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USE OF HIGH VOLUME FLY ASH ON EARLY AGE SHRINKAGE IN CONCRETE FOR LOCAL HOT AND DRY CONDITION

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Abstract

Recently contractors are demanding a reliable and all-weather partial or full replacement material for sand due to government restrictions on natural sand mining from river beds. Many previous studies showed that fly ash as a pozzolanic material is effective for improving the various properties of concrete. Advantages of fly ash as partial replacement of cement in concrete on early age shrinkage are reported in standard literature. However, effect of fly ash as partial replacement of cement and sand in concrete on early age shrinkage is not clearly available in reputed literature. This paper discusses the experimental research carried out on early age shrinkage of concrete mixtures in which cement and sand were partially replaced with high volume class F fly ash. Nine mixes were prepared that is C_{0-0}, C_{20-0}, C_{40-0}, C_{0-20}, C_{0-40}, C_{20-20}, C_{20-40}, C_{40-20} & C_{40-40} by partly replacing cement and sand by fly ash and compared with control concrete at an early age by using shrinkage cone apparatus. Combine replacement up to 40% of cement and 20% sand by fly ash respectively gives the better result than other mixes. Combine replacement 40% cement and 40% sand by fly ash has reduced the shrinkage by 63.13% than the control mix. In general, incorporation of fly ash as a partial replacement of cement and sand reduced the shrinkage properties and adds sustainability to concrete by reducing CO_2 emission during cement production.

Keywords: Durability, Early age, Shrinkage fly ash, Sand, and Sustainable.

1. Introduction

Concrete is the most important construction material and its consumption is increasing gradually in our globe. The current challenges for civil engineers are to produce high volume and high-performance fly ash concrete with increased life and durability of structure, at lowest possible cost [1]. Concrete produced should also have a nominal negative impact on the environment, which is sustainable and green concrete [2]. This can be achieved by reducing the use of natural lime, saving fine and coarse aggregates whose resources are inadequate and are depleting very fast day by day [3]. It could also be achieved by using most possible industrial by-product like fly ash in concrete as it would decrease the landfill area for fly ash disposal and CO_2 emission during the cement manufacturing process [4].

Loss of water to the environment and undergo volumetric changes contributes to the materials performance due to induced stresses that may facilitate deterioration of concrete. The greatest risk of concrete cracking may due to lower tensile capacity of concrete at early ages [5]. The high amount of shrinkage in concrete develop initial cracking. These crack open up on loading and gives entry to harmful gases and water increasing rate of corrosion of steel reinforcement may result reduces structural strength and early failure. Early age drying shrinkage can be reduced by using industrial by-product like fly ash as a partial replacement of cement and sand in concrete

Drying shrinkage of cement mortar decreases with the inclusion of hydrocarbons. These hydrocarbons fill-up voids and microstructural cracks in mortar [6]. The drying shrinkage in fly ash concrete reduces in comparison to ordinary concrete [7], thus generate less crack which ensures greater resistance to deterioration. A researcher found that the drying shrinkage of mortar reduced using fly ash of different fineness. The finer fly ash reduced the drying shrinkage than the coarser one due to lower water binder ratio [8].

The inclusion of high volumes of fly ash as a partial replacement of 70 % cement in concrete with a low water-cementitious material ratio resulted in a reduction in the shrinkage values of up to 30% when compared to OPC concrete [9]. The reduction in drying shrinkage was reported 39%, 51% and 58% with the inclusion of 60% FA as a cement replacement when w/b ratio was 0.4, 0.34 and 0.3 respectively than normal concrete [10].

At an early age, the drying shrinkage found to decrease with the incorporation of fly ash for mortar with the same flow [11]. The drying shrinkage in mortar increases at early ages due to the rate of pozzolanic reaction and size of the capillary pore. When cement is partially replaced by fly ash drying shrinkage of concrete reduced [12]. The HVFA concrete generates nearly 40 percent less heat of hydration at an early age due to a reduction for Portland cement and, therefore, in massive structural members the potential for thermal shrinkage and cracking is also greatly reduced [13].

Researcher found that one of the reasons of shrinkage in concrete is due to temperature effect and they conclude that, 15% fly ash replacement caused a reduction in the peak temperature in the mortar of about 4 to 6°C [14]. Experimental study on partly replacement sand by fly ash concludes that the drying shrinkage of fly ash mixture is similar or somewhat lower than control concrete [15].

2. Research Significance

The accurate definition of early age changes depends on the context and time frame of the measurement. In this paper, early age shrinkage is defined as the volume changes occurring immediately after concrete placing up to the age of about 8 hours. Early age shrinkage measurement provides a challenge due to the difficulty in making an accurate measurement of concrete prior to demoulding. The shrinkage must be measured immediately after casting in a mould, which permits constant reading without disturbing the concrete.

Very few researchers studies on partial replacement of cement and sand by fly ash on early age shrinkage in concrete. Construction industry always required supplementary partial replacement material for sand due to a shortage of good quality of natural sand. In view of this, it is necessary to study the effect of partial replacement of cement and sand by fly ash in concrete. The shrinkage meter used in this study gives accurate shrinkage in micron than another shrinkage meter. The present study aims for early age shrinkage behaviour with partial replacement of cement, sand and their combination by using high volume fly ash in concrete for local condition.

3. Material Testing

The present study gives the details investigation of the effect of fly ash on early age shrinkage in concrete. In this study cement, fine aggregate, coarse aggregate, fly ash and super plasticizer were used and their properties found out in laboratories which are shown in Table 1. Cement, fine aggregate and coarse aggregate were purchased from a local supplier. The sieve analysis of fine aggregate and fly ash is shown in Table 2. The specific gravity of cement was obtained 3.16. The initial and final setting time of cement was 165 minute and 210 minutes respectively.

Fly ash was collected from NSPCL, Bhilai thermal power plant in India and specific gravity of fly ash obtained 2.15. The SEM and EDX test were done on fly ash and ordinary Portland cement, which analyse the surface and internal structure of fly ash and cement particles. The spherical shape of fly ash particle and irregular shape of cement particles as shown in Figs 1(a) and (b). The spherical shape of fly ash particles helps to improve the workability of fresh concrete. The element content of FA and OPC is given in Table 3.

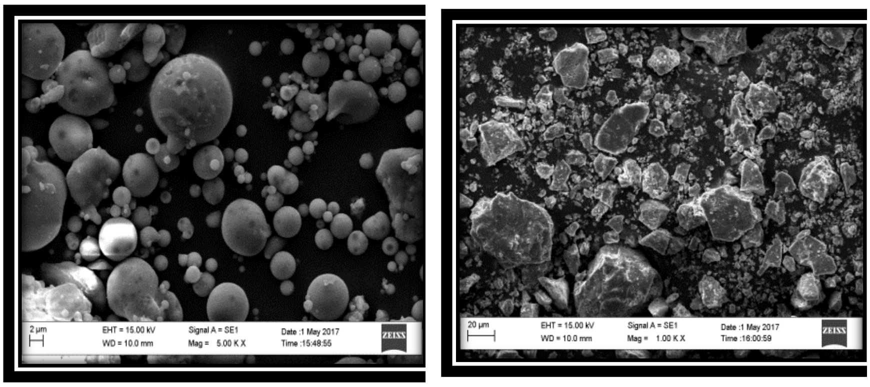
Table 1. Properties of materials.

Materials	Specification
Cement	OPC 53 Grade
Fine aggregate	Zone-II, FM-2.67
Coarse aggregate	20 mm, FM-6.61
Fly ash	Passing on 90µm sieve- 89%
Super plasticizer	Master builder solution from B.A.S.F, Dose of use = 1% by cementatious material

Table 2. Sieve analysis for fine aggregate and FA.

BIS sieve size	ASTM sieve size	% passing of sand	Combined grading of 80% and 20% fly ash	Desirable grading as per IS: 383-1970 (zone II)
10 mm	3/8 in.	100√	100√	100
4.75 mm	No.4	97√	97.60√	90-100
2.36 mm	No.8	92√	93.60√	75-100
1.18 mm	No.16	83√	86.40√	55-90
600 µ	No.30	48√	58.40√	35-59
300 µ	No.50	13√	30.40*	08-30
150 µ	No.100	0√	20*	00-10

√ = within the limit specified by IS- 383-1970 [16]
* = Even though the % passing is higher than guidelines, it will enhance workability [17, 18] and act as filler [19].



(a) Spherical shape of FA particles. **(b) Irregular shape of cement.**

Fig. 1. SEM images of fly ash and cement particles.

Table 3. Element content of FA and OPC in %.

Materials	FA [%]	OPC [%]
Silica (Si)	63.78	15.70
Calcium (Ca)	1.12	68.51
Aluminum (Al)	24.44	4.65
Iron (Fe)	5.01	3.76
Magnesium (Mg)	0.48	1.66
Sulphur (S)	----	2.66
Potassium (K)	2.46	2.35
Sodium (Na)	0.11	0.37

4. Experimentation

In the present study, fly ash was used as the partial replacement of cement and sand by volume. Using fly ash nine types of mixes were prepared for 0.35 water-cement ratio and early age shrinkage behaviour was observed. The mix design shown in Table 4 was prepared using 0.35 water-cement ratio as per IS 10262:2009 [20].

Table 4. Mix proportions of concrete for 0.35 W/C ratio.

	Percentage of ingredient w.r.t. total volume				
Mix	**Cement**	**Fly ash**	**Sand**	**Aggregate**	**Water**
C_{0-0}	450	00	712	1117	157.5
C_{20-0}	360	90	712	1117	157.5
C_{40-0}	270	180	712	1117	157.5
C_{0-20}	450	121	591	1117	157.5
C_{0-40}	450	242	470	1117	157.5
C_{20-20}	396	211	591	1117	157.5
C_{20-40}	396	332	470	1117	157.5
C_{40-20}	297	301	591	1117	157.5
C_{40-40}	297	422	470	1117	157.5

The different mixes are denoted in the form of C_{x-y}. Where C denotes for the concrete mix, first suffix ‘x’ denotes the percentage of replacement of cement by fly ash and second suffix ‘y’ denotes for a percentage of replacement of sand by fly ash.

In this study, the early age shrinkage was measured by using shrinkage meter as shown in Fig. 2. The shrinkage meter consists of the cone, which is used for measuring the shrinkage of various building material like cement paste, mortar, concrete etc. The cone consists of a container having a height of 9 cm and diameter 11 cm. after laying separation foil on the inner side of the wall of the container, the material are filled whose shrinkage property is to be observed. By rack and pinion arrangement, the laser which is mounted on a beam stand can be moved vertically. The laser beam is focused constantly on specimen container and set on the working range by moving up and down vertically. The shrinkage meter attached with the computer and the every second shrinkage can be measured accurately by clicking the start option in the computer. The shrinkage and time is measured in data logger box, which can be extracted in an excel sheet for further analysis.

Figure 3 shows the schematic representation of shrinkage cone, where 1 is the cone formed specimen container, 2 is a concrete mixture, 3 is laser unit, 4 is reflector and 5 is a computer. The prepared homogeneous mix was filled in three layers in the shrinkage cone up to its brim and slightly vibrated to remove air bubble completely in the mix. At the centre of the mix surface, a reflector was kept. The cone is kept inside the shrinkage meter and laser ray was focused at the top centre of the reflector in the middle of the measuring range. The 30 minutes time interval was set to record the shrinkage by data logger box. The measuring of shrinkage was started at every 30 minutes of the interval by giving the required command to the computer. The result up to 24 hours were recorded but however after 8 hours shrinkage was less than a micron per minute hence result up to 8 hours were observed and tabulated in Table 5(a) and 5(b) for different mixes.

Fig. 2. Image of shrinkage meter.

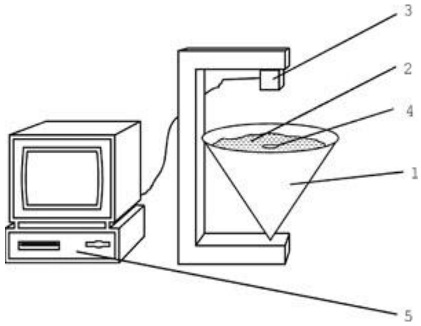


Fig. 3. Schematic representation of shrinkage cone meter.

Table. 5(a) Early age shrinkage in concrete by using FA.

Time (min)	Shrinkage (μm)				
	C_{0-0}	C_{20-0}	C_{40-0}	C_{0-20}	C_{0-40}
30	261.27	170.38	137.38	158.34	146.31
60	357.71	237.58	184.64	147.19	146.43
90	402.31	288.14	221.35	153.11	113.08
120	448.82	331.19	252.82	167.82	109.27
150	491.28	356.74	273.44	193.21	115.82
180	528.11	378.46	290.32	213.00	149.35
210	561.64	406.44	313.21	231.07	177.54
240	583.87	424.11	330.05	245.81	202.67
270	603.29	444.34	339.18	259.19	221.39
300	617.46	450.00	346.72	266.97	233.51
330	628.91	456.26	349.02	271.83	247.06
360	636.35	458.07	351.22	288.06	261.32
390	644.81	460.85	352.14	309.28	252.54
420	650.17	461.18	352.58	312.57	261.00
450	653.97	461.56	352.74	313.17	261.89
480	652.82	461.91	352.82	314.96	260.14

Table. 5 (b) Early age shrinkage in concrete by using FA.

Time (min)	Shrinkage (μm)			
	C_{20-20}	C_{20-40}	C_{40-20}	C_{40-40}
30	159.30	111.32	96.32	145.32
60	198.65	132.87	95.46	172.49
90	246.32	116.84	97.32	213.14
120	287.39	112.93	97.51	228.54
150	308.74	120.54	95.39	235.54
180	327.05	128.19	96.89	237.45
210	342.11	135.61	97.00	235.98
240	363.89	141.78	98.56	238.14
270	370.52	145.93	98.92	241.67
300	377.19	149.30	101.42	232.81
330	381.99	152.52	101.59	236.54
360	383.70	154.83	102.11	239.00
390	379.18	155.98	101.27	241.89
420	381.14	156.66	102.44	240.75
450	383.07	156.82	102.48	241.00
480	383.96	157.02	102.48	240.67

5. Results and Discussion

In this study, early age shrinkage of nine mixes is determine by partially replacing cement and sand with fly ash individually and simultaneously. Many theoretical models are describing the cause of shrinkage, but especially the mechanism in the first hours is not completely understood yet. The shrinkage cone is directly proportional to change in length, however in case of the cylinder the length represents longitudinal shrinkage, and lateral shrinkage is not measured, hence shrinkage value of cylinder is underestimated. The laser-based cone equipment is useful to know the effect of shrinkage at early ages. From Fig. 4, it is seen that when cement is partially replaced by fly ash the rate of shrinkage decreases with increasing time.

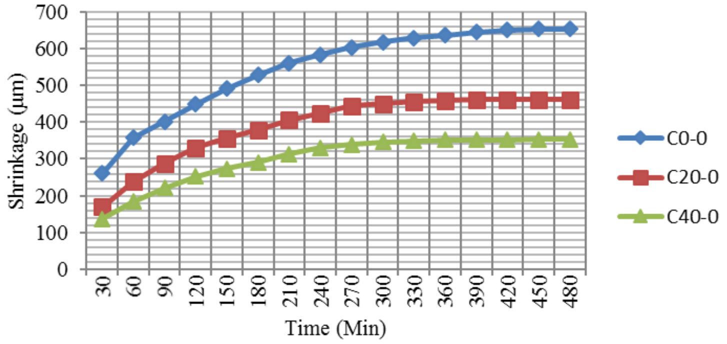


Fig. 4. Early age shrinkage partly replacement of cement by FA.

It is also seen that as the percentage of fly ash increases the rate of shrinkage decreases over control concrete. When cement is partially replaced by 20% and 40% fly ash, shrinkage may reduce by 29.24% and 45.95% respectively than the control concrete after 8 hours. The reason for early age shrinkage reduction is due to a reduction in the amount of cement, which generates nearly 40 percent less heat of hydration at an early age in fly ash concrete. Shrinkage is also reduced due to a reduction in bleeding because of the addition of fine fly ash. Figure 5 shows that when sand is partially replaced by 20% and 40% fly ash the reduction in shrinkage is 51.75% and 60.15% respectively than control concrete after 8 hours. While partially replacing sand by fly ash the reduction of shrinkage is more than control and cement partially replaced by fly ash concrete. The reduction may be due to less bleeding because of a higher volume of fine fly ash, and better packing of material due to the addition of fly ash.

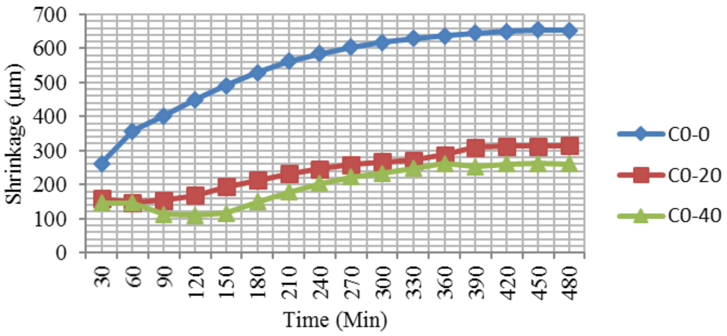


Fig. 5. Early age shrinkage partly replacement of sand by FA.

The partial replacement of cement and sand by fly ash gives the better result than normal concrete. The minimum value of shrinkage at 8 hours was 102.48 micron when cement and sand were replaced with 40% and 20% by fly ash respectively shown in Fig. 6. The mix prepared by 40% replacement of cement and 40% replacement of sand by fly ash showed 63.13% reduction in early age shrinkage than normal concrete.

It is seen that as the percentage of fly ash increases the reduction of shrinkage decreases than control concrete. Table 6 shows the reduction of early age shrinkage in percentage than normal concrete after 8 hours.

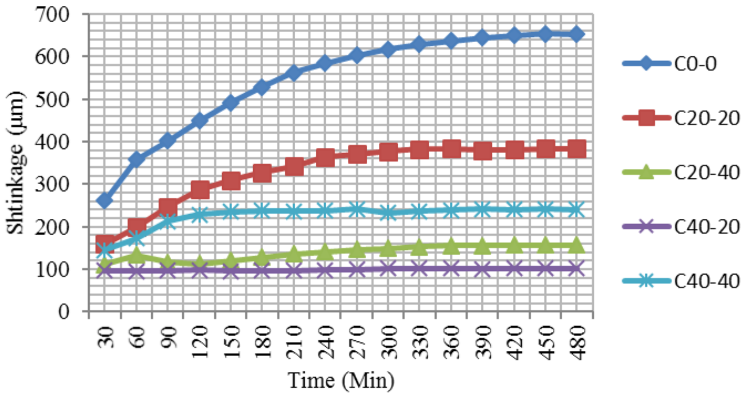


Fig. 6. Early age shrinkage partly replacement of cement and sand simultaneously by FA.

Table 6. Reduction of early age shrinkage in % after 8 hours.

Mix	Shrinkage (*µm*)	Reduction %
C_{0-0}	652.82	0
C_{20-0}	461.91	29.24
C_{40-0}	352.82	45.95
C_{0-20}	314.96	51.75
C_{0-40}	260.14	60.15
C_{20-20}	383.96	41.18
C_{20-40}	157.02	75.94
C_{40-20}	102.48	84.30
C_{40-40}	240.67	63.13

6. Conclusion

The novelty of the present research is in the use of HVFA as a partial replacement of cement and sand on early age shrinkage in concrete. The cracks are developed on the surface of the structure due to shrinkage in concrete, which decreases durability, strength and increases the maintenance cost of the structure. Present study shall be a right step forward in reducing consumption of cement and natural sand and consuming higher volumes of fly ash in concrete for local hot and dry condition. The following conclusion can be drawn from the present research work.

- Partial cement replacement by 20% and 40% fly ash could reduce the shrinkage up to 29.24% and 45.95% respectively than control concrete.
- Partial cement replacement by fly ash could reduce the early age shrinkage in concrete. By use of HVFA in concrete, the shrinkage can be significantly reduced due to low heat of hydration and reduced bleeding at an early age.
- Partial sand replacement by 20% and 40% by fly ash could reduce the shrinkage up to 51.75% and 60.15% respectively than control concrete.
- With the higher percentage of fly ash as a sand replacement, lower shrinkage could be observed in concrete due to higher fineness than other mixes.
- Early age Shrinkage also reduces by partially replacing cement and sand concurrently by fly ash. The maximum shrinkage reduction was 84.3% than the control mix for 40% cement and 20% sand replaced by fly ash.
- A higher percentage of cement and sand replacement simultaneously by fly ash is useful to save virgin materials and consume fly ash.

Higher production and lesser consumption of fly ash will create big environmental issues for coming generations. Also, Government restriction on the extraction of sand from the river bed has recently resulted in an increase in the cost of construction. The production of one tone of cement discharges nearly equal amount of CO_2 into the atmosphere and causes a lot of harm to environment and society. For sustainability of sand and limestone, there is a need of sustainable concrete using such marginal material by partially replacing cement and sand with fly ash to save the environment.

Nomenclatures

C	Concrete
X	Percentage replacement of cement by fly ash
Y	Percentage replacement of sand by fly ash

Greek Symbols

μ	Micron
μm	Micro meter

Abbreviations

ASTM	American Society for Testing and Material
BASF	Baden Aniline and Soda Factory
BIS	Bureau of Indian Standard
CO_2	Carbon Dioxide
EDX	Energy Dispersive X-Rays
FA	Fly Ash
FM	Fineness Modulus
HVFA	High Volume Fly Ash
IS	Indian Standard
NSPCL	NTPC-SAIL Power Company Limited
OPC	Ordinary Portland Cement

SCM	Scanning Electron Microscope
W/C	Water Cement Ratio

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