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Early Age Shrinkage Behavior of Triple Blend Concrete

V. N. Kanthe*, S. V. Deo, M. Murmu

Department of Civil Engineering, National Institute of Technology Raipur, Chhattisgarh, India

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ABSTRACT

The early age shrinkage is responsible for the early age cracking of concrete. It is very critical for durability of concrete. The change in volume of concrete due to evaporation of water or dehydration process is known as shrinkage. To reduce the early age shrinkage utilized the supplementary cementitious material (SCM) in concrete. In present research industrial and agricultural waste byproduct like fly ash (FA) and rice husk ash (RHA) along with cement were used as SCM. The triple blend concrete was prepared by the combination of 20%, 30% and 40% partial cement replacement with FA and RHA for 0.30, 0.35 and 0.40 water-cement ratio. The concrete samples were tested by advanced instrument as shrinkage cone meter were used for measure the shrinkage. The result shows that the early age shrinkage reduced with increasing the SCM content. The microstructure characteristics enhanced with raising the content of FA and RHA up to 30% replacement; that was due to the dense particle packing.

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1. INTRODUCTION

Shrinkage in concrete is a change in the volume of concrete with respect to time. Shrinkage occurs due to movement of water within concrete due to segregation, bleeding, chemical reaction, during hydration process and evaporation. The volume of product generated by the chemical reaction is less than the initial volume of ingredients. Hence a tensile stress develops and pulls the cement paste closer [1]. The shrinkage can be split in two phase. The early age shrinkage occurred in first five hours and other is long-term shrinkage which happened after 5 hours. The early age shrinkage mainly occurs due to evaporation of water, whereas long-term shrinkage occurs due to hydration of cement paste [2]. 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 [3]. Due to the hydrostatic tension absorbed water held by small capillaries was reduced in drying process of concrete. The reduction in free moisture trying to developed tensile forces and due to this concrete shrink resulting development of cracks in concrete. This will affect the strength and durability of concrete. In respect to durability of structure understanding the shrinkage of concrete is important. Large shrinkage could be produced initial cracking of concrete [4]. These cracks will responsible to increased rate of corrosion for reinforcement in concrete structure, reduced structural strength and finally causes the early structural failure. The plastic shrinkage occurs while concrete is placed in form in fresh state. Generally drying shrinkage will continue throw out the life of the concrete. Hence early age shrinkage study is an important specially for such type of triple blend concrete made by industrial and agricultural byproducts. The concrete made with fly ash and pond ash with glass fiber can be reduce early age shrinkage as reported by several researchers [5, 6]. The durability test (shrinkage) of concrete is most vital aspect for checking the long term life of concrete. The durable concrete required durable material and no maintenance. Most of researchers have reported shrinkage can be reduced by using various type of admixtures such as fly as and slag ternary blend concrete [8]. The shrinkage can be reduce using activators by heating at 60^0 temperature [9, 10]. From the literature it shows that very less data

*Corresponding Author Email: *kanthevn@gmail.com* (V.N. Kanthe)

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available on early age shrinkage of triple blend concrete. The marginal materials are the byproduct of industrial and agricultural such as FA and rice husk ash [11]. FA is a generated from the combustion of coal mostly in thermal power plant. The huge quantity of FA available in India and disposal of such waste is an important issue; otherwise it polute the land, water and air. The utilization of such byproduct in concrete is one of the alternatives to address the issue of disposal waste. The FA is in pozzolanic in nature with smooth and spherical in shape. In the studied on early age shrinkage behavior of cement paste by replacing cement with FA and pond ash individually and in combined up to 80% by volume resulted in reduction of the shrinkage strain [5]. RHA is a byproduct of agriculture. RHA generated by combustion of rice husk at control temperature and grinding in fine powder form. Generally RHA have more than 90% silica content. The utilization of RHA in concrete as partial cement replacement is improved the strength and durability of concrete [12]. The use of RHA in concrete reduced the bleeding due to its rough surface texture. The shrinkage occurred in concrete at higher replacement of RHA [13]. To study the effect of FA and RHA along with ordinary Portland cement (OPC) on early age shrinkage of triple blend concrete using cementetious material particle packing approach is an interest in this research work. The ternary blend concrete was preferred for making sustainable high strength concrete and durable concrete using cementitious material [11,14]. Many of the waste byproduct producec from industries such as GGBS, slag, slurry, fly ash etc.[15,16,17,18]. And some of admixture are affect the properties of concrete such as antifreeze admixtures [19]. Less research was found in the study of particle packing of cementitious material. The dense particle packing can be achieved by selecting the several sizes of SCM particle so that it reduced voids between the particles. This fundamental of particle packing used in this research work, by using two types of the binder as FA and RHA finer along with OPC. The average particle size at D10 and D50 were found that 8μm and 32μm for ordinary Portland cement, 1μm and 20μm for type-1 rice husk ash, 2μm and 20μm for type-2 rice husk ash, 4μm and 21μm for type-3 rice husk ash, 5μm, and 22μm for FA particles and for OPC 32. The previous study on cement paste [20] and mortar [21] was reported that the particle packing increased the strength and durability of triple blend concrete than control concrete.

2. MATERIAL AND METHODS:

2. 1. Material The materials were used in this research work such as tap water, cement, local river sand, and 10 and 20mm size coarse aggregate, FA and RHA. The physical and chemical properties of OPC are summarized in Table 1 conformed from IS 8112-2013 [22]. The properties of fine aggregate were conformed from IS: 2386-1963 (part-III) and IS 383-1970. The grading of sand was conforming to Zone-II and 2.56 specific gravity. The properties of coarse aggregate were conformed from IS: 2386-1963 (part-III) and IS 383-1970 with specific gravity 2.62 and 2.64, respectively. The FA used as SCM in the present research work was collected from Bhilai, Chhattisgarh, India. Three types of amorphous RHA (Chhattisgarh, Odisha and Maharashtra state) were used as another SCM in this research work having greater than 90% of silica content was collected from a local vendor. The efficiency of RHA and FA was reported in previously work, as 10%RHA and 10%FA attained maximum strength [12]. The polycarboxylate-based superplasticizer with a 1.2 specific gravity was used to provide the water drop up to 20% without affecting the workability.

2. 2. Experimental Work Triple blend of concrete mix is prepared with 0.30, 0.35 and 0.40 water-cement ratio. The mix design of concrete prepared concerning standards IS 10262-2009 [23]. The detailed description and designation of blended concrete mix design are tabulated in Table 2. The fine aggregate for 0.30, 0.35 and 0.40 watercement ratio 637, 626 and 642.3 kg/m^3 were used, coarse aggrregate 1226, 1205 and 1236 kg/m^3 were used, water 148, 166 and 166 kg/m^3 were used, and chemical admixture 4.05, 2.63 and 1.20 kg/m^3 were used in concrete mixes. The control concrete mix represent by C100-R0-F0 that is 100% OPC content, 0% RHA and 0% FA. The triple blend concrete mixes are C80-1R10-F10 represent that means 80% OPC content, 10% Type-1RHA, Type-2RHA and Type-3RHA with 10% FA. Another combination of replacement of cement by FA and RHA as 70% and 60% for all water cement ratios. For concrete preparation weight batching was used for all the ingredients of concrete for various mixes. The concrete mixing was done by laboratory pan mixture. For

TABLE 1. Physical and Chemical Properties of OPC, FA, and RHA

Chemical Composition	Mass Content (%)				
	OPC	FA	1R	2R	3R
(SiO_2)	15.7	63.78	92.45	90.49	89.39
(CaO)	68.51	1.12	1.94	1.71	1.65
(Al_2O_2)	4.65	24.44	0.79	0.68	0.51
(Fe_2O_3)	3.76	5.01	0.74	0.52	0.66
(MgO)	1.66	0.48	0.37	0.32	0.35
(K_2O)	2.35	2.46	0.22	1.03	1.11
(Na_2O)	0.37	0.11	0.41	0.12	0.13
Specific Gravity	3.14	2.2	2.5	2.4	2.36

mixing all ingredients were placed in pan mixture. It was mixed for 2 to 4 minutes up to getting a uniform colored and homogeneous concrete. And by observing it insured that all surface of aggregate were coated with binder paste uniformly. At last concrete mix were removed and placed in a tray for slump test and casting of various mold.

2. 3. Srinkage Cone Test The shrinkage at early age consider as critical parameter for concrete. The loss of water due to hydration process referred to as drying shrinkage. The shrinkage in concrete developed tensile stresses and it lead to form cracks. In this research, the mainly focused on the effect of early age shrinkage. The Shrinkage Cone apparatus were used in this research work as shown in Figure 1. The apparatus consist of conical mould of diameter 14.5 cm and height 12.5 cm. The stand assembly was consisting with laser and platform for placing the cone mould. Before the fresh concrete poured in conical mould the thin foil placed in mould for easy of separation of concrete after testing from mould. The reflector was placed on centre of concrete in mould, the laser beam striking in it. The readings were taken out through the shrinkage meter and computer software. The laser beams offset were fixed at 2000μm. The total system was control through computer and software.

TABLE 2. Concrete Mix Proportion (kg/m^3)

Concrete Mix	C/W	OPC	RHA	FA
C100-R0-F0	0.3	450	0	0
C80-1R10-F10		396	49.5	49.5
C70-1R10-F20		346.5	49.5	99
C60-1R10-F30		297	49.5	148.5
C100-R0-F0	0.35	438	0	0
C80-1R10-F10		385.42	48.2	48.2
C70-1R10-F20		337.24	48.2	96.36
C60-1R10-F30		289.06	48.2	144.54
C100-R0-F0	0.40	383.2	0	0
C80-1R10-F10		337.2	42.2	42.2
C70-1R10-F20		295.0	42.2	84.30
C60-1R10-F30		252.9	42.2	126.46

Figure 1. Shrinkage Cone Test setup

2. 4. Prediction Model In the ACI 209R-92 code have a guideline for predicting the shrinkage of concrete [24]. In the literature it was reported that the modified Gardner model is more easy and accurate for prediction of shrinkage of concrete. In ACI model or Ross model both required ultimate drying shrinkage which can calculate using various complicated terms. In the present research work modified Gardner model was used for predicting the early age shrinkage of triple blend concrete. Equation (1) referred to modified Gardner model [24,25]:

$$\varepsilon_{sh}(t) = -\beta(h)\,\beta(t)\,\varepsilon_{sh\infty} \quad (1)$$

$$\beta(h) = 1 - 1.18\,h^4 \quad (2)$$

$$\beta(t) = \left(\frac{t}{t+0.15\left(\frac{v}{s}\right)^2}\right)^{0.5} \quad (3)$$

$$\varepsilon_{sh\infty} = 1000 \times 1.15\left(\frac{30}{fcm_{28}}\right)^{0.5} \times 10^{-6} \quad (4)$$

where,($\varepsilon_{sh\infty}$)denotes national ultimate shrinkage strain calculated from regression analysis, $\beta(h)$denotes correction term according to relative humidity, $\beta(t)$denotes correction term for effect of time on shrinkage, (t) denotes time curing period, (v) volume of concrete for given conical apparatus, (s) surface area in contact with atmosphere, (fcm_{28})denotes 28days compressive strength of concrete, (h) denotes relative humidity as 70%.

3. RESULT AND DISCUSSION

3. 1. Early Age Shrinkage of Triple Blend Concrete During the shrinkage test on the sample for 24 hours, it was observed that the shrinkage increased up to first 7 hours after the addition of water in the mix and then it marginal. The shrinkage test was conducted for all blended concrete mixes with 0.30, 0.35 and 0.40 water-cement ratio. The results of early age shrinkage for 0.30 water-cement ratio blended concrete were shown in Figure 2. For 0.35 water-cement ratio blended concrete mix result were shown in Figure 3. And for 0.40 water-cement ratio, the shrinkage result was shown in Figure 4. In triple blend concrete made by FA and RHA, early age shrinkage was reduced over control concrete. The shrinkage was observed for the 0.30 water-cement ratio. The triple-blend concrete of 20, 30 and 40% partial cement replacement by FA type-1 RHA the shrinkage reduction was observed as 18.33, 29.81 and 34.57% over control concrete. The triple-blend concrete of 20%, 30% and 40% partial cement replacement concrete mix with FA and type-2 RHA the shrinkage reduction was observed as 15.60, 22.79 and 32.81% over control concrete. The triple-blend concrete of 20, 30 and 40% partial cement replacement concrete mix with FA and

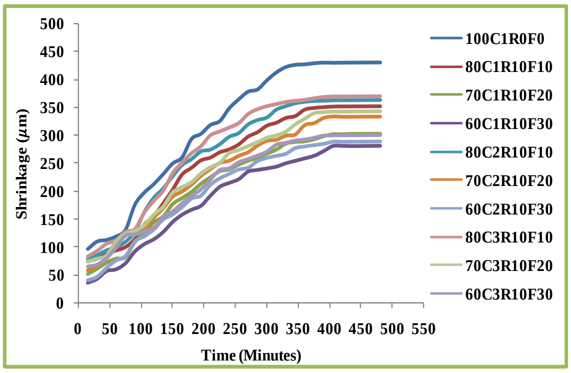

Figure 2. Early Age Shrinkage for 0.30 w/c concrete

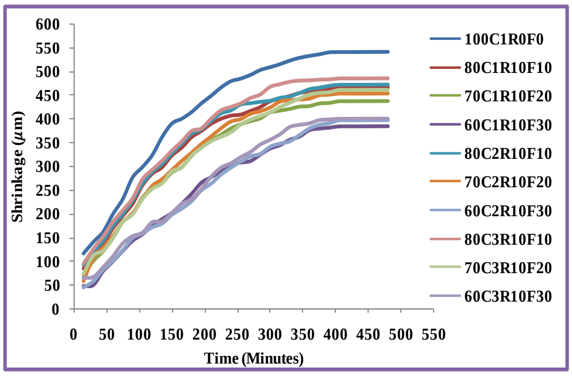

Figure 3. Early Age Shrinkage for 0.35 w/c concrete

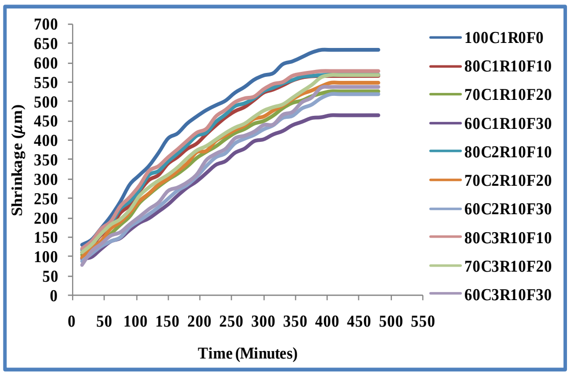

Figure 4. Early Age Shrinkage for 0.40 w/c concrete

type-3 RHA the shrinkage reduction was observed as 13.98, 20.24 and 30.02% over control concrete. Where as the maximum variation of shrinkage reduction for 0.35 water cement ratio observed as 29.06% over control concrete. And for the maximum variation of shrinkage reduction for 0.40 water cement ratio observed as 26.65% over control concrete. According to Neville and Adam [1] autogenous shrinkage and chemical shrinkage are very small as compared to early shrinkage. Hence only early shrinkage is included in present research. It was also noticed that the type-1 RHA blend results getting 2.74 and 4.35% more shrinkage reduction than type-2 and type-3 RHA blend of concrete. The shrinkage is more affected by water-cement ratios. It was observed that the rate of shrinkage is more for higher water-cement ratio concrete due to the higher bleeding possibility in concrete and lower matrix strength. In case of higher water-cement ratio, porosity increased and pore diameter accelerated the reduction in water content and rides capillary pressure in specimen; hence, increased in the early age shrinkage of concrete [7]. The shrinkage was reduced due to reduction in bleeding of concrete. The water stored in the rough surface of RHA. The stored water worked as the internal curing agent. It leads to the vulnerability of early age shrinkage cracking. The slow diffusion of water in fresh concrete also reduced the shrinkage and microcracks. In triple blend concrete, it was also noticed that the shrinkage reduced with the increase in cement replacement. It has happened due to the reduction in heat due to lesser cement content at an early age. In respect to triple blend concrete mix with type-1 and type-2 RHA was reduced more percentage of shrinkage than type-3 RHA blend and control concrete. It was because of reduction in bleeding by the addition of fine particles of RHA and FA. It makes dense particle packing internal concrete matrix and on the surface of concrete, hence the less chance of evaporation and micro cracks [26].

3. 2. Prediction of Early Age Shrinkage for Triple Blend Concrete

In the modified Gardner model equation for predicting the shrinkage of triple blend concrete. The independent variable was the time of exposure (days) and dependant variable was early age shrinkage observed in particular time which was noted as $\epsilon_{sh}(t)$ in (μm). In ACI 209 code required ultimate drying shrinkage. In the present research experimental determined early age shrinkage of triple blend concrete at the period of exposure of 7 hours was used as ultimate drying shrinkage. The regression equation can be used for the determining the ultimate drying shrinkage of concrete. The regression equation used for predicting the ultimate drying shrinkage in present work. The concrete containing various ingredients but for developing the regression equation only cementetious material was selected as FA, RHA and OPC. In the equation variables are denoted as (X1), (X2) and (X3) for FA, RHA and OPC. The least square analysis used to determine the regression coefficient. The final equation for predicting the ultimate drying shrinkage of triple blend concrete shown in Equation (5). The R square for the given regression model is 0.864, hence it may considered as the given regression model is adequate for optimized the experimental work. However, it may be noted that the prediction model are specific to the variables and its properties hence cannot be generalized, but are very useful in predicting the result from the given response.

$$\varepsilon_{sh}(t) = \left[(1 - 1.18\,h^4)\,.\left(\frac{t}{t+0.15\left(\frac{v}{s}\right)^2}\right)^{0.5}.\,(2910)\right] - [(2.59 \cdot X1) - (0.82 \cdot X2) - (3.36 \cdot X3) + (1530)] \quad (5)$$

Table 3 illustrate the results drawn from analysis of modified mathematical model for early age shrinkage of triple blend concrete with variation of composations. It was observed that there is less difference between experimental and predicted values with 0.98 R-square. It was also noticed that the response is not much affected even changing the constituents. It is because of the equation structuraly strong. Hence it may considered as the given model is adequate. However, it may be noted that the prediction model are specific to the variables and its properties.

TABLE 3. Sensitivity analysis for mathematical model

OPC	RHA	FA	Exp. Shrinkage	Pred. Shrinkage	Differ.	R^2
450	0	0	430.45	431.43	-0.98	0.98
396	49.5	49.5	363.32	364.38	-1.06	
346.5	49.5	99	332.34	326.27	6.07	
297	49.5	148.5	289.23	288.15	1.08	
360	0	90	378.41	362.13	15.87	
270	0	180	290.86	292.83	-2.83	

4. CONCLUSIONS

The following are the conclusions drawn from the test results:

1. The triple blend concrete with type-1 RHA can reduce up to 34.57% the early age shrinkage resulting increased durability of concrete.
2. The fine, smooth and spherical structure of FA reduced the shrinkage of concrete and rough surface of RHA reduced the bleeding of concrete resulting reduced shrinkage.
3. The modified Gardner model for prediction of early age shrinkage for triple blend concrete can be used to predict early age shrinkage of triple blend concrete and minimise the experimental work.
4. The combined use of FA and RHA as partial cement replacement up to 30% can reduce the use of cement and environmental issues.
5. The proposed triple blend concrete is strongly recommended for reduce the early age shrinkage of concrete for long durability and sustainable concrete.

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6. CONFLICT OF INTEREST

There is no conflict of interest for this research.

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Persian Abstract

چکیده

انقباض زودرس موجب ترک زودرس بتن است. برای دوام بتن بسیار حیاتی است. تغییر حجم بتن به دلیل تبخیر آب یا فرآیند کم آبی ، به عنوان کوچک شدن شناخته می شود. برای کاهش انقباض بتن ، از مواد سیمانی تکمیلی (SCM) در بتن استفاده شده است. در پژوهش حاضر از فرآورده های زائد صنعتی و کشاورزی مانند خاکستر احتراق (FA) و خاکستر پوسته برنج (RHA) به همراه سیمان به عنوان SCM استفاده شده است. بتن مخلوط سه گانه با ترکیب ۲۰٪ ، ۳۰٪ و ۴۰٪ جایگزینی سیمان جزئی با FA و RHA برای ۰.۳۰، ۰.۳۵ و ۰.۴۰ نسبت سیمان آب تهیه گردید. نمونه های بتنی با استفاده از دستگاه پیشرفته مورد آزمایش قرار گرفتند. نتیجه نشان می دهد که با افزایش محتوای SCM ، انقباض بیش از حدکاهش می یابد. خصوصیات ریزساختار با افزایش محتوای FA و RHA تا ۳۰٪ جایگزینی افزایش یافته است. این به دلیل بسته بندی ذرات متراکم بود.