with epoxy, the specimen is vacuum saturated with water and then soaked for 18 hours. The two flat surfaces of the specimen are exposed to sodium chloride at one end and sodium hydroxide at the other end and 60 V potential is applied to increase the rate of penetration. The total charge passing through the specimen is found by calculating the total area under the plot of time versus current and is expressed in Coulombs [14].
Further the compressive strength of these specimen types was also determined on 150mm cubical specimens as per IS 516:1959 [15]

III. RESULTS AND DISCUSSION

The results of the water absorption test are tabulated in Table 3. It can be seen that the percentage of water absorption has reduced with the replacement of cement by the microfines. It can be further seen from Fig. 4, that the specimen type C2, which has the highest compressive strength at 28 days, has the lowest saturated water absorption indicating the microfines has filled the pores more effectively and there by reduced the water absorption.

Table 3: Saturated Water Absorption Test

Sl No.	Designation of Specimen	28 day Compressive strength (MPa)	% Water Absorption
1	C	42.8	4.19
2	C1	48.54	3.9
3	C2	52.80	3.81
4	C3	47.87	4.02
5	C4	40.93	4.13

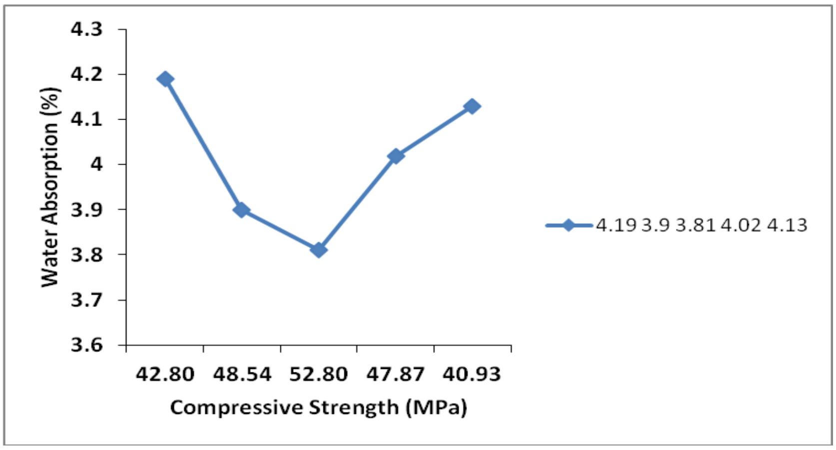

Fig 4: Comparison of Compressive strength with Water Absorption

The images of the specimens after immersion in 5% sulfuric acid, hydrochloric acid and magnesium sulfate acid solutions for 45 and 90 days were compared and studied (Fig. 5). It could be made out that the mortar on the specimen periphery is completely worn out in case specimens exposed to 5% sulfuric acid, whereas in the case of specimens exposed to 5% hydrochloric acid the color of the specimen had changed to rusting color.

Fig 5: Specimens exposed to ordinary water, sulfuric acid (5%) and hydrochloric acid (5%)

The percentage loss of weight, percentage loss of compressive strength and the acid durability factor at 45 and 90 days of immersion in 5% sulfuric acid and hydrochloric acid solutions for the reference mix and other sample types are determined and indicated in Table 4 and Table 5 respectively. It can be observed that the replacement of cement with microfine cement and stone dust has had a positive effect as the percentage loss of weight, percentage loss of compressive strength are reduced and also the acid durability factor has increased. This observation is true for both sulfuric acid and hydrochloric acid although greater deterioration of the concrete is observed with hydrochloric acid.

Table 4: Exposure to 5% sulfuric acid solution at 45 and 90 days

Sl No	Specimen Type	% loss of weight		% Loss of compressive strength		Acid Durability Factor (ADF)	
		45 days	90 days	45 days	90 days	45 days	90 days
1	C	8.46	10.45	13.47	18.29	43.26	81.71
2	C1	7.26	9.5	3.74	16.65	48.13	83.35
3	C2	6.13	9.22	3.55	15.01	48.22	84.99
4	C3	7.21	9.43	8.67	17.20	47.11	82.80
5	C4	7.82	9.95	5.79	17.98	45.67	82.02

Table 5: Exposure to 5% hydrochloric acid solution at 45 and 90 days

Sl No	Specimen Type	% loss of weight		% Loss of compressive strength		Acid Durability Factor (ADF)	
		45 days	90 days	45 days	90 days	45 days	90 days
1	C	4.13	4.95	15.22	42.17	43.97	57.83
2	C1	4.05	4.65	12.05	38.05	42.41	61.95
3	C2	3.61	4.64	10.47	31.78	44.77	68.22
4	C3	3.6	4.77	14.29	39.94	42.39	60.06
5	C4	4.69	4.83	15.18	41.91	42.86	58.09

None of the specimens including the reference mix showed loss of weight or loss of compressive strength on exposure to sulfate attack. Even surface discoloring of the specimens was not visible and the specimens gained normal strength during the period indicating adequate resistance to sulfate attack at 5% concentration for the 90 day period. However, deterioration of the concrete with the increase in the strength of solution and exposure to the medium for 2 to 3 years or more could happen, as suggested by M S Shetty [16].

Table 6 lists the sorptivity values for the specimens at 28 days. It can be noted that the rate of permeability of water in a unidirectional way is low for specimens with higher levels of replacement of cement with microfine cement, where as its effect at lower levels appear to be less. However, all the specimen types have lower values of sorptivity in comparison to the reference mix indicating better packing of the pores. The graph in Fig. 6 indicates that sorptivity is inversely proportional to the compressive strength. It decreases as the strength increases.

Table 6: Sorptivity at 28 days

Sl No.	Designation of Specimen	Sortptivity (10^{-6}mm/min$^{1/2}$)
1	C	26.97
2	C1	14.61
3	C2	12.71
4	C3	24.29
5	C4	23.4

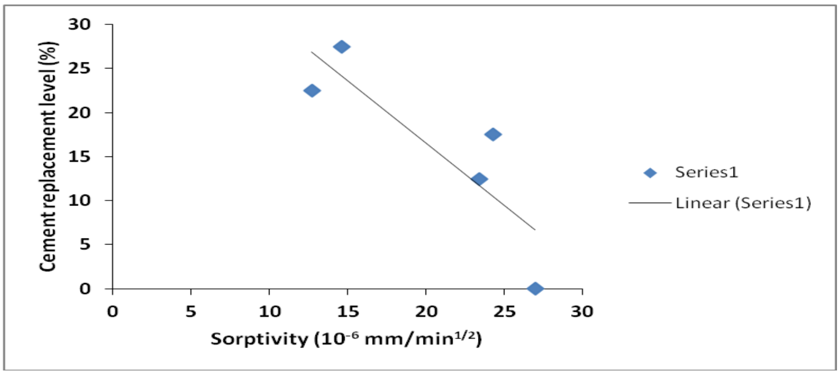

Fig 6: Comparison of Compressive strength with Sorptivity

The results of the RCPT test are shown in Fig. 7. It can be made out that as the percentage of replacement of microfine cement is increased the charge passed (colulomb) decreases. The reference mix has the highest value of charge passed indicating that even with the inert stone dust replacement at 7.5% the chloride penetration is reduced due to reduction in size and number of pores.

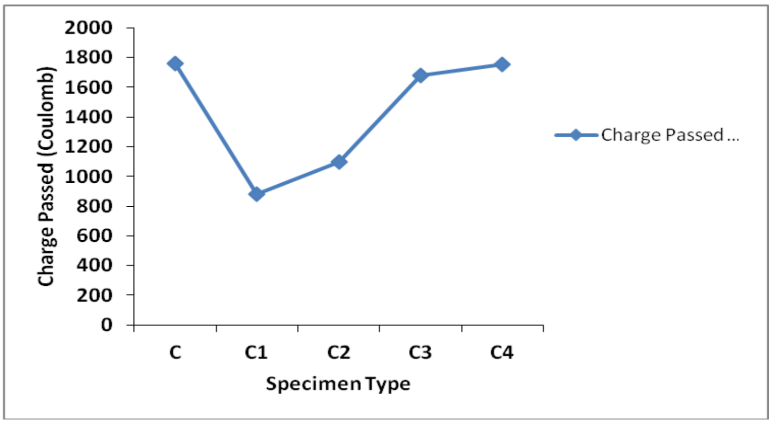

Fig 7: Chloride penetration for different specimen types

From this study, it appears that the anticipated disadvantages, in using higher quantity of quarry dust microfine can be overcome if the concrete is properly designed. In the present study use of microfine cement appears to have induced the enhanced durability characters along with usage of higher microfines making the concrete more impermeable. Better pore refinement could be the reason for this. These findings find resonance with the findings of Fowler [17], wherein he prepared concretes using quarry dust derived from all major mineralogies and determined that these concretes showed better compressive strength and flexural strength and lesser abrasion loss in relation to the reference mix. However, half the concretes had higher drying shrinkages than the reference mix although the excess was marginal. It is noted that no admixture was used in the study. A study conducted by Steven Cramer et al. [18] has also found that microfines from igneous rocks decreased the porosity of cement and also decreased the susceptibility of the concrete to chloride penetration. However, even in this study, increase in the drying shrinkage is reported.

IV. CONCLUSIONS

- The study has demonstrated that when stone dust, a construction industry waste and microfine cement are used for partial replacement of cement the durability characteristics of the concrete are enhanced.
- The concrete can be made more impermeable if the percentage of microfines in cement is enhanced to levels upto about 25%, resulting in more durability to the concrete.
- Sortptivity is inversely proportional to the compressive strength of concrete.

V. SCOPE FOR FURTHER WORK

It appears appropriate to determine the effect of partial replacement of cement with microfines on drying shrinkage of concrete over different periods and correlate the same with other properties of the concrete.

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