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Effects of drying conditions, admixtures and specimen size on shrinkage strains

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Abstract

The paper presents the results of an experimental investigation on the effects of drying conditions, specimen size and presence of plasticizing admixture on the development of shrinkage strains. The measurements are taken in a harsh (50 °C and 5% R.H.) and a moderate environment (28 °C and 50% R.H.). The results include strain development at various levels of cross sections of concrete prisms. The drying conditions are found to be the dominant parameter affecting the shrinkage strain development particularly in specimens of smaller sizes. The effect of plasticizing admixture on shrinkage strains is negligible.

Keywords: Drying; Humidity; Temperature; Shrinkage; Admixture

1. Introduction

Shrinkage is defined as the reduction in volume of unloaded concrete at a constant temperature. Its primary cause is the loss of water during the drying process. Most of the shrinkage strain takes place during the first few months after the curing period [1].

In plain concrete that is completely unrestrained against contraction, a uniform shrinkage would cause no stresses. The amount of shrinkage depends on the exposure and concrete mix. Exposure to wind and dry atmosphere greatly increases the shrinkage rate. The most important concrete mix components affecting drying shrinkage are the amount of water per unit volume of concrete and the cement content. Consequently, concrete with wetter consistency will shrink more than the one that is with dry or stiff consistency. The cement paste is the principal material responsible for all volume changes. In general, a high cement content increases the volume of paste and therefore has a potential for higher shrinkage [2].

Excessive shrinkage is a serious concern of engineers. When not adequately controlled, it will cause unsightly and often deleterious cracks, large and harmful stresses and disintegration of the concrete. For these reasons, it is essential that shrinkage effects be minimized, controlled and well predicted.

2. Research objectives

The current research is designed to investigate the drying shrinkage performance of standard shrinkage specimens and concrete prisms of size 80×150×500 mm in two different drying environments. The drying environments were chosen to simulate a harsh desert climate (50 °C and 5% R.H.) and a moderate climate (28 °C and 50% R.H.). The effects of plasticizing admixture and specimen size were also investigated.

3. Experimental program

The experimental work involved testing four sets of specimens prepared from four concrete batches. One mix

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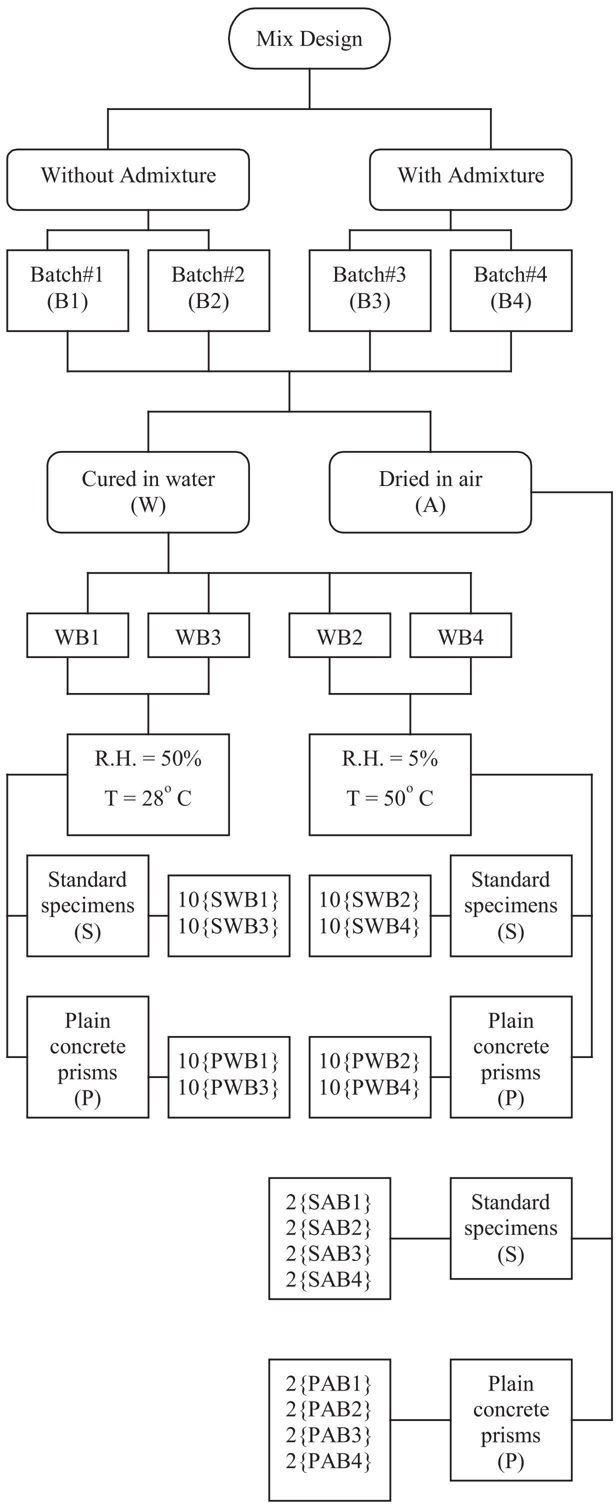

Fig. 1. Flow chart of the experimental program.

design was specified for all batches with the following proportions: cement=350 kg/m^3, aggregate (10 mm)=1175 kg/m^3, white sand=650 kg/m^3, and water=178 kg/m^3. Two batches (batch 1 and batch 2) were without admixture while 1 l/m^3 of plasticizing admixture (P_509) was added to batch 3 and batch 4. The admixture is a formulated blend of polymeric materials based on hydrolysed carbohydrate derivatives. It is designed to give maximum cement particle dispersion without producing unwanted secondary side effects.

Each of the two sets prepared from batch 1 and batch 2 consisted of 24 specimens classified as follows:

1. Twelve plain concrete rectangular prisms (80×150×500 mm) of which ten prisms were cured underwater for 7 days and two were left to dry in air.
2. Twelve standard shrinkage specimens (50×50×300 mm) of which ten specimens were cured in water for 7 days while the remaining two were left to dry in air.

The other two sets were prepared from batch 3 and batch 4. Each set consisted of 24 specimens classified as those prepared from batch 1 and batch 2.

The water-cured specimens prepared from batch 1 and batch 3 were moved to humidity room which was controlled at 50% relative humidity and 28 °C. The corresponding specimens prepared from batch 2 and batch 4 were moved to a temperature room which was controlled at 50 °C. The average relative humidity at the room was estimated to be 5%. A summary of the classifications and the specimen designations is shown in Fig. 1.

4. Research methodology

The measurements of shrinkage deformations were started immediately after the end of the 7-day curing period. The specimens were then placed in the controlled rooms and the measurements were taken three times during the first week after the end of curing period, twice a week for the second and third weeks, once a week for the next 3 weeks, then once every 2 weeks until the end of the testing program.

The shrinkage deformations for the standard specimens were measured using dial gauges of 0.01-mm accuracy.

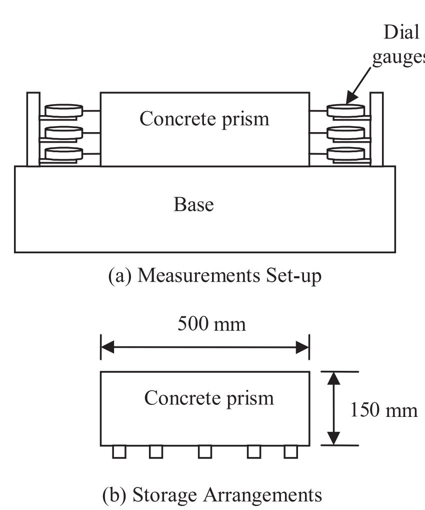

Fig. 2. Instrumentation and storage arrangements for concrete prisms.

Table 1
Average shrinkage strains in the standard specimens

Batch no.	Strain, micro (mm/mm)							
	Batch 1		Batch 2		Batch 3		Batch 4	
Time (days)	SWB1	SAB1	SWB2	SAB2	SWB3	SAB3	SWB4	SAB4
1	87	78.3	321.5		70.1	82.7	451.1	145.8
6	182.7	169.7	569.8	152.2	228	308.8	591.6	175
10	267.1	289.3	661.7	245.8	278.4	378.5	626	250
14	323.6	374.1	669	258.8	327.6	467.6	643.8	343.8
20	358	382.8	738.6	332.8	391.5	502.5	754.7	358.3
27	399.8	402.4	757.3	389.3	423.7	350.2	762.5	233.3
34	407.2	365.4	831.2	441.5	477.2	400.2	726	333.3
48	453	335	835.2	261	505.5	530.7	760.7	489.6
62	484.6	456.8	840	345.9	512.4	628.6	804.3	529.2
118	585	543	890	507.4	615	668.2	845	609.7

Shrinkage strain was then calculated using the following equation:

$$\epsilon = (R_n - R_1)/L \qquad (1)$$

where, ϵ=shrinkage strain (mm/mm), R_1=average of the two initial dial gauge readings, R_n=average of the two dial gauge readings at the nth time period, and L=length of specimen.

For the rectangular concrete prisms, the shrinkage strains were measured using a designed instrument with three dial gauges of 0.01-mm accuracy placed at each end as shown in Fig. 2. The positions of the gauges were set to measure shrinkage at three levels of prism cross section. The measurement levels were at 25 mm from the bottom and the top edges and at the middle of the cross section. The shrinkage strain at the level under consideration is calculated as follows:

$$L_1 = R_{1l} + R_{1r} + 500 - S_{1l} - S_{1r}$$

$$L_n = R_{nl} + R_{nr} + 500 - S_{nl} - S_{nr} \qquad (2)$$

$$\epsilon = (L_1 - L_n)/500 \qquad (3)$$

where L_1=the initial length of the prism at the level considered (mm). L_n=the length of the prism at the nth time period at the corresponding level (mm). R_{1l}, R_{1r}=the initial dial gauge readings at the left- and right-hand sides of the reference steel prism at the level under consideration. S_{1l}, S_{1r}=the initial dial gauge readings at the left- and right-hand sides of the concrete prism at the level under consideration. R_{nl}, R_{nr}=the dial gauge readings at the left- and right-hand sides of the reference steel prism after the nth time period and at the level under consideration. S_{nl}, S_{nr}=the dial gauge readings at the left- and right-hand sides of the concrete prism after the nth time period and at the level under consideration.

5. Results and analysis

The average shrinkage strains that were measured experimentally are summarized in Table 1 for the standard specimens and in Tables 2 and 3 for the rectangular plain prisms without and with admixtures, respectively.

Table 2
Average shrinkage strains measured at the specified levels on the cross sections of plain concrete prisms without admixtures

Batch no.	Strain, micro (mm/mm)											
	Batch 1						Batch 2					
Environment	Humidity Room						Temperature Room					
Level of cross section	Bottom		Middle		Top		Bottom		Middle		Top	
Time (days)	PWB1	PAB1	PWB1	PAB1	PWB1	PAB1	PWB2	PAB2	PWB2	PAB2	PWB2	PAB2
1	50	22	40	65	52.5	28	−19.8	32	36.6	79	12.66	35
6	153.6	61	162.7	142	175.1	56	155	138	248.5	233	210.5	166
10	222.9	121	225.1	162	275.3	152	187	208	298.7	304	261.2	258.1
14	246	109	250.8	148	284.4	128	242	239	320.4	298	289.7	295
20	255.3	210	345.2	302	328.3	194	296.2	260	354.3	338	324.8	307
27	294.1	178	369.6	294	367.1	207	304.9	317	385.7	357	334.7	359
34	325.4	245	425.3	329	404.9	204	340	254	413.7	349	369.3	242.1
48	385	213	460	308	457.7	173	360	299	437	336	397.7	373.1
62	421.5	338	474.9	434.9	488.6	300	414.7	445	475.1	499	404.1	442
76	454.6	403	502.4	471	506.4	312						
90	467.6	210	519.7	288	635	142	447.6	307	512.8	378	476.5	289.1
118	511.1	262	575.3	386	677.9	275.9	455.7	431	530	491	506.1	446.1

Table 3
Average shrinkage strains measured at the specified levels on the cross section of plain concrete prisms with admixtures

	Strain, micro (mm/mm)											
Batch no.	Batch 3						Batch 4					
Environment	Humidity Room						Temperature Room					
Level	Bottom		Middle		Top		Bottom		Middle		Top	
Time (days)	PWB3	PAB3	PWB3	PAB3	PWB3	PAB3	PWB4	PAB4	PWB4	PAB4	PWB4	PAB4
1	55.7	45	54.8	8	68.7	57	−7	61	18.6	32	80.7	128
6	195.5	210	221	184.9	223.7	204.1	173.7	204	211.8	267.9	252.1	278
10	217.5	239	223.5	176	261.9	236	211.4	303	255.3	338	315.7	408
14	268.1	249	226.8	139	273.9	206	282	328	351.6	345	398.9	401
20	341.3	382	298.8	279	340.7	346	343.9	411	388.1	453	437.9	497
27	352.5	309	316.7	214	384.2	228	364.9	316	402.3	330	458.4	342
34	403.7	339	389.5	236	445.1	284	383	338	417.5	334	487.3	437
48	428.4	381	396.2	267	468.8	369	398.6	236	432.8	222	531.4	146
62	459.1	542	487.7	482	483.6	499	444.3	472	514.5	486.9	551.1	573
76	467.2	410	504.4	354	540.9	362	451	522	519.7	549.9	563.6	512
90	476.4	378	527.7	299	580.2	327	477.2	378	547.2	390	580.7	391
118	502.7	380	541.8	329	602.7	381.1	483	358	549.2	379	586.6	403

5.1. Effect of drying conditions

The effect of drying conditions on shrinkage strain development is illustrated in Fig. 3a and b. Fig. 3a shows that the standard specimens that were left to dry in controlled temperature room (SWB2) exhibited a higher shrinkage strain to begin with compared to specimens that were left to dry in controlled humidity room (SWB1). Also, SWB2 specimens exhibited a higher rate of strain development during the first 20 days then the rate became smaller.

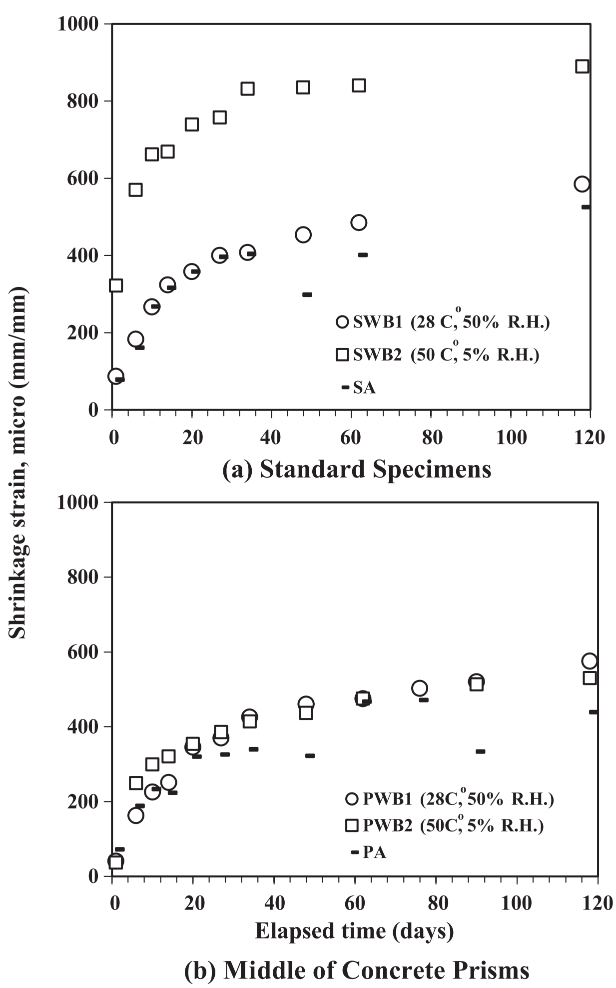

Fig. 3. Effect of drying conditions on shrinkage strains.

In the case of standard specimens that were left to dry in air, shrinkage strains development was similar to SWB1 specimens for the first 40 days of drying time, then the trend became fluctuated due to the change in the environmental conditions. Although duration of testing was limited, the trend of behavior reveals that specimens in all environments will continue approaching the same ultimate shrinkage strain but at different times. In Fig. 3b, shrinkage strains that measured at the middle of the cross section of concrete prisms PWB1, PWB2, and PA were plotted against drying time. This figure shows that the effect of drying conditions (in the context of the limited duration of testing) is negligible compared to standard specimens shown in Fig. 3a. Similar trends of behavior were observed by Sakata and Ayano [3].

5.2. Effect of admixtures

The effect of the plasticizing admixture on shrinkage strains in standard specimens is shown in Figs. 4 and 5. The plasticizing admixture was found to have a moderate effect on shrinkage strains in both drying environments. This observation about the effect of admixtures on shrinkage strains is in contrast to that was observed by Brooks [4] where an increase in the shrinkage strain of about 20% due to admixtures was reported.

5.3. Effect of specimen size

The effects of specimen size on shrinkage strain development are illustrated in Figs. 6 and 7 for standard

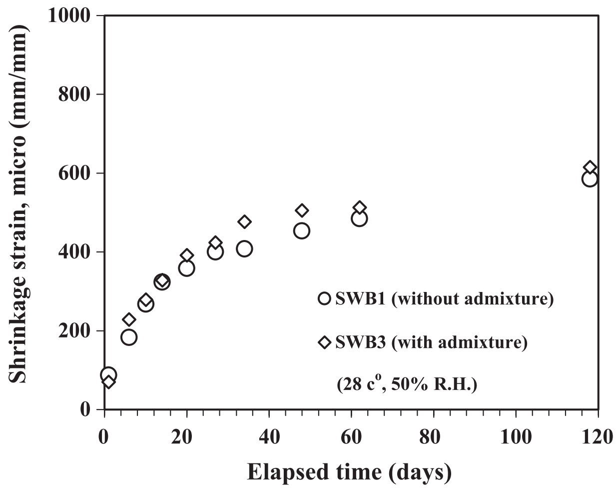

Fig. 4. Effect of admixture on shrinkage strains of standard specimens in humidity room, SWB1 and SWB3.

specimens and rectangular plain prisms in humidity room (SWB1 and PWB1) and in temperature room (SWB2 and PWB2), respectively. Fig. 6 shows that the standard specimens, in general, exhibited more shrinkage strains as compared to strains at the various levels of the plain concrete prisms. Comparing Fig. 6 with Fig. 7 indicates that in high-temperature climate, the size of specimen has a larger effect on shrinkage strain development.

The effects of specimen size on shrinkage strain development of specimens with admixture is illustrated in Fig. 8 for specimens in humidity room and in Fig. 9 for specimens in temperature room. The figures show that the effect of size is more pronounced in specimens with admixture. Comparing Fig. 6 with Fig. 8 and Fig. 7 with Fig. 9 indicates a low correlation between the effect of size and the presence of admixture.

Although the duration of measurements was limited, Figs. 6–9 suggest that both the standard specimens and plain concrete prisms will reach the same ultimate shrinkage

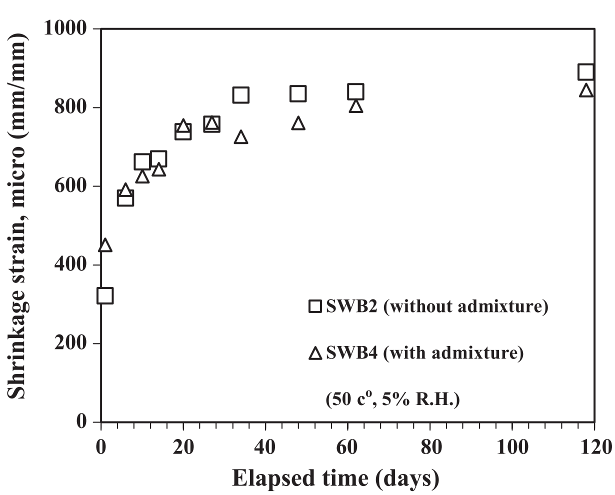

Fig. 5. Effect of admixture on shrinkage strains of standard specimens in temperature room, SWB2 and SWB4.

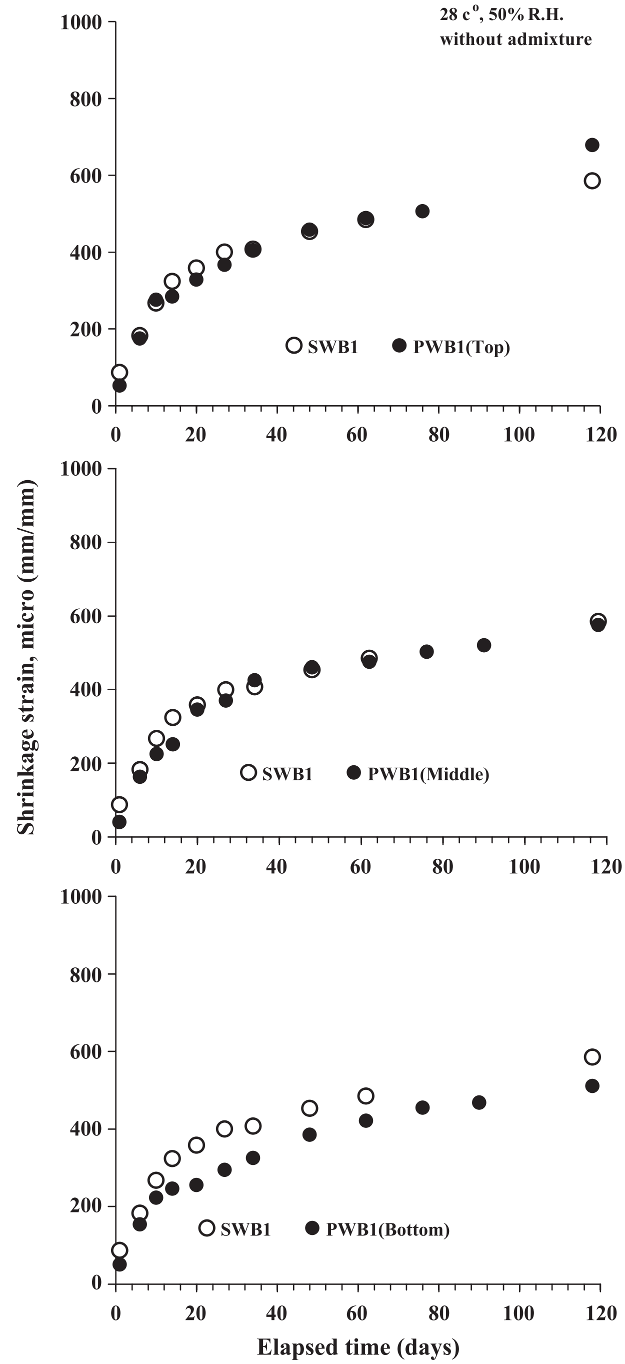

Fig. 6. Effect of size on shrinkage strains of specimens in humidity room, SWB1 and PWB1.

strain but with a higher rate in the specimens of smaller size. This result has also been observed by Almudaiheem and Hanson [5] and several others [6,7] and is in contrast of the assumption made by ACI Committee 209 [8].

6. Conclusions

The paper presented the results of an experimental testing on drying shrinkage strain of standard specimens and

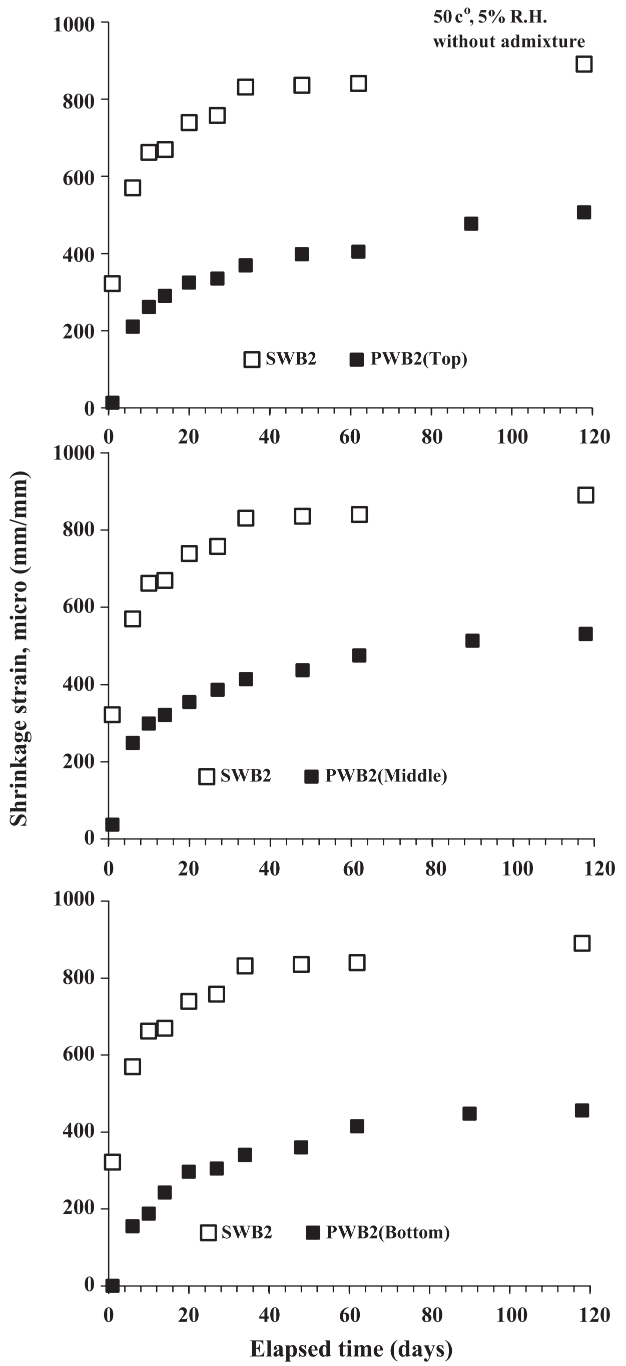

Fig. 7. Effect of size on shrinkage strains of specimens in temperature room, SWB2 and PWB2.

concrete prisms 80×150×500 mm. The measurements were taken in a harsh environment (50 °C and 5% R.H.) and a moderate one (28 °C and 50 % RH) over a duration of 4 months. The effects of a plasticizing admixture and specimen size were also investigated.

Based on the testing results, the following conclusions can be drawn:

1. The standard shrinkage specimens that were left to dry at a temperature of 50 °C and a relative humidity of 5% exhibited a higher shrinkage strain to begin with and higher strain development during the first 20 days of drying as compared to those left to dry in the moderate climate of 28 °C and a relative humidity of 50%. This significant difference between shrinkage behaviors in both environments was less recognized in case of large size specimens (80×150×500 mm). Nevertheless, the trends of strain development reveal that all specimens in both environments will reach the same ultimate shrinkage strain but at different times.

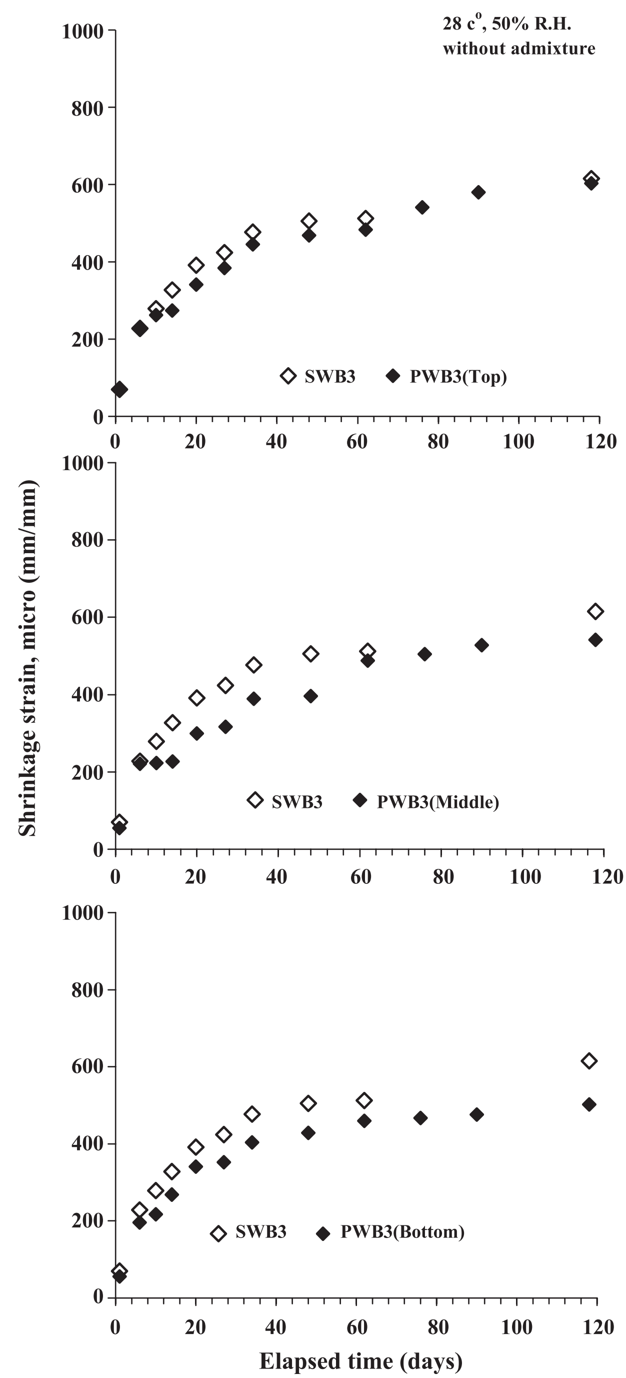

Fig. 8. Effect of size on shrinkage strains of specimens in humidity room, SWB3 and PWB3.

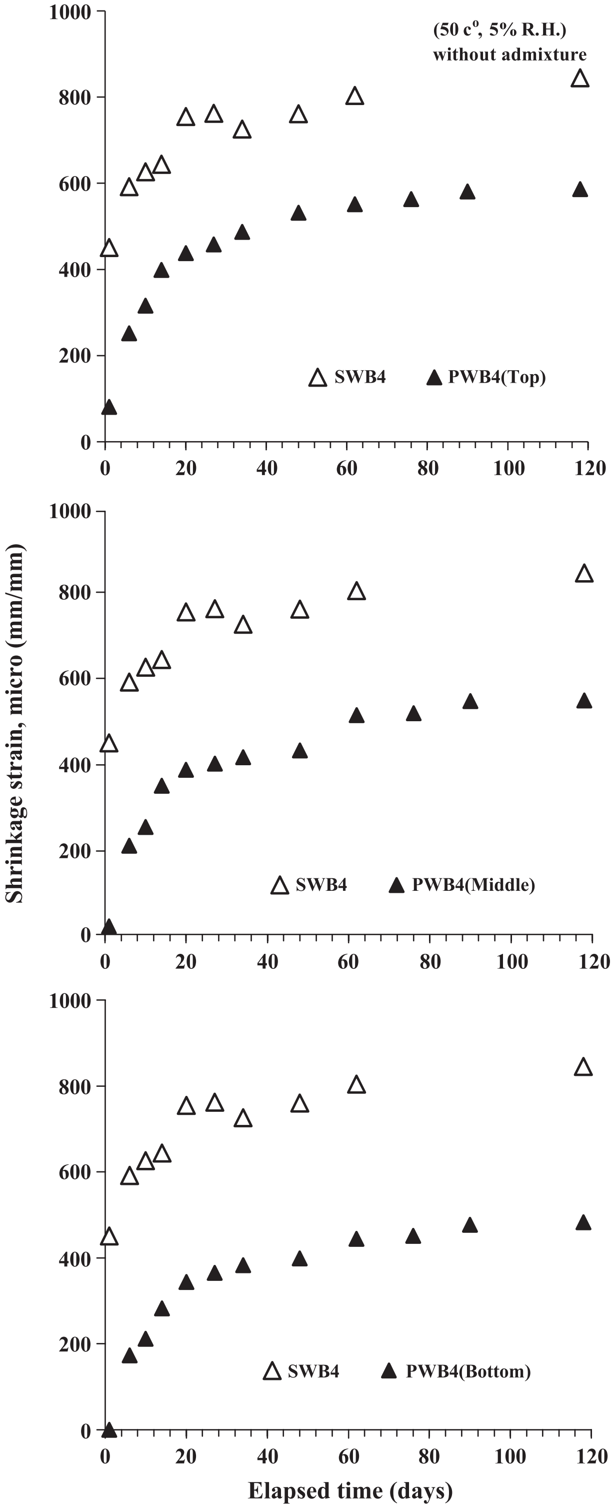

Fig. 9. Effect of size on shrinkage strains of specimens in temperature room, SWB4 and PWB4.

2. The plasticizing admixture was found to have a moderate effect on shrinkage strain specimens in both environments. This observation is in contrast to what is in literature where an increase of about 20% was reported.
3. The effect of size on shrinkage strain was more pronounced in the specimens that were left to dry under a temperature of 50 °C and 5% R.H. as compared to those in moderate climate of 28 °C and 50 % R.H.

References

[1] K. Billing, Structural Concrete, Macmillan and Co., London, 1963.
[2] H. Rusch, D. Jungwith, H.K. Hilsdorf, Creep and Shrinkage, Spring-Verlag New York, NY, 1983.
[3] K. Sakata, T. Ayano, Effect of temperature and relative humidity on concrete creep and shrinkage, ACI Special Publication 179 (1998 (June)) 1043–1053.
[4] J.J. Brooks, Elasticity, creep, and shrinkage of concrete containing admixtures, ACI Special Publication 194 (2000 (May)) 283–360.
[5] J.A. Almudaiheem, W. Hansen, Effect of Specimens Size and Shape on Drying Shrinkage, ACI Material Journal 84 (2) (1981 (March–April)) 130–135.
[6] D.W. Hobbs, A.R. Mears, The influence of specimens geometry upon weight change and shrinkage of air dried mortar specimens, Magazine of Concrete Research 23 (75) (1971) 89–98.
[7] D. Campbell-Allen, D.F. Rogers, Shrinkage of concrete as affected by size, Material Structural Research Testing 8 (45) (1975) 193–202.
[8] ACI Committee 209, Prediction of Creep, Shrinkage, and Temperature Effects of Concrete Structures (ACI 209 R-82), American Concrete Institute, Detroit, 1982, p. 108.