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DURABILITY PROPERTIES OF FIBRE-REINFORCED POND ASH-MODIFIED CONCRETE

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Abstract

This paper presents an experimental study on the durability properties of pond ash-modified concrete randomly reinforced with steel fibres. Durability properties such as drying shrinkage, water absorption, permeable voids and acid attack were studied. The specimens were cast with three different pond ash contents of 10%, 20% and 30% by weight of cement. Grooved type steel fibres were added as 0.5%, 1% and 2% by volume of concrete to all the specimens. The results obtained were compared with those obtained with the conventional concrete. Change in length was measured for time periods of 1 day, 7 days, 14 days, 28 days, 56 days, 90 days and 180 days. The results indicated that drying shrinkage decreased with increase in pond ash content and fibre content. A pond ash content of 30% yielded good values of water absorption and permeable voids. Acid attack studies revealed that weight loss significantly decreased with increasing pond ash content and fibre content.

Keywords: Pond ash, Steel fibres, Durability, Drying shrinkage, Water absorption, Permeable voids, Acid attack and sustainable concrete.

1. Introduction

Concrete is a unique composite material that is porous and has highly heterogeneous properties. The use of fly ash, slag, and other industrial by products may translate to cost savings and reduced energy use, greenhouse gas emissions and landfill waste, without sacrificing quality and long-term performance of the concrete. Unused fly ash and bottom ash from thermal power plants, mixed in slurry form and deposited in ponds, is known as Pond Ash [1].

Steel fibres bridge the cracks, increasing the ductility of the member [2]. A brief experimental study on the durability properties of self-compacting concretes

Nomenclatures

A	Weight of surface dried saturated sample
B	Weight of oven dried sample in air
L	Nominal Length of the specimen
l_1	Initial dial gauge reading
l_2	Final dial gauge reading
V	Volume of sample
W_1	Initial weight before immersion in acid solution
W_2	Final weight after immersion in acid solution
w/c	Water-cement ratio

Abbreviations

ASTM	American society for testing and materials
ECC	Engineered cementitious composite (ECC)
FA	Fly ash
IS	Indian Standard code
LWCs	Light weight concretes

(SCCs) with high volume replacements of fly ash was studied. The results indicated that the SCC showed higher permeable voids and water absorption than the vibrated normal concretes of the same strength grades [3].

The role of mineral admixtures in concrete durability, the methods of measuring the chloride ingress into concrete, the challenges in assessing concrete durability from its chloride diffusivity, and the service life modelling of reinforced concrete in chloride-laden environments has to be investigated thoroughly [4].

The behaviour of self-consolidating concrete to sulphate attack under combined cyclic environments and flexural loading were studied. Based on the tested mixture design variables such as type of binders, air-entrainment, sand-to-total aggregates mass ratio, and hybrid fibre reinforcement, potential performance risks in terms of mechanical parameters under such a combined exposure were identified [5]. The addition of polypropylene fibre has greatly improved the durability of the concrete composite containing fly ash and silica fume [6].

The positive interactions between polypropylene fibres and fly ash lead to the lowest drying shrinkage of fibrous concrete with fly ash [7]. The incorporation of mineral admixtures improves mechanical and durability characteristics of the mixes [8]. The addition of fly ash improved the rapid chloride ion permeability and sorptivity of concrete [9]. The Engineered cementitious composite (ECC) is a newly developed high performance fibre reinforced cementitious composite. Test results show that both mechanically pre-loaded and virgin (without pre-loading) ECC mixtures with high volumes of FA remain durable in terms of mechanical performances after accelerated aging period, and show a tensile strain capacity of more than 2% [10].

Durability of concrete can be enhanced by using a novel technique which involves bacterial-induced calcite precipitation. The test results indicated that inclusion of S. Pasteurii enhanced the compressive strength, reduced the porosity and permeability of the concrete with fly ash and silica fume [11]. The incorporation of fibre reinforced geo-polymer composites in concrete improves concrete strength and shows better durability properties when compared with normal concrete [12]. Class F fly ash may replace 50% of the Portland cement and at the same time result in improving resistance to chloride initiated corrosion [13]. Durability related properties of the lightweight concretes (LWCs) including either cold bonded (CB) or sintered (S) fly ash aggregates were studied. The results revealed that S aggregate containing LWCs had relatively better performance than LWCs with CB aggregates [14].

A volume fraction 0.07% of polypropylene fibre reduces drying shrinkage of about 66%, but larger volume fractions did not increased linearly this effect, and even worse results were obtained [15]. Both isophtalic and orthophtalic polyester polymer concrete, display good mechanical and chemical behaviour [16]. The fibres increase the tensile strength of the light weight aggregate concrete [17]. High absorption values were obtained with increasing amount of fly ash [18]. The behaviour of class C and class F fly ashes in concrete were studied. Moreover, regardless the fly ash type, the addition of fly ash significantly increased the resistance to sulphate attack [19]. A comprehensive study on the properties of concrete containing fly ash and steel fibres were conducted. Laboratory test results showed that addition of steel fibres to Portland cement concrete or fly ash concrete improves the tensile strength properties, drying shrinkage and freeze-thaw resistance [20]. The shrinkage behaviour of high strength concrete was studied. From the test results it can be concluded that the shrinkage strain of high strength concrete increases with age [21].

This paper presents durability studies on pond ash concrete reinforced with steel fibres. The work is an experimental investigation on durability properties such as drying shrinkage, water absorption, permeable voids, and acid attack.

2. Experimental programme

2.1. Test materials

2.1.1. Cement

Ordinary Portland 53 grade cement was used for making the concrete specimens. The specific gravity of the cement was found to be 3.15. The initial setting time and the final setting time of the cement were found to be 140 minutes and 245 minutes respectively [22]. The chemical compositions of the cement and the pond ash are shown in Table 1.

Table 1 Chemical composition of cement and pond ash.

Parameter	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Loss of ignition
Standard limitations of Cement	17-25	3-8	0.5 - 6.0	60-67	0.1-4.0	1.3-3.0	0.4-1.3	0.4-1.3	≤ 4
Cement	19.94	5.15	3.38	63.37	1.58	1.93	0.90	0.24	0.98
Pond ash	54.46	33.11	1.76	7.97	0.35	1.20	0.00	0.00	2.16

2.1.2. Pond ash

The pond ash used in the test programme was obtained from Mettur-Thermal power station, TN, India. The specific gravity of the pond ash was found to be 2.04. In this study, pond ash content was varied as 0%, 10%, 20% and 30% by the weight of cement.

2.1.3. Aggregate

Aggregates of size ranging from 20 mm and 12 mm were used in this work. The specific gravity of the coarse aggregates was found to be 2.78, and the water absorption of the coarse aggregates was 0.5%. The specific gravity of the fine aggregates was 2.60 and its water absorption was 1.02% ASTM C 127-01 [23], ASTM C128-01 [24].

2.1.4. Fibre reinforcement

Discrete steel fibres conforming to ASTM A 820 /A 820M – 04 [25] were used. They were Type 1 cold-drawn, wire-grooved. The steel fibres had a length of 50 mm and a diameter of 1 mm. Hence, their aspect ratio was 50. The tensile strength of the fibre was found to be 1098 MPa by using tensometer. Fibre content was varied as 0%, 0.5%, 1% and 2% by volume of concrete.

2.2. Composition of concrete and preparation of mixtures

Workability measurements based on the slump value were carried out on fresh fibre- reinforced pond ash concrete. Table 2 shows the mix designation and the results of the slump values. It was found that increase in pond ash content increased workability, whereas increase in steel fibre content reduced workability.

Table 2. Mix variables.

Mixture no.	Pond ash content (%)	Steel fibre content (%)	Slump value (mm)	w/ (c+pond ash) ratio
A1	0	0	28	0.45
A2	0	0.5	27	
A3	0	1	26	
A4	0	2	25	
B1	10	0	29	0.46
B2	10	0.5	28	
B3	10	1	27	
B4	10	2	27.5	
C1	20	0	30	0.47
C2	20	0.5	29	
C3	20	1	28.5	
C4	20	2	28	
D1	30	0	32	0.50
D2	30	0.5	31	
D3	30	1	29.5	
D4	30	2	29	

For each cubic meter of concrete, w/c+pond ash ratio was determined according to the pond ash content, and the mix was prepared accordingly. Table 2 shows the w/c+pond ash ratios for different ash contents. Mix design was made in accordance with the IS 10262-2009 [26]. Table 3 shows the mix proportions of all the specimens. Fresh concretes containing 10%, 20% and 30% pond ash as cement replacement in mass basis were prepared by modifying the reference Portland cement concrete. Similarly, fresh fibre reinforced concretes containing 0.5%, 1.0% and 2.0% steel fibre in volume basis were also prepared.

Table 3. Mix proportions.

Ingredients	Cement (kg/m^3)	Pond ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate	
				12 mm (kg/m^3)	20 mm (kg/m^3)
0% pond ash	413.33	-	671.84	410	762
10% pond ash	372.00	41.33	667.88	407	758
20% pond ash	330.67	82.66	652.08	397	740
30% pond ash	289.34	124.00	653.06	398	738

The procedures for mixing the fibre-reinforced concrete involved the following steps:

(i) gravel and sand were placed in a concrete mixer and dry mixed for 1 min;
(ii) then, cement and steel fibre were spread and dry mixed for 1 min;
(iii) (iii) after that, mixing water was added and mixed for approximately 2 min.;
(iv) and finally, the freshly mixed fibre-reinforced concrete was cast into specimen moulds and vibrated to remove entrapped air.

After casting, each of the specimens was allowed to stand for 24 hours before demoulding. Demoulded specimens were stored in water at 23 ± 2 °C until testing days. The specimens were named as A1, A2, etc. to indicate different pond ash contents and fibre contents. See Table 2.

3. Tests Conducted and Test Procedures

3.1. Drying shrinkage

Drying shrinkage of concrete specimens was measured by using length comparator equipment. Change in length was measured according to ASTM C157 [27]. The dimensions of the specimens were 285 mm × 75 mm × 75 mm. The prismatic specimens with gauge plugs at both the ends were immersed in water. The temperature of water was maintained as 27 ± 2° C. The first measurement of length was made as soon as possible but not later than half an hour after removing the samples from water. Prior to placing the specimens in the measuring device, surplus moisture was removed from the surface of the prisms, and the gauge plugs wiped carefully in order to avoid the presence of a moisture film on the surface which could lead to faulty readings. The specimens were placed on the length comparator device and the readings were noted on the dial gauge provided in the equipment. Figure 1 shows the drying shrinkage apparatus and placing of the specimen in the apparatus. The drying shrinkage value in terms of percentage can be calculated from the difference between the first reading and the final reading divided by the length of the specimen. Change in length was measured for time periods of 1 day, 7 days, 14 days, 28 days, 56 days, 90 days and 180 days. Tables 4 to 7 show the results of drying shrinkage in terms of shrinkage strain for varying curing periods.

Shrinkage strain (%) = $=(l_1 - l_2)/L$ (1)

Fig. 1. Drying shrinkage apparatus and testing of the specimen.

Table 4. Drying shrinkage of concrete (0% pond ash content).

Days	Shrinkage strain (%)			
	A1	A2	A3	A4
0	0	0	0	0
7	0.0315	0.024	0.017	0.007
14	0.0736	0.0526	0.035	0.024
28	0.087	0.084	0.08	0.0526
56	0.078	0.074	0.07	0.064
90	0.067	0.065	0.059	0.055
180	0.054	0.052	0.049	0.047

Table 5. Drying shrinkage of concrete (10% pond ash content).

Days	Shrinkage strain (%)			
	B1	B2	B3	B4
0	0	0	0	0
7	0.017	0.0162	0.015	0.0141
14	0.0385	0.035	0.033	0.031
28	0.136	0.132	0.13	0.127
56	0.127	0.123	0.12	0.114
90	0.122	0.119	0.116	0.111
180	0.118	0.114	0.11	0.107

Table 6. Drying shrinkage of concrete (20% pond ash content).

Days	Shrinkage strain (%)			
	C1	C2	C3	C4
0	0	0	0	0
7	0.112	0.0175	0.0165	0.0145
14	0.14	0.087	0.0596	0.047
28	0.157	0.122	0.108	0.066
56	0.152	0.117	0.101	0.052
90	0.146	0.112	0.096	0.044
180	0.141	0.108	0.092	0.04

Table 7. Drying shrinkage of concrete (30% pond ash content).

Days	Shrinkage strain (%)			
	D1	D2	D3	D4
0	0	0	0	0
7	0.028	0.0267	0.0175	0.016
14	0.052	0.04	0.038	0.024
28	0.066	0.061	0.058	0.028
56	0.054	0.051	0.048	0.024
90	0.048	0.043	0.038	0.019
180	0.043	0.037	0.031	0.016

3.2. Water absorption and permeable voids

For the study on water absorption and permeable voids, only 1% fibre content was used and test results were compared with those of conventional concrete. Permeability can be measured by conducting water permeability test as per standards, percentage of water absorption test and initial surface absorption test. In the present investigation, percentage of water absorption and percentage of permeable voids were determined as per ASTM 642–82 [28]. Water absorption and permeable voids were determined from cubes of dimensions 150 mm × 150 mm × 150 mm. Saturated surface dry cubes were kept in hot air oven at 105°C till a constant weight was attained. The ratio of the difference between the mass of saturated surface dry specimen and the mass of the oven dried specimen at 105°C to the volume of the specimen (1000 ml) is expressed as permeable voids. It is expressed as a percentage and is written as:

$$\text{Permeable voids} = [(A - B) / V] \times 100 \quad (2)$$

The oven dried cubes after attaining constant weight were then immersed in water and the weight gain was measured at regular intervals until a constant weight was reached. The absorption at 30 min (initial surface absorption) and final absorption (at a point when the difference between two consecutive weights at 12 hour interval was almost negligible) were determined. The final absorption in all the cases was determined at 96 h. Table 8 shows the average initial and final water absorption values.

The absorption characteristics indirectly represent the volume of pores and their connectivity. Table 9 shows the average permeable voids for all the specimens.

Table 8. Average initial and final water absorption.

Mixture No.	Initial Absorption {(*B*-*A*)/*A*}*100%	Final Absorption {(*B*-*A*)/*A*}*100%
A1	1.24	2.83
A3	1.31	3.3
B1	2.236	3.24
B3	2.732	3.546
C1	2.894	3.538
C3	2.369	3.712
D1	1.688	3.388
D3	1.657	3.355

Table 9. Average permeable voids.

Mixture No.	Permeable voids [(*A*-*B*)/*V*]*100%
A1	9.175
A3	10.975
B1	9.625
B3	7.525
C1	7.900
C3	7.375
D1	7.775
D3	7.225

3.3. Acid attack studies

The chemical resistance of the concretes was studied through chemical attack by immersing them in an acid solution. Acid attack study was conducted only for 1% steel fibre content and the results were compared with conventional concrete. After a curing period of 90 days the specimens were removed from the curing tank and their surfaces were cleaned with a soft nylon brush to remove weak reaction products and loose materials from them. The initial weights were measured and the specimens were identified with numbered plastic tokens that were tied around them. The specimens were immersed in 3% H_2SO_4 solution and the pH (~4) was maintained constant throughout. The solution was replaced at regular intervals to maintain a constant concentration throughout the test period. The mass of the specimens was measured at regular intervals up to 90 days, and the losses in mass were determined. Figure 2 shows the deterioration of concrete specimens due to acid attack. Table 10 shows the results of acid attack studies.

Table 10. Acid attack test results.

Mixture No.	7th day (*W2-W1*) ×100%	14th day (*W2-W1*) ×100%	28th day (*W2-W1*) ×100%	56th day (*W2-W1*) ×100%	90th day (*W2-W1*) ×100%
A1	-6.7	-11.1	-24	-49.45	-82.9
A3	-7.8	-11.8	-27.25	-52.9	-86.95
B1	-7.5	-8.9	-20.9	-43.55	-78.05
B3	-5.95	-17.3	-32.35	-50.75	-87.95
C1	-4.4	-12.4	-27.1	-40.6	-75.2
C3	-1.45	-6.4	-20.4	-36.35	-61.2
D1	-2.3	-7.1	-21.3	-56.55	-63.55
D3	-1.875	-5.4	-18.4	-35.15	-60.3

Fig. 2. Deterioration of concrete specimens due to acid attack.

4. Results and Discussion

4.1. Drying shrinkage

Figure 3 shows the rate of shrinkage of concrete specimens for different fibre contents. Rate of shrinkage is presented as change in length (%) in certain time periods, which are curing periods. Hence, Fig. 3 shows the change in length (%) for curing periods of 7, 14, 28, 56, 90 and 180 days for 0% pond ash specimens. When the fibre content increased from 0% to 2%, shrinkage strain decreased. This was found to be true for all the curing periods. When the curing period increased, the change in length of the specimens (%) increased up to 30 days, and thereafter it decreased. This was found to be true for all fibre contents.

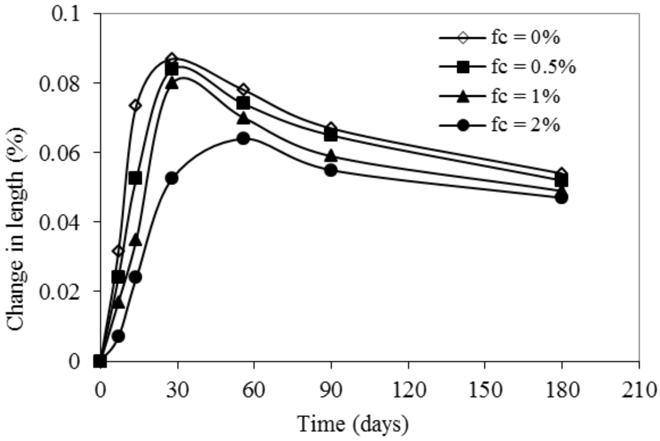

Fig. 3. Rate of shrinkage of fibre- reinforced cement concrete (PA = 0%).

Figure 4 shows the rate of shrinkage or change in length of the specimens (%) for curing periods of 7, 14, 28, 56, 90 and 180 days for 10% pond ash content. The data shown are for different fibre contents. When a pond ash content of 10% was added, the shrinkage strain for 7 days reduced from 0.0315 to 0.017 at 0% steel fibre. Further, at 10% pond ash, shrinkage strain decreased when the fibre content increased from 0% to 2%.

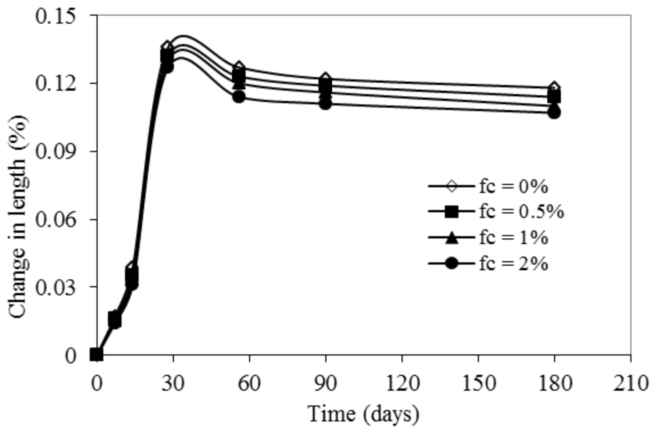

Fig. 4. Rate of shrinkage of fibre-reinforced cement concrete (PA = 10%).

At 20% pond ash, the change in length (%) decreased from 0.141 to 0.04 for a curing period of 180 days when the fibre content increased from 0% to 2%. The reduction in change in length (%) could be attributed to the interfacial bonds caused by increased pond ash content (see Fig.5).

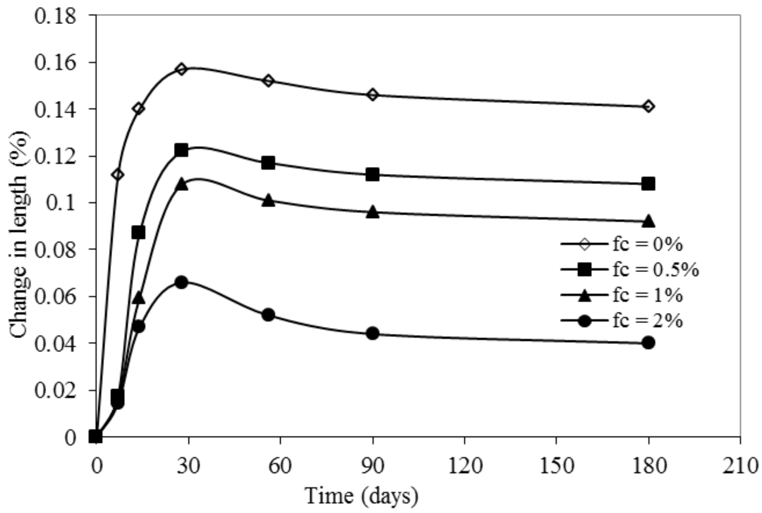

Fig. 5. Rate of shrinkage of fibre-reinforced cement concrete (PA= 20%).

Figure 6 shows the rate of shrinkage or change in length (%) for curing periods of 7, 14, 28, 56, 90 and 180 days for 30% pond ash specimens. The shrinkage data shown are for different fibre contents. The reduction in change in length (%) for 2% steel fibre specimens increased from 60% to 70% when the pond ash content increased from 20% to 30% for a curing period of 180 days.

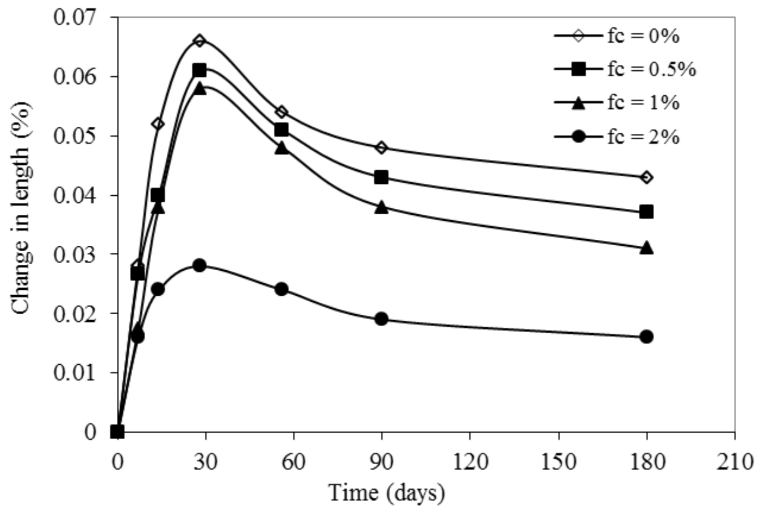

Fig. 6. Rate of shrinkage of fibre-reinforced cement concrete (PA=30%).

4.2. Water absorption

For water absorption test on pond ash-modified and fibre-reinforced concrete specimens, 0% and 1% steel fibre was added to 0%, 10%, 20% and 30% pond ash concrete specimens. Figure 7 shows the variation of 30 minute initial absorption (%) with pond ash content. The data shown pertain to 0% and 1% steel fibre. When pond ash content increased from 0% to 30%, the absorption value increased up to 20% pond ash content and 10% pond ash content respectively for 1% and 0% fibre contents and thereafter decreased at higher pond ash contents. Initial absorption peaked at lesser pond ash content when 1% steel fibre was added, and it peaked at higher pond ash content when there was no fibre (0% steel fibre). As steel fibre occupied some space in the specimen, a lesser pond ash content was required for peaking absorption.

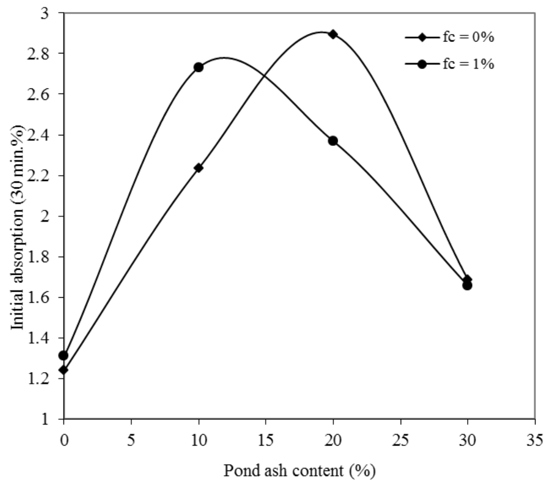

Fig. 7. Effect of pond ash content on initial absorption.

Figure 8 shows the variation of final absorption (96 hours) with pond ash content for 0% and 1% fibre contents. When the fibre content increased from 0% to 1%, final absorption increased. This was found to be true for all pond ash contents. Irrespective of the steel fibre content, final absorption increased up to 20% pond ash and thereafter, it decreased. Hence, 20% pond ash may be taken as the optimum ash content for final absorption.

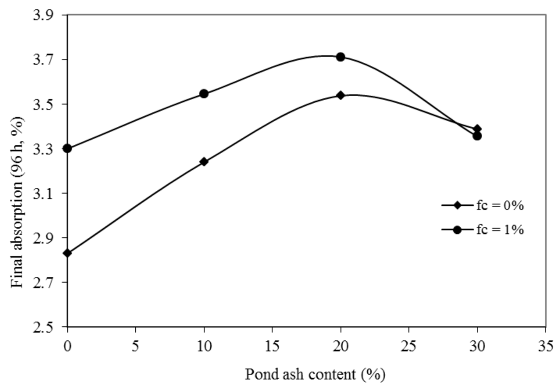

Fig. 8. Influence of pond ash content on final absorption.

4.3. Permeable voids

Figure 9 shows the variation of permeable voids with different percentages of pond ash replacement for a curing period of 90 days. When the pond ash content increased from 0% to 30% for a fibre content of 0%, the reduction in permeable voids was about 15%. For a fibre content of 1%, the reduction in permeable voids was about 34% when pond ash content increased from 0% to 30%. Due to the pozzolanic reaction of pond ash, the interfacial bonding increases with increasing curing period. This results in a reduction of permeable voids (%) when pond ash content increases.

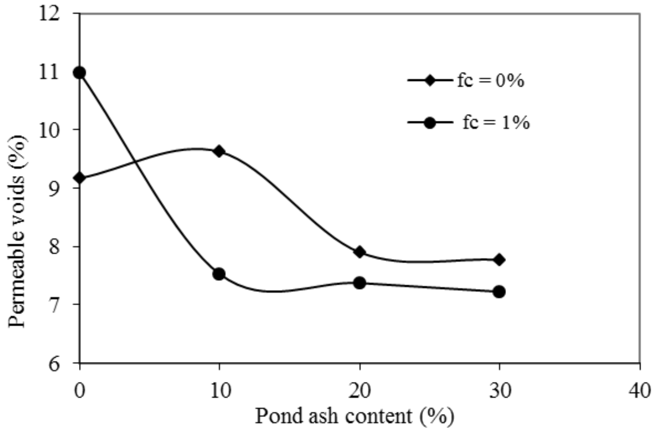

Fig. 9. Variation of permeable voids with pond ash content.

4.4. Acid attack

Figures 10 to 14 show the variation of weight loss (%) with pond ash content. The weight loss was because of acid attack. The data shown pertain to curing periods of 7, 14, 28, 56 and 90 days. Figure 10 shows the variation of weight loss (%) for a curing period of 7 days. When the pond ash content increased from 0% to 30% for a fibre content of 0%, the % weight loss decreased from 6.7% to 2.3%. For 1% fibre content, the % weight loss decreased from 7.8% to 1.875% when pond ash content increased from 0% to 30%.

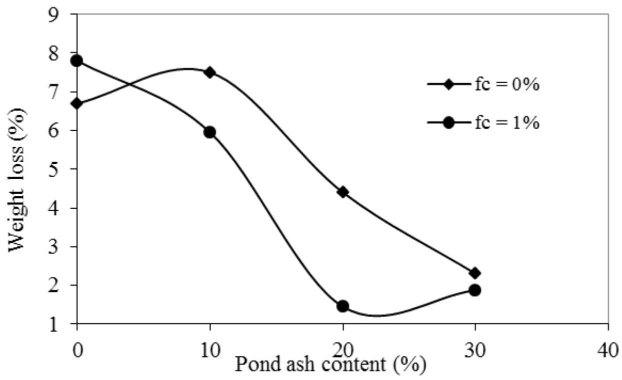

Fig. 10. Weight loss (%) in acid attack (7 days).

Figure 11 shows the variation of weight loss (%) for a curing period of 14 days. When the pond ash content increased from 0% to 30% for a fibre content of 0%, the % weight loss decreased from 11.1% to 7.1%. For 1% fibre content, the % weight loss decreased from 11.8% to 5.4% when pond ash content increased from 0% to 30%.

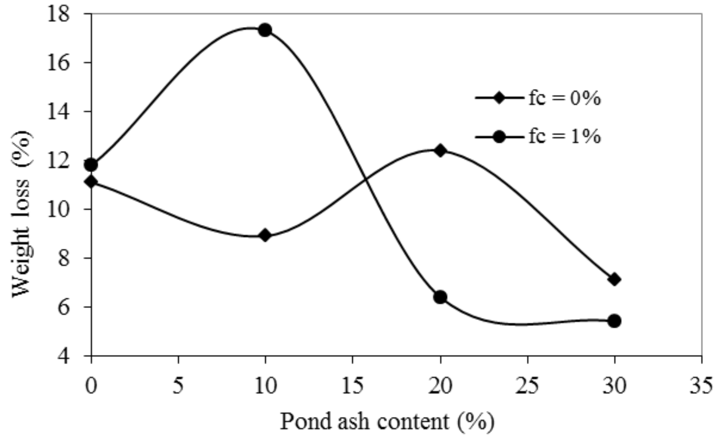

Fig. 11. Weight loss (%) in acid attack (14 days).

For a curing period of 28 days, when the pond ash content increased from 0% to 30% for a fibre content of 0%, the % weight loss decreased from 24% to 21.3%, which was not significant. However, at 1% steel fibre, the % weight loss decreased from 27.25% to 18.4% when pond ash increased from 0% to 30% (see Fig. 12).

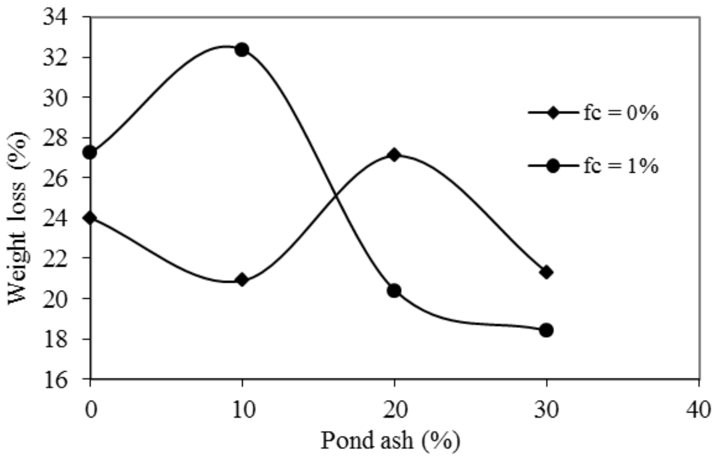

Fig. 12. Weight loss (%) in acid attack (28 days).

For a curing period o 56 days, when the pond ash content increased from 0% to 30% for a fibre content of 0%, the % weight loss increased from 49.45% to 56.55%. However, at 1% steel fibre, the % weight loss decreased from 52.90% to 35.15% when pond ash increased from 0% to 30% (see Fig. 13)

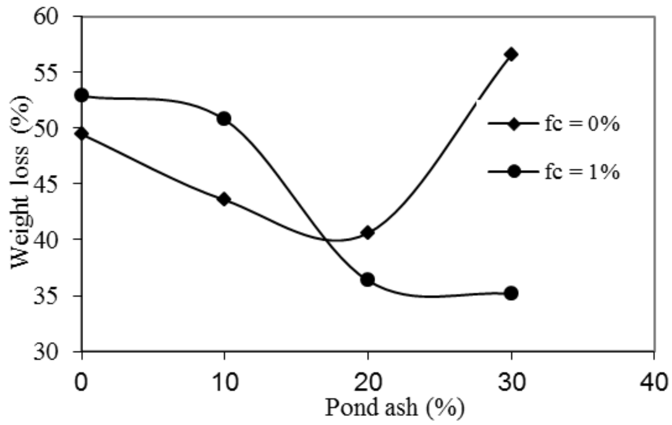

Fig. 13. Weight loss (%) in acid attack (56 days).

When the curing period of 0% steel fibre specimens increased to 90 days, the % weight loss decreased from 82.9% to 63.55% when pond ash content increased from 0% to 30% (see Fig. 14). For the same curing period, at 1% fibre content, the % weight loss decreased from 86.95% to 60.3% when the pond ash content increased from 0% to 30%. The test results showed that % weight loss due to acid attack decreased when cement content decreased. Further, when fibre content increased from 0% to 1%, weight loss decreased.

It may be mentioned here that the condition of steel fibre was not studied after the acid attack. It was observed that, irrespective of fibre content, when pond ash content (%) increased, weight loss (%) due to acid attack decreased for varying curing periods. This could be attributed to a low cement content used in concrete. Generally, concretes of higher cement contents show higher weight loss (%) due to acid attack, and those of low cement contents show a better resistance against acid attack. This could be attributed to a low amount of reaction compounds like $Ca(OH)_2$ at low cement contents. Therefore, it can be concluded that acid attack decreased with decreasing cement content.

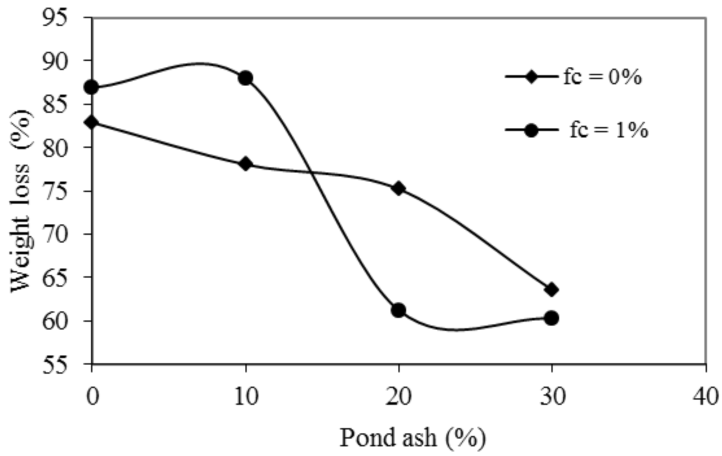

Fig. 14. Weight loss (%) in acid attack (90 days).

5. Conclusions

A series of laboratory experiments such as drying shrinkage, water absorption, permeable voids and acid attack studies has been performed. The following conclusions can be drawn from the experimental study:

- Shrinkage (%) decreased with increasing pond ash content (%) for all fibre contents. In comparison to conventional concrete, the reduction in shrinkage was about 70% at a pond ash content of 30% and a fibre content of 2%.
- The reduction in absorption in the initial 30 min was about 39% for 10% pond ash content and 1% fibre content in comparison to that for 30% pond ash and 1% fibre content. For 96 hour of final absorption the reduction was about 6% for 10% pond ash content in comparison with 30% pond ash content when the fibre content was 1%.
- The permeable voids present in the concrete decreased with increasing pond ash content and fibre content. The decrease in permeable voids was respectively 14% and 34% for 20% and 30% pond ash contents when the fibre content increased from 0% to 1%.
- The deterioration of concrete subjected to 3% H_2SO_4 solution showed that the weight loss significantly decreased with increasing pond ash content and fibre content. The reduction in loss of weight was about 30% for a curing period of 90 days. The condition of steel fibre was not studied after the acid attack. Irrespective of fibre content, when pond ash content (%) increased, weight loss (%) due to acid attack decreased for varying curing periods. This is due to low cement content used in concrete. Concrete of higher cement content shows higher weight loss (%) due to acid attack. Low cement content concrete shows better resistance against acid attack. This could be due to low amount of reaction compounds like $Ca(OH)_2$ at lower level of cement content for deterioration process. Therefore, it can be concluded that acid attack decreased with decrease in cement content.

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