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A Study on Early Age Shrinkage Behaviour of Cement Paste with Binary and Ternary Combination of Fly Ash and Pond Ash

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Abstract

Objectives: To investigate the early age shrinkage behavior of cement, when it is partially replaced with fly ash and pond ash individually and simultaneously by volume. **Methods:** Fifteen mixes were prepared by replacing ordinary portland cement with fly ash and pond ash up to 80 percentage by volume individually as well as combined. Shrinkage-Cone is used for early shrinkage measurement of above fifteen mixes and suitable combinations are proposed for local conditions. **Findings:** A comparative statement is prepared for reduction of shrinkage when cement is replaced with fly ash and pond ash individually and simultaneously. The shrinkage meter used in present study gives shrinkage in micron which gives more accurate result than other shrinkage meter used in previous research. Also ACI 209 model is modified to include supplementary cementitious materials. An equation is proposed which has given satisfactory results with partial replacement of cement with fly ash and pond ash. **Applications/Improvements:** Generally shrinkage of concrete depends upon temperature and humidity. Due to high rate of shrinkage, cracks develop on the surface of the structure and reduce its durability. Shrinkage strain reduces by replacement of cement with both fly ash and pond ash individually and simultaneously. Hence the binary or ternary combination of cement concrete with supplementary cementitious materials may be beneficial for construction of structure in hot humid region.

Keywords: ACI 209 Model, Fly ash, Pond ash, Replacement Material, Shrinkage-Cone

1. Introduction

One of the major causes of the cracks in concrete structures may be due to drying shrinkage. The volume of water lost inside the concrete or mortar causes change in their volume. Due to continuation of drying process of concrete, reduction of adsorbed water in small capillary continues significantly¹. The hydrostatic tension of adsorbed water in small capillary reduced continuously. Hence concrete shrinks due to tensile stresses produced by loss of free water and adsorbed water causing cracks. This may adversely affect the durability and strength of concrete if not appropriately considered in the design. Shrinkage of concrete is related to service life period of structure. Generally initial cracking of concrete may be caused due to high amount of shrinkage. On loading these cracks may open up and provide entry to water

and harmful gases increasing rate of corrosion of steel reinforcement. Hence structural strength is reduced and finally causes the early structural failure.

Shrinkage of concrete is more in case of local hot and dry condition reducing the durability of structure. The fresh concrete can be affected by high temperatures, high wind velocity and low relative humidity. The high rate of evaporation leads early age drying shrinkage cracking or results in plastic shrinkage before concrete sets. Due to rapid change of temperature thermal cracking may result, such as when concrete slabs or beams are placed on a hot day and a cool night alternatively. Also hydration of cement accelerates due to high temperature and leads for thermal cracking in thicker concrete section. On the other hand the production of cement in large scale is a significant source of pollution. The industrial by-products like fly ash, pond ash, blast furnace slag etc play a vital

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role for the reduction of shrinkage effect and increasing the service life period of concrete. Therefore blending of two or three supplementary cementitious materials are already started to optimize durability and cost for the benefit of engineers, owners, contractors and material suppliers.

Again drying shrinkage of cement mortar decreases with inclusion of hydrocarbons. These hydrocarbons fill-up voids and micro structural cracks in mortar². The introduction of fly ash by weight in mortar reduced the drying shrinkage as compare to ordinary Portland cement. The fine fly ash reduced the drying shrinkage than coarse one due to lower water binder ratio³.

Ground granulated blast furnace slag (GGBS) having fineness values of 3000, 4000 and 8000 cm²/g are used by some researchers as a cement replacement material, with up to 45% by weight of binding material⁴. It is found that cement mortar shows more shrinkage when GGBS having fineness 800 cm²/g is used as a cement replacement material. This phenomenon occurred due to higher fineness exhibited a denser pore volume, in which a higher capillary stress was developed and increased the drying shrinkage.

To reduce the cost of cement in construction industry new binders were developed by some researchers, with the help of alkaline activation of industrial by-products (i.e. ground granulated slag and fly ash). These low cost binders were prepared by mixing 2.5%, 3.5% and 4.5% of Na₂O by mass with ground blast furnace slag and activated sodium silicate⁵. Use of high amount of sodium silicate as an activator for preparation of new type binders results large amount of shrinkage in concrete. Due to the refinement of activated slag cement porous system, autogenous shrinkage is responsible for total shrinkage. Again some researchers measured shrinkage value of mortar by using some different sodium activators such as liquid sodium silicate (LSS), sodium hydroxide (SH) and sodium carbonate (SC) at different sodium concentrations⁶. They concluded that shrinkage caused due to liquid sodium silicate was six times more than Portland cement mortar. On the other hand shrinkage of slag mortar was three times more than the Portland cement mortar.

The dose of silica fume up to 15% also affects the early age shrinkage of cement mortar than latter age. The short term drying shrinkage (i.e 28 days) of cement mortar increases by increasing the percentage of silica fume but the long term shrinkage (after 365 days) is not affected⁷.

The drying shrinkage increased in mortar in early ages due to rate of pozolanic reaction and size of capillary pore. The drying shrinkage of concrete is reduced when cement is partially replaced by fly ash8. Concrete cubes and cylinders were cast using of ground bottom ash silica fume and fly ash replacing of cement partially up to 50% by weight9. The concrete cubes were cured in air at normal room temperature and cured in water at 25°C, 40°C and 60°C for 28 days. It is seen that the drying shrinkage of control Portland cement was higher than air cured blended cement mortar. The 10% of silica fume is replaced with cement by weight and cured in water at 25°C with plastic sealed is shows higher drying shrinkage than control Portland cement mortar. This phenomenon occurs due to pore refinement and high autogenous shrinkage. High Calcium Wood Ash (HCWA) is also used in mortar as a cement replacement material up to 25% by total weight of binder. The reduction in shrinkage of mortar was observed for mortar mixtures containing up to 10% HCWA¹⁰. Also aggregate size plays a vital role on the drying shrinkage of mortar. The drying shrinkage of mortar of 1.18 mm size of fine aggregate is more than 2.36 mm size due to the restraining action of the larger size aggregate. When concrete is prepared by using river sand and manufacturing sand, drying shrinkage is less in natural river sand than manufacturing sand11. The shrinkage strain of normal strength of concrete is more than the shrinkage strain of high strength concrete¹². Some researcher also prepared high strength concrete by using fly ash and silica fume with partial replacement of cement and found that the shrinkage strain of concrete without Fly ash and Silica fume is less 6 to 10% than the shrinkage strain of concrete with replacement of cement by 10% of fly ash and silica fume.

2. Research Significance

Shrinkage is a natural phenomenon accompanying drying processes occurring in nature. The mechanism of shrinkage in concrete is mainly associated with two stages i.e. the adsorption of moisture from the atmosphere during surface drying and reduction of volume due to hydration of cement. Shrinkage also depends upon the temperature and humidity. The elastic shrinkage of concrete or mortar can be described by three phase model¹³. They are aggregate, bulk cement paste and interfacial transition zone. Generally the shrinkage of aggregate zone is very small which can be negligible. Only shrinkage occurs on

cement paste, hence it is required to study on shrinkage of cement paste. Very few investigations are carried on the shrinkage of cement paste on the ternary combination of marginal materials and cement till now by using various types of shrinkage meter. The shrinkage meter used in present study gives shrinkage in micron for cone than other shrinkage meter. This study aims for investigation of shrinkage effect due to partial replacement of cement with fly ash, pond ash and their combination by volume in local condition.

Experimentation

In present study both fly ash and pond ash were used as the replacement of cement partially by volume. Using fly ash and pond ash 15 types of mixes were prepared and shrinkage behavior was observed. The different mixes are denoted in the form of C_{x-y} . Where C denotes for cementitious paste, first suffix 'x' denotes the percentage of replacement of cement with fly ash and second suffix y denotes for percentage of replacement of cement with pond ash by volume. Table-1 summarizes the mix designed patterns of binary and ternary blended cement paste.

In this research the shrinkage is measured by shrinkage meter as shown in Figure-1. It consists of shrinkage cone which is used for measuring the swelling or shrinkage of various building material like paste, mortar, concrete etc. The cone consists of a container having diameter 11 cm and height 9 cm. After laying separation foil on the wall of container, paste or mortar are filled whose shrinkage property is to be observed. A laser is mounted on a beam stand and can be moved vertically by rack and pinion arrangement. The laser beam is focused constantly on specimen container and set on the working range by moving up and down vertically. The total system is controlled by computer. With computer attached with instrument the shrinkage can be measured accurately in every second. The measurement is started by clicking the START option. The time and corresponding shrinkage is measured and recorded in data logger box, which can be extracted in an Excel sheet for further analysis.



Figure 1. Typical Sketch of Shrinkage-Cone.

Fly ash and pond ash were collected from NSPCL, Bhilai and replaced with cement by volume as given in Table-1. The specific gravity of fly ash was 2.06 and pond ash was 2.16. Ordinary Portland cement was taken

Table 1. Mix Proportions of Cement Paste incorporating with Fly Ash and Pond Ash

S.N.	Mix			Ingredients	Percentage	of Ingredients	w.r.t Total Volume	
		Cement (gm)	Fly Ash (gm)	Pond Ash (gm)	Water (ml)	Cement	Fly Ash	Pond Ash
1	C_{0-0}	1000	0	0	300	100	0	0
2	C_{20-0}	870	130	0	300	80	20	0
3	C_{40-0}	738	262	0	300	60	40	0
4	C_{60-0}	608	392	0	300	40	60	0
5	C_{80-0}	477	523	0	300	20	80	0
6	C_{0-20}	863	0	137	300	80	0	20
7	C_{0-40}	726	0	274	300	60	0	40
8	C_{0-60}	588	0	412	300	40	0	60
9	C_{0-80}	451	0	549	300	20	0	80
10	C_{20-20}	732	131	137	300	60	20	20
11	C_{20-40}	595	131	274	300	40	20	40
12	C_{20-60}	458	131	411	300	20	20	60
13	C_{40-20}	601	262	137	300	40	40	20
14	C_{40-40}	464	262	274	300	20	40	40
15	C_{60-20}	470	393	137	300	20	60	20

whose specific gravity was 3.13. The constant amount of water 300 ml was added to all the mixes and prepared a homogeneous paste. The paste was filled in shrinkage cone up to its brim in three layers and vibrated slightly to remove the air bubbles completely. A reflector was kept at the center of the cement paste surface. The total assembly was kept inside the shrinkage meter and laser ray was focused at the top centre of reflector in the middle of the measuring range. The time was set up in such way that the shrinkage was recorded in 15 minutes interval by data logger box. Then the measuring of shrinkage was started by giving the required command through computer. For few mixes results up to 24 hours were recorded. However after 8 hours shrinkage was less than a micron per minute, hence further study of shrinkage was not carried. Thus the result up to 8 hours and shrinkage behavior of every mix were only observed.

Table 2. Shrinkage of Cement Paste Partially Replaced with Fly Ash

Time (min)	Shrinkage (μm)				
	C _{0.0}	C ₂₀₋₀	C ₄₀₋₀	C _{60.0}	C ₈₀₋₀
15	126.17	94.32	53.26	12.76	32.19
30	167.45	120.35	82.34	27.85	21.81
45	203.45	149.87	105.56	41.76	12.34
60	270.42	187.38	127.45	52.53	8.36
75	300.76	209.35	148.34	63.26	9.37
90	328.65	234.45	165.35	71.34	13.28
105	352.57	257.86	182.54	80.93	27.74
120	373.56	278.56	198.52	91.92	35.39
135	396.34	289.43	209.16	106.78	50.28
150	415.43	302.45	219.32	119.45	62.64
165	431.45	320.54	229.86	132.34	74.31
180	447.34	333.46	237.54	144.38	79.43
195	459.23	350.43	249.19	158.34	84.73
210	472.34	362.54	261.95	170.87	86.54
225	484.57	373.09	270.83	185.33	88.73
240	495.23	384.21	279.45	193.64	90.92
255	504.37	392.67	284.28	202.52	91.35
270	512.45	401.34	287.84	211.65	92.67
285	520.49	405.43	291.34	219.29	93.24
300	527.64	409.45	293.54	221.83	93.97
315	534.28	412.56	294.31	222.02	94.04
330	540.31	414.23	294.87	222.56	94.36
345	545.28	415.45	295.07	222.83	94.71
360	549.39	415.57	295.23	223.91	95.02
375	553.65	415.62	295.47	223.04	95.34
390	558.62	415.78	295.58	223.12	95.89
405	561.48	415.84	295.31	223.19	96.06
420	563.43	415.87	295.38	223.23	96.16
435	565.21	415.89	295.41	223.28	96.28
450	566.28	415.9	295.61	223.3	96.31
465	567.31	415.91	295.61	223.32	96.32
480	567.45	415.91	295.61	223.33	96.36

Initially cement is replaced with fly ash partially and shrinkage is observed upto 8 hrs and tabulated in Table-2. It is seen that as the replacement of cement increased the shrinkage of new mixes reduced. It is observed that shrinkage of cement paste is reduced upto about 90 percentage when it is replaced with fly ash up to 60 percentage. Beyond 60% replacement it slightly swells. From Table-3 it is seen that shrinkage of pond ash is very low but it swells initially, when it comes in contact with water. Further study may be required to find out the reason of swelling. Table-4 shows the amount of shrinkage, when cement is partially replaced with fly ash and pond ash. It is observed that the swelling of pond ash compensate to the shrinkage of fly ash.

Table 3. Shrinkage of Cement Paste Partially Replaced with Pond Ash

Time (min)	Shrinkage (μm)				
	C ₀₋₀	C ₀₋₂₀	C ₀₋₄₀	C ₀₋₆₀	C ₀₋₈₀
15	126.17	110.35	104.56	74.97	8.4
30	167.45	98.36	89.34	55.34	-15.78
45	203.45	89.45	78.53	42.38	-25.43
60	270.42	82.96	68.23	31.75	-32.48
75	300.76	87.27	59.34	23.76	-40.67
90	328.65	95.28	55.61	15.31	-42.34
105	352.57	115.38	51.45	18.25	-43.14
120	373.56	139.45	53.27	26.78	-44.23
135	396.34	163.63	59.64	33.56	-44.87
150	415.43	184.46	65.39	55.87	-44.63
165	431.45	196.84	83.29	67.32	-40.54
180	447.34	205.48	103.56	79.51	-38.46
195	459.23	217.56	118.39	92.65	-37.23
210	472.34	225.89	132.98	101.23	-37.07
225	484.57	232.48	150.21	114.24	-36.98
240	495.23	243.76	167.36	123.41	-36.71
255	504.37	255.82	185.24	132.32	-36.65
270	512.45	267.45	203.43	141.45	-36.54
285	520.49	290.74	215.59	149.96	-36.52
300	527.64	312.19	229.37	160.17	-36.52
315	534.28	334.56	241.45	171.59	-36.49
330	540.31	350.23	253.25	179.94	-36.49
345	545.28	370.43	267.37	184.01	-36.49
360	549.39	390.46	278.47	187.34	-36.49
375	553.65	401.75	290.93	189.49	-36.49
390	558.62	415.98	301.49	191.52	-36.49
405	561.48	425.32	312.52	192.55	-36.49
420	563.43	435.21	322.87	193.35	-36.49
435	565.21	438.45	333.43	193.94	-36.49
450	566.28	440.32	335.05	194.56	-36.49
465	567.31	441.65	337.54	195.06	-36.49
480	567.45	442.15	337.89	195.34	-36.49

4. Results Analysis

In this study early age shrinkage of fifteen mixes is determined by replacing cement with fly ash, pond ash and both. The rate of shrinkage of cementitious paste is more after the addition of water. It is seen that shrinkage is negligible after 8 hours. The percentage of reduction of shrinkage after 8 hours of each mix is recorded in Table-5. From Figure-2 it is again seen that when cement is replaced with fly ash it decreases the rate of shrinkage with time as well as final shrinkage after 8 hours. The minimum value of shrinkage is recorded as 133.33 microns after 8 hours when cement replaced with fly ash 60% by volume. The total reduction of shrinkage is 76.5% of control volume. When cement is replaced with fly ash up to 80%, slight swelling is seen initially. But replacing cement with pond ash by volume, total matrix swells up when it comes in contact with water this may result in increasing of porosity. Due to swelling of matrix, shrinkage phenomenon of cement paste is slightly reduced. The minimum shrinkage value is recorded as 63.56 microns after 8 hours when cement replaced with pond ash 60% by volume, which is 88% reduction of shrinkage as compared to control volume. It is noticed from Figure-3 that replacement of cement with pond ash above 40% initial swelling occurs for a while, which creates voids inside the paste and may decrease the compressive strength. It can be concluded that though the shrinkage decreases by higher replacement of pond ash with cement, but it may hamper the compressive strength due to formation of porous matrix. Similar behavior is also observed by replacement of cement with both fly ash and pond ash i.e. the ternary combination of fly ash and pond ash in cement paste as shown in Figure-4. The minimum value of shrinkage after 8 hours is 130.65 microns, when cement is replaced by 60% fly ash and 20% pond ash and the total matrix swells (i.e. negative shrinkage) when cement is replaced with 20% fly ash and 60% pond ash. Due to shrinkage of concrete cracks are developed on the surface of the structure, which decreases the strength, durability and increases life cycle cost of structures. The shrinkage cracks depend upon the magnitude of shrinkage strain developed on the surface of structure. Various models have been developed to calculate shrinkage strain of concrete. Among those models ACI 209 is discussed and given below and shrinkage strain of all fifteen mixes are determined by using the model and tabulated in Table-6.

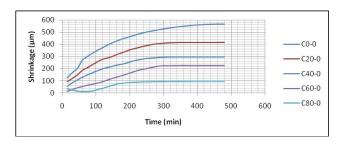


Figure 2. Effect of Fly Ash on Shrinkage of Cement Paste.

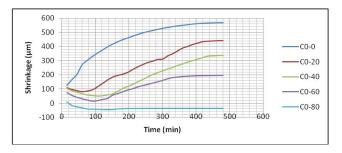


Figure 3. Effect of Pond Ash on Shrinkage of Cement Paste.

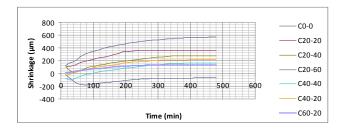


Figure 4. Early Shrinkage of Cement Paste Replaced by both Fly Ash and Pond Ash Simultaneously.

ACI 209 Model: This model is applicable for normal and light weight concrete and shrinkage strain recommended as follows.

$$\varepsilon_{sh}(t,t_c) = \frac{(t-t_c)^{\alpha}}{T_c + (t-t_c)^{\alpha}} \varepsilon_{shu}$$

For our experiment

t = age of cement paste at time of interest (days) =0.33 i.e. 8 hours.

t = 7 days (for moist cured cement paste)

r = Radius of specimen = 5.5 cm, h= Height of specimen= 9 cm.

V = Volume of cement paste= $\frac{1}{3}\pi r^2 h = 285099 \text{ mm}^3$ 285099 mm³

S = Surface area in contact with atmosphere= πr^2 = 9503 mm².

Table 4. Shrinkage of Cement Paste Partially Replaced with both Fly Ash and Pond Ash

Time (min)			Sh	rinkage (µ	.m)		
	C ₀₋₀	C ₂₀₋₂₀	C ₂₀₋₄₀	C ₂₀₋₆₀	C ₄₀₋₂₀	C ₄₀₋₄₀	C ₆₀₋₂₀
15	126.17	105.32	101.25	-17.38	-3.88	-79.99	5.87
30	167.45	112.56	41.26	-82.95	-7.94	-106.3	14.85
45	203.45	132.54	14.95	-143.09	15.68	-72.9	35.27
60	270.42	168.32	48.35	-170.86	37.17	-43.5	46.31
75	300.76	189.52	77.75	-176.44	58.04	-19.79	55.93
90	328.65	212.37	101.46	-168.58	76.3	-5.01	63.87
105	352.57	232.34	116.24	-161.88	90.7	10.59	72.56
120	373.56	246.94	131.84	-156.95	104.0	23.87	79.45
135	396.34	258.45	145.12	-146.03	117.15	40.82	84.31
150	415.43	279.45	162.07	-138.2	127.73	49.95	96.43
165	431.45	299,67	171.2	-126.41	136.15	61.83	103.78
180	447.34	314.45	183.08	-119.68	147.35	69.61	109.42
195	459.23	338.67	190.86	-110.61	161.87	81.67	112.59
210	472.34	345.41	202.92	-103.02	172.37	89.6	117.43
225	484.57	351.76	210.85	-97.01	177.57	97.53	120.54
240	495.23	358.86	218.78	-92.18	181.75	106.78	124.75
255	504.37	362.54	228.03	-88.02	185.92	114.7	127.43
270	512.45	364.96	235.95	-85.58	191.01	124.3	128.61
285	520.49	365.21	245.55	-80.34	197.54	131.74	129.03
300	527.64	365.75	252.99	-78.95	202.86	136.01	129.54
315	534.28	365.93	257.26	-77.69	205.15	140.94	129.89
330	540.31	366.01	262.19	-73.73	206.93	150.2	130.12
345	545.28	366.02	271.45	-73.7	207.15	154.45	130.59
360	549.39	366.02	275.7	-73.7	210.79	156.77	130.61
375	553.65	366.04	278.02	-72.41	212.13	156.68	130.61
390	558.62	366.04	277.93	-72.34	213.42	157.94	130.65
405	561.48	366.04	279.19	-71.75	216.07	158.15	130.65
420	563.43	366.04	279.4	-71.05	216.57	159.39	130.65
435	565.21	366.04	280.64	-69.72	218.78	159.47	130.65
450	566.28	366.04	280.72	-69.77	219.98	159.46	130.65
465	567.31	366.04	280.71	-70.49	220.87	159.49	130.65
480	567.45	366.04	280.71	-70.49	220.87	159.49	130.65

Table 5. Percentage of Reduction of Shrinkage after 8 Hours

S.N.	Mix	Shrinkage	% of Reduction
1	C ₀₋₀	567.45	0
2	C ₂₀₋₀	415.91	26.7
3	C ₄₀₋₀	295.61	51.43
4	C ₆₀₋₀	223.33	76.5
5	C ₈₀₋₀	96.36	72.09
6	C ₀₋₂₀	442.15	23.31
7	C ₀₋₄₀	337.89	48.20
8	C ₀₋₆₀	195.34	88.79
9	C ₀₋₈₀	-36.49	106.43
10	C ₂₀₋₂₀	366.04	35.49
11	C ₂₀₋₄₀	280.71	50.53
12	C_{20-60}^{20-40}	-70.49	112.42
13	C ₄₀₋₂₀	220.87	61.07
14	C ₄₀₋₄₀	159.49	71.89
15	C _{60.20}	130.65	76.97

$$T_c = 26.0e^{1.42X10^{-2}\left(\frac{V}{S}\right)} = 39.8$$

h= Relative humidity = 0.6

$$\begin{split} \varepsilon_{\mathit{shu}} &= \mathit{Notional\ ultimate\ shrinkage\ strain} = 780\,\gamma_{\mathit{sh}} X 10^{-6} \\ \gamma_{\mathit{sh}} &= \gamma_{\mathit{sh,tc}} * \gamma_{\mathit{sh,RH}} * \gamma_{\mathit{sh,vs}} * \gamma_{\mathit{sh,s}} * \gamma_{\mathit{sh,\psi}} * \gamma_{\mathit{sh,c}} * \gamma_{\mathit{sh,c}} \\ \end{split}$$

 $|sh - sh,tc| sh,RH |sh,vs| sh,s |sh,\psi| sh,c |sh,\alpha|$

$$\begin{split} \gamma_{\it{sh,tc}} &= MoistCuringCoefficient = 1.202 - 0.2337 \log(t_c) = 1.202 - 0.2337 \log(7) = 1.004 \\ \gamma_{\it{sh,RH}} &= Relative Humidity Coefficient = 1.40 - 1.02h = 1.40 - 1.02X0.6 = 0.788 \end{split}$$

 $\gamma_{\rm sh, vs} = Volume surface ratio coefficient = 1.2e^{-0.00472\left(\frac{V}{S}\right)} = 1.2e^{-0.00472\left(\frac{285099}{9503}\right)} = 1.04$

 $\gamma_{sh,s} = Slump factor = Not applicable incement paste$

 $\gamma_{sh,\psi}$ = Fine aggregate factor = Not applicable incement paste

 $\gamma_{sh.c}$ = Cement content factor = 0.75 + 0.00061c

 $\gamma_{sh,a} = Air content \ factor = 0.95 + 0.008\alpha = 1.0$

Table 6. Percentage of Error between Actual Shrinkage and Calculated Shrinkage

S.N.	Mix	Shrinkage	ε sh, act	ε sh, cal	% of error
1	C ₀₋₀	567.45	6.31X10 ⁻³	6.303X10 ⁻³	0.02
2	C_{20-0}	415.91	4.625X10 ⁻³	4.980X10 ⁻³	7.7
3	C ₄₀₋₀	295.61	3.065X10 ⁻³	2.675X10 ⁻³	10.7
4	C ₆₀₋₀	223.33	1.483X10 ⁻³	2.314X10 ⁻³	6.73
5	C_{80-0}	96.36	$1.07X10^{-3}$	0.981X10 ⁻³	8.36
6	C ₀₋₂₀	442.15	4.839X10 ⁻³	5.349X10 ⁻³	8.88
7	C_{0-40}	337.89	3.268X10 ⁻³	4.396X10 ⁻³	17.08
8	C ₀₋₆₀	195.34	$0.707X10^{-3}$	3.435X10 ⁻³	21.70
9	C_{0-80}	-36.49	-0.410X10 ⁻³	2.481X10 ⁻³	511.87
10	C ₂₀₋₂₀	366.04	4.07X10 ⁻³	4.016X10 ⁻³	1.24
11	C_{20-40}	280.71	3.121X10 ⁻³	3.062X10 ⁻³	1.81
12	C_{20-60}	-70.49	-0.78X10 ⁻³	2.109X10 ⁻³	169.2
13	C ₄₀₋₂₀	220.87	2.456X10 ⁻³	2.683X10 ⁻³	9.33
14	C_{40-40}	159.49	$1.773X10^{-3}$	$1.729X10^{-3}$	2.41
15	C ₆₀₋₂₀	130.65	1.453X10 ⁻³	1.350X10 ⁻³	6.99

$$\gamma_{\it sh} = \gamma_{\it sh,tc} * \gamma_{\it sh,RH} * \gamma_{\it sh,vs} * \gamma_{\it sh,s} * \gamma_{\it sh,s} * \gamma_{\it sh,t} * \gamma_{\it sh,c} * \gamma_{\it sh,c} = 1.004 \times 0.788 \times 1.04 \times \gamma_{\it sh,c} \times 1.0 = 0.822 \gamma_{\it sh,c} \times 1.00 \times 1.0$$

$$\varepsilon_{sh}(t,t_c) = \frac{(t-t_c)^{\alpha}}{T_c + (t-t_c)^{\alpha}} \varepsilon_{shu} = \frac{(0.33-7)^{\alpha}}{39.8 + (0.33-7)^{\alpha}} X780 X10^{-6} X0.822 \gamma_{sh,c} = -1.29 X10^{-4} \gamma_{sh,c}$$

The negative sign indicates the shrinkage. Here the negative sign is not considered and total value is taken as positive. Since we are going to check the shrinkage property of combination of cement, fly ash and pond ash cement content factor should be determined. For binary and ternary combination of fly ash and pond ash with cement the cementitious material content factor can be written as

 $\gamma_{sh.c}$ = Cementatious material content factor = 0.75 + 0.00061c + ac₁ + bc₂

Where c= Cement content in kg/m³, c_1 = Fly ash in kg/m³, c_2 = Pond ash content in kg/m³

From regression analysis it is found that,

a = -0.00072 and b = -0.0003

Hence the modified equation of Cementatious material content factor will be

 $\gamma_{sh.c}$ = Cementatious material content factor = $16.91(0.75 + 0.00061c - 0.00072c_1 - 0.0003c_2)$

In ACI 209 model, cementitious material content factor is silent about the shrinkage properties of the various cementitious materials. For sustainability more and more use of alternate cementitious materials like fly ash and pond ash are used in concrete. In view of this ACI model needs to include supplementary cementitious materials for present use. For our experiment total

cementitious material is bifurcated into cement, fly ash and pond ash. Hence the shrinkage coefficient of cement, fly ash and pond ash will be different according to their shrinkage behavior. According to ACI 209 model the shrinkage coefficient factor of cement is taken as 0.00061. By regression analysis the value of shrinkage coefficient factor of fly ash and pond ash is found as -0.00072 and -0.0003. Negative sign indicates the lower shrinkage of fly ash and pond ash in compared to cement concrete. Since rate of shrinkage of fly ash is very low than cement and pond ash swells in contact with water, therefore they deaccelerate the total shrinkage. ACI 209 model is prepared for prediction of shrinkage strain for cement concrete. Shrinkage of concrete depends on cementitious material added. However as previously reported, shrinkage of cone is reduced due to addition of coarse and fine aggregate. Aggregates provide restraining action due to which shrinkage of concrete is less as compared to cement paste. Since rate of shrinkage of cementitious paste is more than concrete a constant factor 16.91 is multiplied with cementitious material content factor. Table No -6 gives the total shrinkage strain and calculated shrinkage strain by calibrated ACI model. Again C₀₋₈₀ and C₂₀₋₆₀ gives negative value of shrinkage which calculated experimentally indicates that pond ash swells when water is added. Due to high swelling nature the predicted value and actual value of shrinkage strain did not match each other. Based on the actual and predicted results a very good co relation is found between predicted and actual values for cement replaced with fly ash.

The proposed model does not verify when it is measured for shrinkage strain of only fly ash i.e. there is no cement content and pond ash content. The shrinkage strain becomes negative when c=0 and c₂=0, which indicates the swelling action of fly ash. This happens due to considering high value of cementitious material content factor (i.e. the constant value 0.75) in ACI Model. It is recommended that the cementitious material content factor must be revised.

5. Conclusion

The following points can be concluded from the above test results.

- Fly ash used as a cement replacement reduces the early shrinkage of cement paste. The shrinkage can be sustantially reduced by recommending high volume fly ash concrete at construction site.
- The shrinkage reduces when cement is increasingly replaced with fly ash up to 60%. But 80% replacement of cement with fly ash paste initially swells slightly than 60% cement replacement with fly ash.
- Pond ash swells initially when it comes in contact with water. So pond ash can also act as shrinkage resisting material.
- As the swelling action of pond ash is very high it is recommended that it may replace cement maximum upto 40%.
- ACI 209 model is calibrated to include the shrinkage property of cement, fly ash and pond ash making it suitable for sustainable concretes. Calibrated model was able to predict the shrinkage of various pastes very closely and hence could be used for prediction of shrinkage.
- Shrinkage strain reduces when cement is replaced with both fly ash and pond ash individually and simultaneously. Hence durability may be increased by using these types of marginal materials as a replacement of cement.
- Higher percentage of cement replacement with pond ash, fly ash and both reduces the shrinkage but it may hamper the compressive strength. So it is recommended that replacement of cement with such marginal materials should be such that it will give minimum shrinkage and required compressive strength.

- Replacement of cement with fly ash or 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.

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