BNUT

Iranian (Iranica) Journal of Energy & Environment

Journal Homepage: www.ijee.net

IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Behaviour of Early Age Shrinkage of Concrete with Binary and Ternary Combination of Fly Ash and Pond Ash with Addition of Glass Fiber

B. Rath[1]*, S. Deo[2], G. Ramtekkar[2]

[1] *Civil Engineering Department, ICFAI University Tripura, Agartala, India*

[2] *Civil Engineering Department, National Institute of Technology Raipur (NIT Raipur), Chhattisgarh, India*

P A P E R I N F O

Paper history:
Received 29 August 2019
Accepted in revised form 24 November 2019

Keywords:
Early Age Shrinkage
Fly Ash
Glass Fiber Reinforced Concrete
Pond Ash
Strength and Durability

A B S T R A C T

Fly ash and pond ash are two by-products of thermal power stations. These industrial wastes require a lot of landfill area and are also causing harm to the environment. By using locally available fly ash and pond ash as partial replacement of cement and fine aggregate, a green concrete shall be produced. These by-products substantially reduce the consumption of natural lime and sand for sustainable development. Before using them in concrete, a deep study should be conducted on the physical behavior of concrete with these industrial by-products. The objective of this paper is to investigate the influence of coarse fly ash, pond ash, and fiber on the early age shrinkage behavior of concrete. In this research cement is partially replaced with fly ash and sand is partially replaced with pond ash individually and simultaneously in addition to 0.1% of glass fiber. Suitability of these materials considering cost is suggested for practical use.

***doi**: 10.5829/ijee.2019.10.04.04*

INTRODUCTION

Concrete shrinkage is defined as a reduction of volume over time. Shrinkage occurs due to movement of water within concrete due to bleeding, chemical reaction, and evaporation. The volume of product generated by the chemical reaction is less than the initial volume of ingredients. Hence tensile stress develops and pulls the cement paste closer [1,2]. The shrinkage can be divided into two phases. One is early age shrinkage, which occurs in the first 5 hours and the other is long-term shrinkage which occurs after 5 hours. The early age shrinkage mainly occurs due to evaporation of water, while long-term shrinkage occurs due to the hydration of cement paste [3]. For low water-cement ratios, the early age shrinkage plays an important role. In this case, the early age strain occurs at a time when concrete is developing stiffness at a faster rate than its strength. Hence shrinkage cracks develop at a faster rate in lower water-cement ratios [4]. Farshad et al. [5] explained that as the drying process of the concrete continues, the adsorbed water held by hydrostatic tension in the small capillaries is significantly reduced [5]. The loss of the water (free water and adsorbed water) produces tensile stresses, which forces concrete to shrink, thereby causing cracks that can adversely affect the durability and strength of concrete if not appropriately considered in the design. Shrinkage of concrete is a part of the durability of the structure. Excessive shrinkage may cause initial cracking of concrete [6]. On loading these cracks may open up which may lead to increase corrosion rate of steel reinforcement in the concrete structure, reduce structural strength and finally causes the early structural failure. Rath, Deo, and Ramtekkar [7] studied on early age shrinkage behviour of cement paste by replacing cement with fly ash and pond ash individually and in combined up to 80% by volume. According to them shrinkage strain of cement paste reduces when cement is replaced with both fly ash and pond ash individually and simultaneously up to 80%. Hence durability may be increased by using these types of marginal materials as a replacement of cement.

This study aims to the investigation of shrinkage effect due to partial replacement of cement with fly ash and sand with pond ash individually and simultaneously in local conditions. On earlier age, various researchers have been studied on shrinkage of concrete by measuring the decreasing of the longitudinal dimension of the rectangular concrete bar. This type of shrinkage measurement is nothing but linear shrinkage measurement of concrete. But in present research concrete shrinkage is measured with the help of conical vessel and shrinkage is measured in terms of volume. Hence the current research provides the volumetric shrinkage in

*Corresponding Author Email: *badrinarayanratha@iutripura.edu.in* (B. Rath)

microns. Very few investigations were carried on the shrinkage of cement concrete on the ternary combination of marginal materials and cement till now by using various types of shrinkage meter. No research has been carried on volumetric shrinkage of concrete by replacing both cement and sand simultaneously by supplementary cementitious materials.

RESEARCH SIGNIFICANCE

Drying shrinkage is one of the major causes of the cracks generated in concrete structures due to its volumetric change. The volume of water lost inside the concrete causes changes in their volume. Due to the high amount of shrinkage initial cracks develop on the surface of the concrete structure and it may expand due to external loading. Water and CO_2 enter inside the crack and accelerate the corrosion of steel reinforcement. On the other hand, coal ash generated from the thermal power plant requires a lot of landfill area. Also, it badly pollutes the environment. Hence it has to be systematically disposed. The present investigation focuses upon searching for the alternate shrinkage reducing materials from such industrial by-products due to ample availability of coal ash. Thus, in this research, the shrinkage effect is observed by replacing cement partially with fly ash and sand replaced with pond ash. Also, the present attempt will provide a solution for the problems of scarcity of sand and lime, respectively. In addition, this work focuses on to reduce environmental impact by partially replacing cement with fly ash and sand with pond ash.

MATERIALS AND METHODS

In the present study fly ash, up to 40% and pond ash up to 20% were used for partial replacement of cement and sand. Both fly ash and pond ash were selected as supplementary cementitious materials and collected from NSPCL, Bhilai. Glass fibers of diameter 14 μm and length 12 mm were collected from a local supplier. The addition of glass fiber decreases shrinkage and slump. Reduction of slump could increase the voids hence the optimum value of fiber dose was decided as 0.1% of the total volume of concrete considering adequate shrinkage and workability. The dose of fly ash, pond ash was fixed by balancing the workability and strength resistance of concrete. The details of the materials used in the present research are shown in Table 1.

In this research, the shrinkage was measured by shrinkage meter as shown in Figure 1. It is quite different than another shrinkage meter because it measures the volumetric shrinkage in micron where other shrinkage meter measures only linear shrinkage. A total of fifty four types of mixes were prepared of both fiber and no fiber reinforced concrete by using fly ash and pond ash. Shrinkage behavior for proposed mixes was observed by taking three w/c. The detailed mix design is shown in Table 2.

The different non-fiber reinforced concrete mixes are denoted in the form of Cx-y and Fiber-reinforced concrete are denoted in the form of Fx-y. Where C denotes for Non-Fiber Reinforced Concrete (NFRC), F denotes for Fiber Reinforced Concrete (FRC), first suffix ‘x' denotes the percentage of replacement of cement with fly ash and second suffix y denotes for the percentage of replacement of cement with pond ash by volume.

RESULTS AND DISCUSSION

In this study, early age shrinkage of fifty-four mixes was determined by replacing cement and sand with fly ash, pond ash along with and without glass fiber. The rate of shrinkage of cementitious paste is more after the addition of water. It is seen that shrinkage is negligible after 8 hours, beyond that it became constant. The amount of shrinkage before 8 hours of each mix is shown in Figure 2. Influence of fly ash, pond ash, glass fiber and w/c on shrinkage of concrete individually and combined was studied and is quoted in Table 3 with some conclusive remarks. It is found that glass fiber, fly ash and pond ash helps to reduce the shrinkage of concrete in different ways. Glass fiber arrests the shrinkage cracks, fly ash reduces the evolution of heat during the hydration process and reduced bleeding, improved packing in the first 8 hours, whereas pond ash reduces the bleeding of concrete. In this way, three ingredients reduce the shrinkage of cement paste in concrete. When these three ingredients are used individual and combined in concrete the shrinkage of concrete is minimized. Mix F_{40-20} shows the lowest shrinkage among all fifty-four mixes of three w/cs. But the participation of three ingredients in the process of reduction of shrinkage is different. To know the influence of glass fiber, fly ash and pond ash eleven groups are formed summarized in Table 3.

TABLE 1. Physical Properties of Materials

Particulars	Cement	Fly Ash	Sand	Pond Ash	Aggregate (10 mm)
Specific Gravity	3.13	2.06	2.61	2.16	2.73
Bulk Density (kg/m^3)	1440	1310	1852	1203	1600
Fineness Modulus		0.89	2.67	1.49	5.9
Surface index			1.15	1.08	0.44
Grading Zone			Zone-II	Zone-IV	
Procured From	Local supplier	NSPCL, Bhilai	Mahandi River Basin	NSPCL, Bhilai	Local Supplier

Figure 1. Shrinkage Cone used in Present Research

TABLE 2. Mix Proportions of Concrete Containing Different Water to Cementitious Materials Ratios

(a)

Mix	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Fly Ash (kg/m^3)	Pond Ash (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)	Fiber (kg/m^3)
Control Concrete								
C_{0-0}	450	917	960	0	0	158	3.4	0
C_{20-0}	360	917	960	90	0	158	3.4	0
C_{40-0}	270	917	960	180	0	158	3.4	0
C_{0-10}	450	841	960	0	76	158	3.4	0
C_{0-20}	450	765	960	0	152	158	3.4	0
C_{20-10}	360	841	960	90	76	158	3.4	0
C_{20-20}	360	765	960	90	152	158	3.4	0
C_{40-10}	270	841	960	180	76	158	3.4	0
C_{40-20}	270	765	960	180	152	158	3.4	0
Fiber Reinforced Concrete								
F_{0-0}	450	917	960	0	0	158	3.4	2.65
F_{20-0}	360	917	960	90	0	158	3.4	2.65
F_{40-0}	270	917	960	180	0	158	3.4	2.65
F_{0-10}	450	841	960	0	76	158	3.4	2.65
F_{0-20}	450	765	960	0	152	158	3.4	2.65
F_{20-10}	360	841	960	90	76	158	3.4	2.65
F_{20-20}	360	765	960	90	152	158	3.4	2.65
F_{40-10}	270	841	960	180	76	158	3.4	2.65
F_{40-20}	270	765	960	180	152	158	3.4	2.65

(b)

Mix	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Fly Ash (kg/m^3)	Pond Ash (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)	Fiber (kg/m^3)
Control Concrete								
C_{0-0}	413	914	956	0	0	166	3.1	0
C_{20-0}	330	914	956	83	0	166	3.1	0
C_{40-0}	247	914	956	166	0	166	3.1	0
C_{0-10}	413	838	956	0	76	166	3.1	0
C_{0-20}	413	762	956	0	152	166	3.1	0
C_{20-10}	330	838	956	83	76	166	3.1	0
C_{20-20}	330	762	956	83	152	166	3.1	0
C_{40-10}	247	838	956	166	76	166	3.1	0
C_{40-20}	247	762	956	166	152	166	3.1	0
Fiber Reinforced Concrete								
F_{0-0}	413	914	956	0	0	166	3.1	2.65
F_{20-0}	330	914	956	83	0	166	3.1	2.65
F_{40-0}	247	914	956	166	0	166	3.1	2.65
F_{0-10}	413	838	956	0	76	166	3.1	2.65
F_{0-20}	413	762	956	0	152	166	3.1	2.65
F_{20-10}	330	838	956	83	76	166	3.1	2.65
F_{20-20}	330	762	956	83	152	166	3.1	2.65
F_{40-10}	247	838	956	166	76	166	3.1	2.65
F_{40-20}	247	762	956	166	152	166	3.1	2.65

(c)

Mix	Cement (kg/m³)	Sand (kg/m³)	Aggregate (kg/m³)	Fly Ash (kg/m³)	Pond Ash (kg/m³)	Water (kg/m³)	Admixture (kg/m³)	Fiber (kg/m³)
Control Concrete								
C_{0-0}	367	934	977	0	0	166	2.75	0
C_{20-0}	294	934	977	73	0	166	2.75	0
C_{40-0}	220	934	977	146	0	166	2.75	0
C_{0-10}	367	857	977	0	77	166	2.75	0
C_{0-20}	367	780	977	0	154	166	2.75	0
C_{20-10}	294	857	977	73	77	166	2.75	0
C_{20-20}	294	780	977	73	154	166	2.75	0
C_{40-10}	220	857	977	146	77	166	2.75	0
C_{40-20}	220	780	977	146	154	166	2.75	0
Fiber Reinforced Concrete								
F_{0-0}	367	934	977	0	0	166	2.75	2.65
F_{20-0}	294	934	977	73	0	166	2.75	2.65
F_{40-0}	220	934	977	146	0	166	2.75	2.65
F_{0-10}	367	857	977	0	77	166	2.75	2.65
F_{0-20}	367	780	977	0	154	166	2.75	2.65
F_{20-10}	294	857	977	73	77	166	2.75	2.65
F_{20-20}	294	780	977	73	154	166	2.75	2.65
F_{40-10}	220	857	977	146	77	166	2.75	2.65
F_{40-20}	220	780	977	146	154	166	2.75	2.65

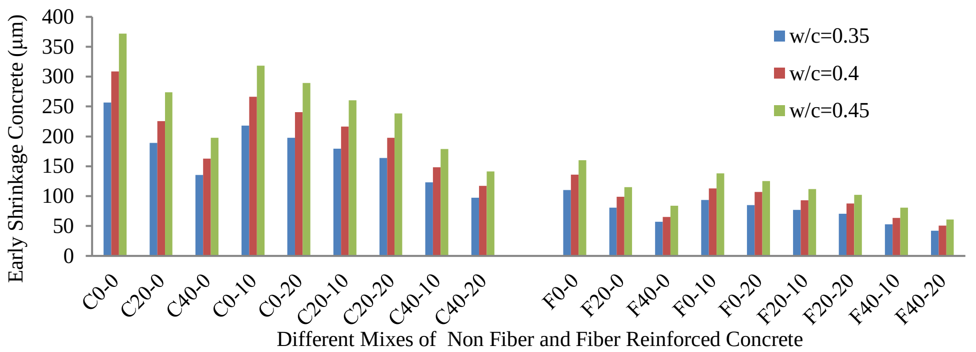

Figure 2. Early Shrinkage of Fresh Concrete for Different Mixes of Non-Fiber and Fiber Reinforced Concrete

TABLE 3. Influence of Fly Ash, Pond Ash and Glass Fiber in Concrete

Gr. No.	Mix	Shrinkage (µm)	% of Decrement	Shrinkage (µm)	% of Decrement	Shrinkage (µm)	% of Decrement	Comments	Remarks
		w/c=0.35		w/c=0.4		w/c=0.45			
1	C_{0-0}	256.42	+ 26.21	308.85	+ 27.00	372.16	+ 26.46	Increasing dose of fly ash up to 100%, the result is improved only 80%. Cement replacement up to 40% is useful in reducing shrinkage.	Influence of Fly Ash in NFRC
	C_{20-0}	189.19		225.46		273.68			
2	C_{0-0}	256.42	+ 47.21	308.85	+ 47.35	372.16	+ 46.92		
	C_{40-0}	135.34		162.60		162.6			
3	C_{0-0}	256.42	+ 14.99	308.85	+ 13.70	372.16	+ 14.46	Increasing the dose of pond ash up to 100%, the result is improved only 53%. Sand replacement up to 20% is useful in reducing shrinkage.	Influence of Pond Ash in NFRC
	C_{0-10}	217.96		266.52		318.34			
4	C_{0-0}	256.42	+ 22.97	308.85	+ 22.03	372.16	+ 22.19		
	C_{0-20}	197.45		240.81		289.56			

5	C_{20-10}	179.5	+ 29.99	216.19	+ 30.00	260.51	+ 30.00	Increasing the dose of pond ash up to 100%, the result is improved the result 24 %.	Influence of Fly Ash & Pond Ash in NFRC (Comparison with C_{0-0})
	C_{20-20}	164.11	+ 36.00	197.66	+ 36.25	238.18	+ 36.00		
	C_{40-10}	123.08	+ 52.00	148.25	+ 51.99	178.64	+ 51.99	Increasing the dose of pond ash up to 100%, the result is improved the result 19 %.	
	C_{40-20}	97.44	+ 62.00	117.36	+ 62.10	141.42	+ 62.38		
6	C_{0-0}	256.42	+ 57.00	308.85	+ 56.03	372.16	+ 56.99	The addition of 0.1% of glass fiber improves result 57%.	Influence of Fiber in Concrete
	F_{0-0}	110.26		135.80		160.03			
7	F_{0-0}	110.26	+ 27.00	135.80	+ 27.13	160.03	+ 28.25	Increasing dose of fly ash up to 100%, the result is improved only 77% at a constant dose of fiber.	Influence of Fly Ash in FRC
	F_{20-0}	80.49		98.95		114.82			
8	F_{0-0}	110.26	+ 47.99	135.80	+ 52.09	160.03	+ 47.37		
	F_{40-0}	57.34		65.06		84.22			
9	F_{0-0}	110.26	+15.01	135.80	+ 16.87	160.03	+ 13.75	Increasing the dose of pond ash up to 100%, the result is improved only 53%.	Influence of Pond Ash in FRC
	F_{0-10}	93.72		112.88		138.02			
10	F_{0-0}	110.26	+ 23.00	135.80	+ 21.00	160.03	+ 21.75		
	F_{0-20}	84.90		107.26		125.22			
11	F_{20-10}	77.18	+ 30.02	92.96	+ 31.54	112.02	+ 30.00	Increasing the dose of pond ash up to 100%, the result is improved the result 19.8 % at constant dose of fiber..	Influence of Fly Ash & Pond Ash in FRC (Comparison with F_{0-0})
	F_{20-20}	70.57	+ 35.99	87.99	+ 35.20	102.42	+ 35.99		
	F_{40-10}	52.93	+ 51.99	63.75	+ 53.05	80.81	+ 49.50	Increasing the dose of pond ash up to 100%, the result is improved the result 19 %.	
	F_{40-20}	41.90	+ 61.99	50.47	+62.83	60.81	+ 62.00		

It is seen that percentage reduction of shrinkage due to fly ash and pond ash is near about equal in nonfiber reinforced concrete and all three water-cement ratios. The shrinkage reduction activity of fly ash and pond ash is slightly lower in fiber reinforced concrete. From Table 3 it can be noticed that 0.1% glass fiber may reduce the shrinkage by about 57% (Group No. 6), where 40% replacement of cement with fly ash reduces the shrinkage 47.21% (Group No. 2) and 20% replacement of sand with pond ash reduces the shrinkage only 22.97% (Group No. 4) independently. Hence it may be concluded that the role of 0.1% glass fiber in the reduction of shrinkage of concrete is more than fly ash and next to pond ash. In the total reduction of shrinkage process, 57% shrinkage is reduced by glass fiber, remaining 43% role of fly ash in the reduction of shrinkage is 20% (47.21% of remaining 43%) and role of pond ash is 10% (22.97% of remaining 43%). The role of glass fiber, fly ash and pond ash is shown in Figure 3. The influence of fly ash as a cement replacement material on early shrinkage of concrete with different w/c is shown in Figure 4 (Group 1 and 2). It is found that increasing the percentage of replacement of cement with fly ash up to 40% at lower w/c, the shrinkage of concrete decreases about 47%. The addition of fly ash improved the packing due to fine particle size and better workability which resisted the surface tension force and improved bond of fiber with the matrix [11]. Hence the shrinkage was reduced as the percentage of cement replacement of fly ash was increased. Also, it can be noticed that fly ash reacts slowly in the hydration process [12]. Hence the heat evolved in the hydration process is very low in the first 8 hours. Hence the evaporation of water from the cement paste was very less, due to the lower difference between atmospheric temperature and concrete temperature. Hence the amount of shrinkage was very less in fly ash concrete.

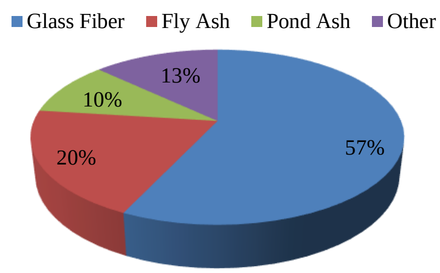

Figure 3. Percentage Role of Glass Fiber, Fly Ash and Pond Ash on Shrinkage of Concrete

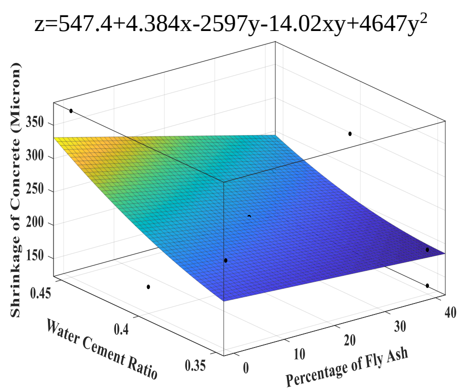

Figure 4. Shrinkage of Concrete at Various Percentage of Fly Ash as Cement Replacement Material

But when sand is replaced with pond ash up to 20% (Group 3 and 4), the shrinkage of concrete is decreased by 15% of that corresponding w/c as shown in Figure 5. The particles of pond ash are finer than sand particles. So the bleeding that occurred due to the addition of pond ash was more than the fly ash. On the other hand, pond ash has more surface area hence absorbs more water than sand. Thus more water was held on the surface and evaporation of water from concrete was further reduced. Hence the reduction of shrinkage of pond ash was less as compared with sand in concrete. Again Figure 6 shows the shrinkage behavior of concrete when 20% cement is replaced by fly ash and sand is replaced with pond ash up to 20% (i.e. C20-10 and C20-20) at different w/c. It can be seen in both FRC and NFRC that the presence of both fly ash and pond ash simultaneously in concrete reduces the shrinkage more than their presence. The shrinkage reduces 6% more when pond ash dose increases double from 10% to 20%, combined with 20% fly ash. But the shrinkage value reduces 21% when pond ash dose increases double from 10% to 20% without the presence of fly ash in concrete. Similarly, the shrinkage reduction of C40-20 is 10% more than C40-10. Hence it is concluded that participation of pond ash in the reduction of shrinkage of concrete is more when it replaces the sand only than replacing cement and sand by fly ash pond ash simultaneously. Hence it can be noted that the participation of fly ash is more than pond ash for reducing the shrinkage of concrete when they are mixing simultaneously for all w/c. Again from Figure 4 and 5, it can be noticed that the shrinkage value of cement replacement with fly ash is less than the shrinkage value of sand replacement with pond ash. Again shrinkage is reduced when both cement and sand are replaced with fly ash and pond ash up to 40% and 20% respectively (Figure 6 and 7). From Figure 8 it can be noticed that the compressive strength of concrete gradually increased when cement is replaced with fly ash up to 20% or sand is replaced with pond ash up to 10% in both fiber and non-fiber reinforced concrete. Beyond this percentage, the compressive strength gradually decreased. The maximum compressive strength obtained for mix F20-10 which is 50% more than the control concrete. Also in that mix, the shrinkage value decreases by about 70%. Hence this mix can be recommended for achieving better durability. When fiber was added it acted in two ways. Firstly, by providing means for stress to be transferred across cracks, crack bridging occurs which prevents the crack growth [13]. Secondly cracks depend on tensile strength of concrete, so that it can resist cracking due to volume change. Glass fibers have very high tensile strength [14]. Hence, in turn, they will

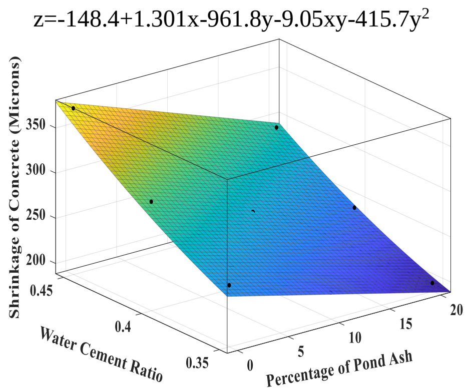

Figure 5. Shrinkage of Concrete at Various Percentage of Pond Ash as Sand Replacement Material

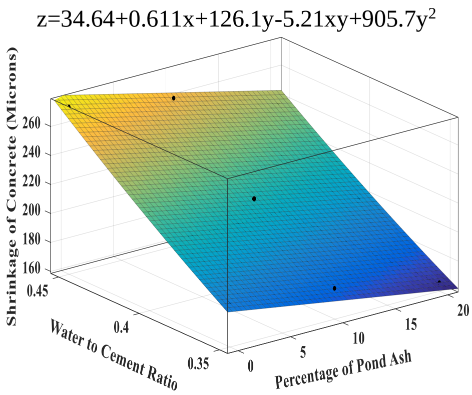

Figure 6. Shrinkage of Concrete at Various Percentage of Pond Ash as Sand Replacement Material with 20% Cement is Replaced with Fly Ash

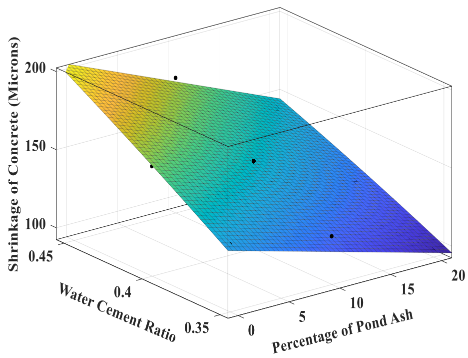

Figure 7. Shrinkage of Concrete at Various Percentage of Pond Ash as Sand Replacement Material with 40% Cement is Replaced with Fly Ash

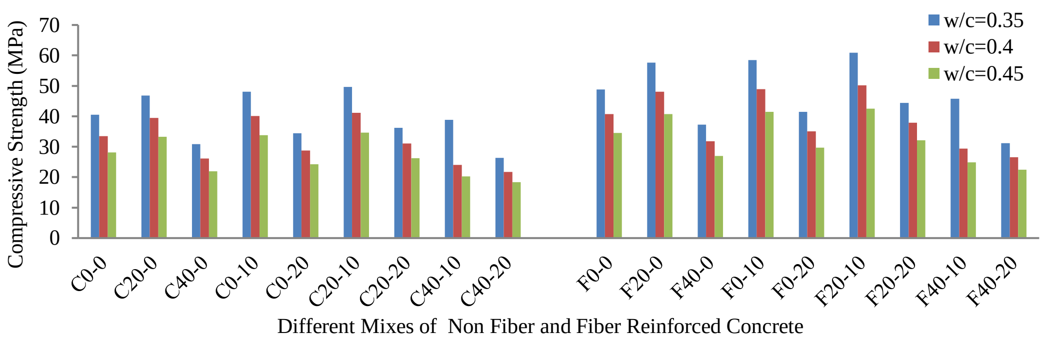

Figure 8. Compressive Strength of Concrete for Different Mixes of Non-Fiber and Fiber Reinforced Concrete at 28 Days Curing

increase the tensile strength of fresh concrete. This will further reduce the shrinkage cracking of concrete. The compressive strength of the F40-20 mix shows 25% less than the compressive strength of C0-0, with the lowest value of shrinkage. Hence it is concluded that for higher replacement of cement and sand with fly ash and pond ash in concrete, the addition of 0.1% glass fiber must be added to compensate for the loss of compressive strength. It is also found that the rate of shrinkage was more for higher w/c concrete due to the higher bleeding possibility of concrete with higher w/cs and lower matrix strength. The initial rate of shrinkage value is more for high water-cement ratios. The early shrinkage lasted for only six to eight hours. After that, the shrinkage value was nearly constant. During shrinkage of cement paste, a strain develops inside the concrete due to the development of tensile capillary pressure. Hence a crack develops inside the concrete if the strength of cement paste is weak [15]. In our study when w/c was low and fibers were added inside the concrete the strength of cement paste increased i.e fiber resisted the crack inside the concrete. Hence the shrinkage of cement paste was decreased. The addition of fly ash and pond ash increased the compaction factor as well as packing density which can be seen in SEM Image as shown in Figure 9. The plate-like structure indicates un hydrated calcium hydroxide are more in control mix i.e C0-0 mix. Due to the addition of fly ash or pond ash un hydrated calcium hydroxide reacted with silica of coal ashes and formed secondary CSH gel which is seen as ettringite needle in SEM image of C20-0 and C0-20 mixes. The amounts of ettringite and CSH gels more in case of simultaneous replacement of cement and sand with fly ash and pond ash (i.e. C20-20 and C40-20). In Figure 9 it can be noticed that the packing density has been increased gradually from left to right. Hence the early age shrinkage value recorded very much low as compared to other mixes due to its high packing density.

The cost analysis of fifty-four mixes is shown in Tables 4(a), 4(b) and 4(c). Though the cost of fiber reinforced concrete is more than nonfiber reinforced concrete of the corresponding mix, the amount of shrinkage per unit price investment in fiber reinforced concrete is more than 50% less than non-fiber reinforced concrete.

TABLE 4. The cost analysis of fifty-four mixes

(a) Total Cost of Different Mixes at 28 days Curing in Rs/m^3

Mix	NFRC			Mix	FRC		
	w/c=0.35	w/c=0.4	w/c=0.45		w/c=0.35	w/c=0.4	w/c=0.45
C_{0-0}	4545	4253	3917	F_{0-0}	5472	5181	4845
C_{20-0}	4014	3770	3487	F_{20-0}	4942	4698	4414
C_{40-0}	3484	3280	3050	F_{40-0}	4411	4208	3978
C_{0-10}	4530	4238	3902	F_{0-10}	5458	5165	4829
C_{0-20}	4515	4223	3886	F_{0-20}	5443	5151	4814
C_{20-10}	3999	3755	3471	F_{20-10}	4927	4683	4399
C_{20-20}	3984	3744	3459	F_{20-20}	4911	4671	4387
C_{40-10}	3469	3238	3006	F_{40-10}	4396	4166	3934
C_{40-20}	3454	3250	3019	F_{40-20}	4381	4178	3947

(b). Cost of Different Ingredients used in Concrete

Particulars	Cement	Sand	Aggregate	Admixture	Fiber
Rate (Rs/Kg)	6	0.45	0.55	225	350

(c). Shrinkage of Different Mix per Unit Cost μm/Rs

Mix	NFRC			Mix	FRC		
	w/c=0.35	w/c=0.4	w/c=0.45		w/c=0.35	w/c=0.4	w/c=0.45
C_{0-0}	0.056	0.073	0.095	F_{0-0}	0.020	0.026	0.033
C_{20-0}	0.047	0.060	0.078	F_{20-0}	0.016	0.021	0.026
C_{40-0}	0.039	0.050	0.065	F_{40-0}	0.013	0.015	0.021
C_{0-10}	0.048	0.063	0.082	F_{0-10}	0.017	0.022	0.029
C_{0-20}	0.044	0.057	0.075	F_{0-20}	0.016	0.021	0.026
C_{20-10}	0.045	0.058	0.075	F_{20-10}	0.016	0.020	0.025
C_{20-20}	0.041	0.053	0.069	F_{20-20}	0.014	0.019	0.023
C_{40-10}	0.035	0.046	0.059	F_{40-10}	0.012	0.015	0.021
C_{40-20}	0.028	0.036	0.047	F_{40-20}	0.010	0.012	0.015

SEM Image of C_{0-0} SEM Image of C_{20-0} SEM Image of C_{0-20} SEM Image of C_{20-20} SEM Image of C_{40-20}

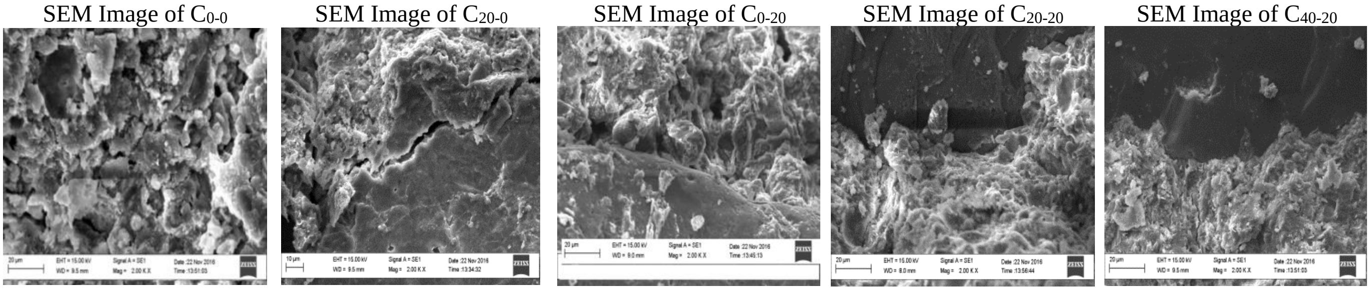

Figure 9. SEM Images of Different Mixes [16]

CONCLUSIONS

The following are concluded from the above test results.

1. From the test results, it can be concluded that combined use of fly ash, pond ash and glass fiber may be recommended in concrete as shrinkage reduction ingredients.
2. The maximum percentage of shrinkage in concrete is reduced by glass fiber than fly ash and pond ash when they are used simultaneously in concrete.
3. The replacement of cement with fly ash reduces the early shrinkage of concrete. The shrinkage can be substantially reduced by recommending high volume fly ash concrete at the construction site.

4. When pond ash is used as a shrinkage reduction material in concrete by replacing sand in higher volume, fly ash must be added in concrete or replaced with cement to compensate the loss of workability and strength of concrete.
5. Also, shrinkage strain reduces by replacement of cement with fly ash and sand with pond ash individually and simultaneously. Hence durability may be increased by using these types of marginal materials as a replacement of cement and sand.
6. The initial cost of glass fiber reinforced concrete is high as compared to non-fiber reinforced concrete. But the amount of shrinkage per investment of unit price is very low in fiber reinforced concrete. Hence glass fiber reinforced concrete is beneficial to high volume fly ash concrete as well as high water-cement ratio concrete.
7. 20% cement replacement with fly ash by weight and 10% replacement of sand with pond ash by volume should be followed for better strength and durability of concrete. Where 40% cement replacement with fly ash and 10% sand replacement with pond ash along with 0.1% glass fiber at low w/c is highly recommended for durable concrete at comparable strength and cost with control concrete without fiber.
8. Replacement of cement with fly ash and sand with pond ash encourages the sustainability of natural resources. Therefore, it can be concluded that introducing the fly ash or pond ash in concrete, not only reduces the shrinkage rate but also reduces the construction cost and keeps the environment green.

REFERENCES

1. Tazawa, E.I., Miyazawa, S. and Kasai, T., 1995. Chemical shrinkage and autogenous shrinkage of hydrating cement paste. ***Cement and concrete research***, *25*(2), pp.288-292.
2. Chun, Y.M., Naik, T.R. and Kraus, R.N., 2006. Reducing shrinkage cracking of structural concrete through the use of admixtures. Wisconsin Highway Research Program, [A CBU Report], Department of Civil Engineering and Mechanics College of Engineering and Applied Science, The University of Wisconsin – Milwaukee.
3. Holt, E., 2005. Contribution of mixture design to chemical and autogenous shrinkage of concrete at early ages. ***Cement and concrete research***, *35*(3), pp.464-472.
4. Nawa T., and Horita T., 2004. Autogenous Shrinkage of High-Performance Concrete, In Proceeding of the International Workshop on Microstructure and Durability to Predict Service Life of Concrete Structures, Japan, pp-12-20.
5. Rajabipour, F., Maraghechi, H. and Fischer, G., 2010. Investigating the alkali-silica reaction of recycled glass aggregates in concrete materials. ***Journal of Materials in Civil Engineering***, *22*(12), pp.1201-1208.
6. Gilbert, R.I., 2017. Cracking caused by early-age deformation of concrete–prediction and control. ***Procedia Engineering***, *172*, pp.13-22.
7. Rath B., Deo S. and Ramtekkar G., 2016. A Study on Early Age Shrinkage Behaviour of Cement Paste with Binary and Ternary Combination of Fly Ash and Pond Ash, ***Indian Journal of Science and Technology***, *9*(44), pp.1-9.
8. Neville, A. M., 2012. Properties of Concrete, Longman Scientific and Technical Publishing, London.
9. Owens, G., 2012. Fundamentals of Concrete, 2nd Edition, Midrand: Cement & Concrete Institute.
10. Altoubat, S., Junaid, M.T., Leblouba, M. and Badran, D., 2017. Effectiveness of fly ash on the restrained shrinkage cracking resistance of self-compacting concrete. ***Cement and Concrete Composites***, *79*, pp.9-20.
11. Chindaprasirt, P., Homwuttiwong, S. and Sirivivatnanon, V., 2004. Influence of fly ash fineness on strength, drying shrinkage and sulfate resistance of blended cement mortar. ***Cement and Concrete Research***, *34*(7), pp.1087-1092.
12. Wongkeo, W., Thongsanitgarn, P. and Chaipanich, A., 2012. Compressive strength and drying shrinkage of fly ash-bottom ash-silica fume multi-blended cement mortars. ***Materials & Design*** (1980-2015), *36*, pp.655-662.
13. Messan, A., Ienny, P. and Nectoux, D., 2011. Free and restrained early-age shrinkage of mortar: Influence of glass fiber, cellulose ether and EVA (ethylene-vinyl acetate). ***Cement and Concrete Composites***, *33*(3), pp.402-410.
14. Riad, M., Genidi, M.M., Shoeib, A.E.K. and Abd Elnaby, S.F., 2017. Effect of discrete glass fibers on the behavior of RC Beams exposed to fire. ***HBRC journal***, *13*(2), pp.145-151.
15. Cohen, M.D., Olek, J. and Dolch, W.L., 1990. Mechanism of plastic shrinkage cracking in portland cement and portland cement-silica fume paste and mortar. ***Cement and Concrete Research***, *20*(1), pp.103-119.
16. Ramtekkar, G., Deo, S. and Rath, B., 2017. Durable glass fiber reinforced concrete with supplimentary cementitious materials. ***International Journal of Engineering***, *30*(7), pp.964-971.

Persian Abstract

DOI: 10.5829/ijee.2019.10.04.04

چکیده

خاکستر سوخت و خاکستر حوضچه دو محصول جانبی نیروگاه‌های حرارتی هستند. این ضایعات صنعتی به محل دفن زباله زیادی احتیاج دارد و همچنین به محیط زیست آسیب می‌رساند. با استفاده از خاکستر سوخت و حوضچه به عنوان بخش جایگزینی سیمان و مصالح ساختمانی در دسترس قرار می‌گیرد، بتون سبز تولید می‌شود. این فرآورده‌های فرعی برای توسعه پایدار باعث کاهش مصرف آهک و ماسه طبیعی می‌شوند. قبل از استفاده از آن‌ها در بتن، باید مطالعه عمیق در مورد رفتار بتن با این محصولات فرعی صنعتی انجام شود. هدف از این مقاله، بررسی تأثیر خاکستر درشت، خاکستر حوضچه و فیبر بر رفتار انقباض بتن است. در این تحقیق سیمان به طور جزئی با خاکستر سوخت جایگزین شده و ماسه به طور جداگانه با خاکستر برکه به صورت جداگانه و همزمان با علاوه بر این ۱/۱ درصد فیبر شیشه جایگزین می‌شود. مناسب بودن این مواد با توجه به هزینه برای استفاده عملی پیشنهاد می‌شود.