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Shrinkage Behaviour of GRC Thin Sheets

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Abstract

Tests are reported on the drying shrinkage of glass fibre reinforced cement panels. Two types of GRC panels were used; panels made using a premixing casting process and panels made using a spray suction casting process. The variables studied in these tests are, thickness of panels, different wet and dry conditions, size of specimens and different Demec gauge length for measurement of moisture movements. It is shown that the loss and absorption of moisture and the behaviour of specimens depend upon the type of casting process used, the thickness of the specimen and the curing conditions, but it is almost independent of the size of the specimen and the length of Demec gauge used. The loss of moisture was, in general, less than the absorption of moisture.

Keywords: Fibre cement composites, glass reinforced cement, shrinkage properties, fabrication method, curing regime, size effect, moisture loss, water absorption.

INTRODUCTION

Fibre concrete, like all cementitious materials, undergoes dimensional and volumetric changes when exposed to dry and wet environments. After setting shrinkage in cement pastes, concrete and fibre concrete occurs as water is lost to the atmosphere and swelling takes place as water is absorbed. These changes usually produce cracking which may be aesthetically displeasing and eventually can lead to structural unsoundness and poor durability in a component. Various forms of shrinkage are associated with cementitious materials and since drying shrinkage is among the most troublesome, its knowledge is a useful tool in the development of improved materials.

In ordinary concrete the presence of large volume fractions of rigid aggregates restrains the amount of moisture-induced movements. In fibre cement composites, the volume concentration of the fibres is very low compared to the aggregate volume and the matrix tends to be slightly richer than that in comparable normal concrete. The presence of fibres can therefore be expected to have no undue beneficial influence on the drying shrinkage of the matrix. The results published on free shrinkage of cement matrices containing steel fibres, although not always consistent, show a reduction in the shrinkage strains,[1–5] this reduction being dependent on the type of specimen used, the type and amount of fibre reinforcement, as well as the type of the cement matrix. The final free shrinkage of concrete over a period of three months exposed to various curing environments was unaffected by the presence of steel fibres,[1] whereas reductions ranging from 10[2] to 39%[4] have been reported in matrices with steel fibre volume fractions 1 and 3%, respectively. On the other hand, nylon and glass fibres[5,6–8] have been known to reduce shrinkage of the cement and mortar matrix by 20–35% whereas the presence of low polypropylene fibre content had hardly any influence on the behaviour in free shrinkage conditions.[9]

The methods used for determination of drying shrinkage of cement bonded composites are usually designed to be applied to concretes and mortars. Typical methods are described in standards such as BS 1881 and ASTM C490. Each method involves casting a square section prism; the prism varies in section and may be from 25 × 25 mm up to 75 × 75 mm. Thus the methods essentially measure the changes in an

almost massive block of material. The data obtained from such specimens could be useful as indicators of the magnitude of moisture movements of the material systems, but they do not provide a comprehensive picture of moisture movement in large fibre concrete products. In order to make realistic estimates of moisture movements in full size fibre concrete products such as cladding panels, formwork, street furniture, etc., the moisture movements must be measured on thin plates.[10,11]

This paper describes the behaviour of glass reinforced cement panels when exposed to alternating wet and dry environments and the effects of different panel casting process and panel shape.

TEST PROGRAMME

Specimen details

The drying shrinkage tests reported here were carried out on two types of GRC plates:

(1) on plates made using the premixing method
(2) on plates made using the spray suction method

Eight panels of 1·0 m were provided. All panels had 5·0% by weight glass fibres. Three specimens of different dimensions were cut off from each panel, designated as:

Specimen A, 300 × 300 mm
Specimen B, 300 × 600 mm
Specimen C, 600 × 600 mm

Table 1 shows the details of panels used in these tests. Absorption and shrinkage strain readings were measured on both sides of the A, B and C specimens, by using 100, 200 and 400 mm Demec gauges. Typical Demec point layouts are shown in Fig. 1. The stainless-steel discs, 6 mm diameter with a central accurate reference hole, were accurately located and bonded on the test specimen using a setting-bar. Precautions were taken to ensure that the discs in the two directions were located at right angles.

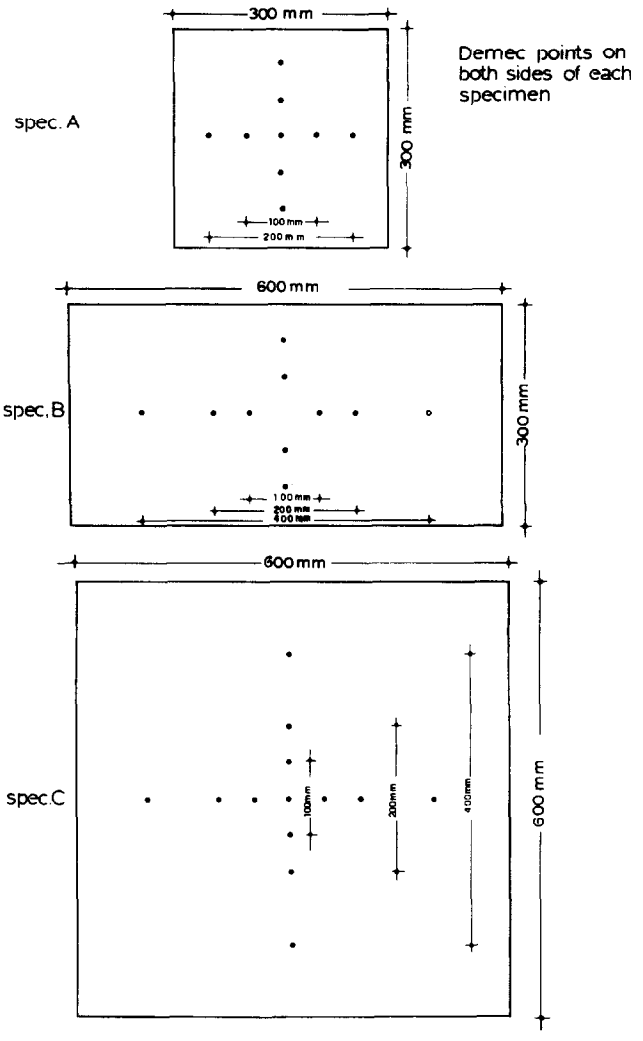

Fig. 1. Layout of Demec points positions.

Table 1. Details of panels

Panel No.	*Approximate thickness in mm (t)*	*Percentage of fibre by weight*	*Percentage of fibre by volume*	*Method of casting*
P1	16 mm	5·0	3·7*	Premixing
P2	11 mm	5·0	3·7	Premixing
P3	16 mm	5·0	3·7	Premixing
P4	11 mm	5·0	3·7	Premixing
P5	16 mm	5·0	3·7	Spray
P6	11 mm	5·0	3·7	Spray
P7	16 mm	5·0	3·7	Spray
P8	11 mm	5·0	3·7	Spray

*Density of mortar=2000 kg/m^3.

Table 2. Test environments

Panel No.	*Method of casting*	*Wet environment*	*Dry environment*
P1	Premixing	Water	Uncontrolled lab. condition (ULC)
P2	Premixing	Water	Uncontrolled lab. condition (ULC)
P3	Premixing	100% relative humidity (RH)	Constant temp. room (CTR)
P4	Premixing	100% relative humidity (RH)	Constant temp. room (CTR)
P5	Spray	Water	Uncontrolled lab. condition (ULC)
P6	Spray	Water	Uncontrolled lab. condition (ULC)
P7	Spray	100% relative humidity (RH)	Constant temp. room (CTR)
P8	Spray	100% relative humidity (RH)	Constant temp. room (CTR)

Table 3. Duration of the repeated curing process

Series No.	*Curing (days)*	
	Wet	*Dry*
S_I	45	96
S_{II}	45	96
S_{III}	16	20
S_{IV}	8	—

The variables studied in these tests were:

(a) type of glass fibre panels
(b) thickness of panels
(c) wet and dry conditions
(d) size of specimens
(e) gauge length

Test environments

The tests consisted of exposing the specimens to wet and dry environments and measuring the dimensional variations. Table 2 shows the wet and dry conditions of the test specimens of each panel. The temperature and humidity conditions involved in the tests are:

laboratory { temperature 15–23°C; relative humidity 50–60%

constant temperature

room (CTR) { temperature 22°C; relative humidity 66%

Table 3 shows the duration of four stages of the repeated process of wet and dry conditions under which the specimens were cured, designated as Series I–IV. For example, in Series II, the specimens, after being cured in dry conditions for 96 days in Series I, either in uncontrolled laboratory conditions or in a constant temperature room, were allowed to be wetted and consequently to dry for 45 and 96 days, respectively.

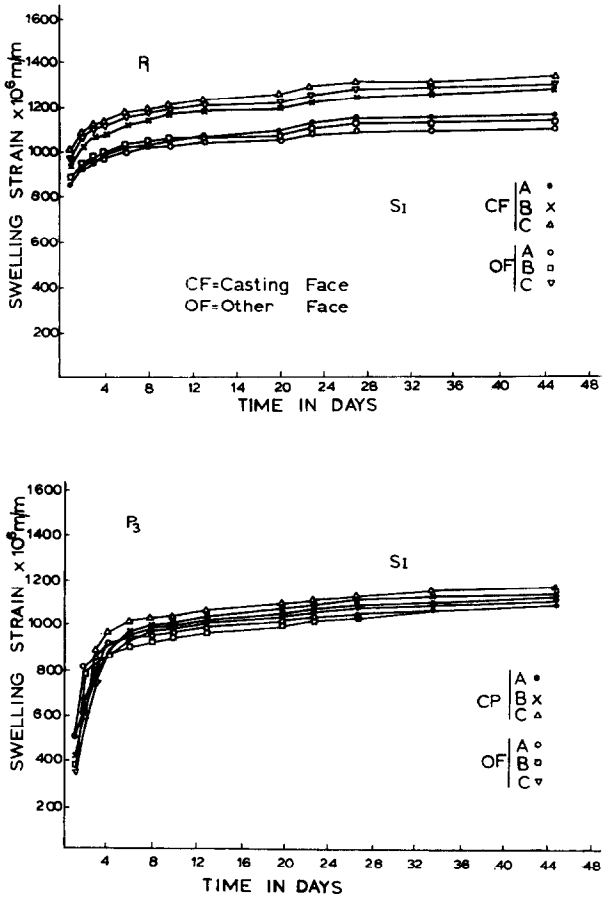

Fig. 2. Swelling strains of GRC sheets, Series I, Panels P_1 and P_3, t=16 mm, gauge length=200 mm, curing P_1: water, P_3: 100% RH.

TEST RESULTS

The results obtained from the absorption and dry shrinkage tests are discussed below. Only representative figures and tables are presented to show the results of this investigation.

Series I

All three specimens from each panel were cured under wet conditions (see Tables 2 and 3) for 45 days. Figures 2 and 3 show the swelling strains measured by a 200 mm Demec gauge.

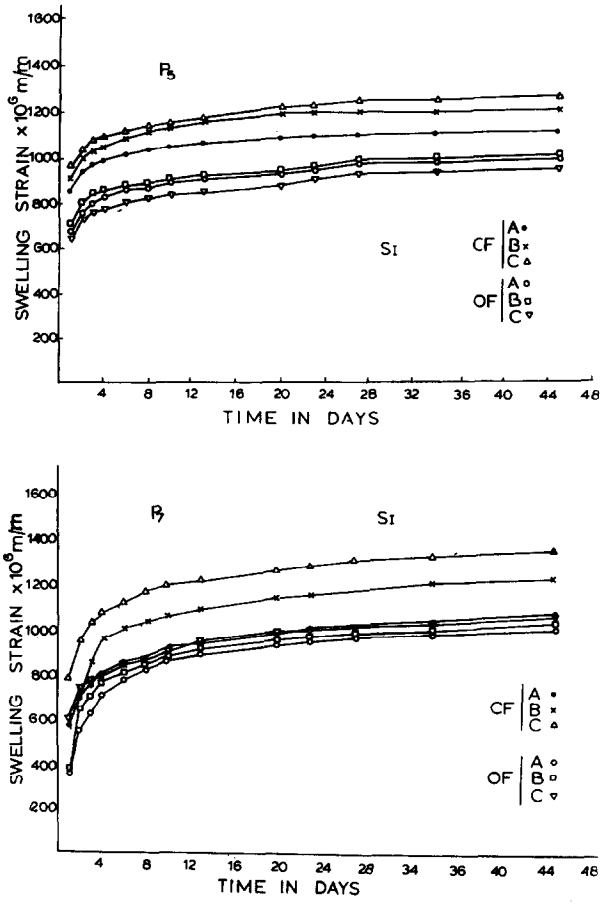

Fig. 3. Swelling strains of GRC sheets, Series I, Panels P_5 and P_7, t=16 mm, gauge length=200 mm, curing P_5: water, P_7: 100% RH.

These figures show two important results. Firstly, for the same type of glass fibre panel, the rate of absorption is higher when the specimens were soaked in the water than when cured in the 100% relative humidity room. Secondly, the swelling strains tended to stabilize earlier in the specimens soaked in the water than in the specimens cured in the humidity room.

The swelling strains at 45 days of all the specimens are shown in Table 4. The values of strains quoted in Table 4 are the average of two strains in two orthogonal directions. The difference in these two values ranges from 0–50 microstrain. From Table 4 some important conclusions can be drawn:

(1) The swelling strains, for the same type and number of panel and the same gauge length, are higher on the casting face of Specimens A, B and C than those on the other face.
(2) The swelling strains, for one particular

Table 4. Swelling strains of GRC sheets at 45 days, Series I (microstrain)

Curing	*Mix*	*Plate No.*	*Thickness (mm)*	*Specimen A (300 × 300 mm)*				*Specimen B (300 × 600 mm)*				*Specimen C (600 × 600 mm)*			
				Cast face		*Other face*		*Cast face*		*Other face*		*Cast face*		*Other face*	
				100 mm	*200 mm*	*100 mm*	*200 mm*	*100 mm*	*200 mm*	*400 mm**	*100 mm*	*200 mm*	*400 mm*	*100 mm*	*200 mm*	*400 mm*
Water	Premixed	1	16	1150	1160	1050	1100	1260	1286	1290	1180	1136	1175	1320	1336	1290	1270	1296	1275
Water	Premixed	2	11	1290	1328	1100	1136	1340	1368	1335	1220	1224	1180	1380	1264	1320	1280	1288	1240
Water	Spray	5	16	1120	1152	980	1008	1220	1248	1195	1010	1016	1015	1250	1280	1220	920	960	955
Water	Spray	6	11	1300	1356	1030	1100	1340	1388	1375	1110	1144	1100	1350	1408	1370	1020	1120	1100
RH 100%	Premixed	3	16	1140	1120	1050	1088	1140	1136	1115	1100	1088	1120	1180	1168	1130	1120	1104	1110
RH 100%	Premixed	4	11	1290	1272	1170	1100	1310	1264	1250	1240	1084	1215	1310	1336	1345	1240	1228	1260
RH 100%	Spray	7	16	1070	1072	1020	1008	1180	1274	1225	1030	1032	1080	1330	1352	1330	1060	1060	1105
RH 100%	Spray	8	11	1340	1352	1150	1128	1370	1368	1350	1170	1130	1175	1410	1400	1385	1150	1200	1190

*Only one reading.

panel and for the same gauge length, are in general higher in Specimen C than those in Specimens B and A.

(3) The strains measured with different gauge lengths in any specimen are comparable.

(4) The swelling strains, for the same type of GRC are less in thicker panels.

(5) For the same type of GRC of the same thickness and for the same curing conditions, the swelling strains at 45 days are in general higher in panels soaked in the water than those cured in the humidity room.

(6) The strains measured in any specimen with different gauge length differ slightly but no general conclusion can be drawn for the order of the measurements.

(7) The specimens from panels made with the spray method showed slightly less swelling strains than those made with the premixing method, under the same curing conditions.

After 45 days when the absorption of the water was almost completed the specimens were removed from the water and humidity room and were left to shrink for 96 days. Figures 4 and 5 show the shrinkage strains measured by a 200 mm Demec gauge. From Figs 2–5 it can be seen that the rate of absorption of moisture is much higher than the rate of drying shrinkage in both types of GRC panels and for any specimen size. Figure 4 shows that the shrinkage strain curves have almost the same form for both sides of all specimens of Panels 1 and 3 (premixing method), while Fig. 5 shows that the two sides of specimens of Panels 5 and 7 have different shrinkage behaviour. The form of shrinkage curves of the specimens in Fig. 5 in the other face at the first day of shrinkage is due to warping of the specimens. This was also verified by visual examination of test specimens.

The drying shrinkage strains at 96 days of all specimens are shown in Table 5. Table 5 shows that all conclusions drawn for the expansion of specimens under wet conditions are also valid

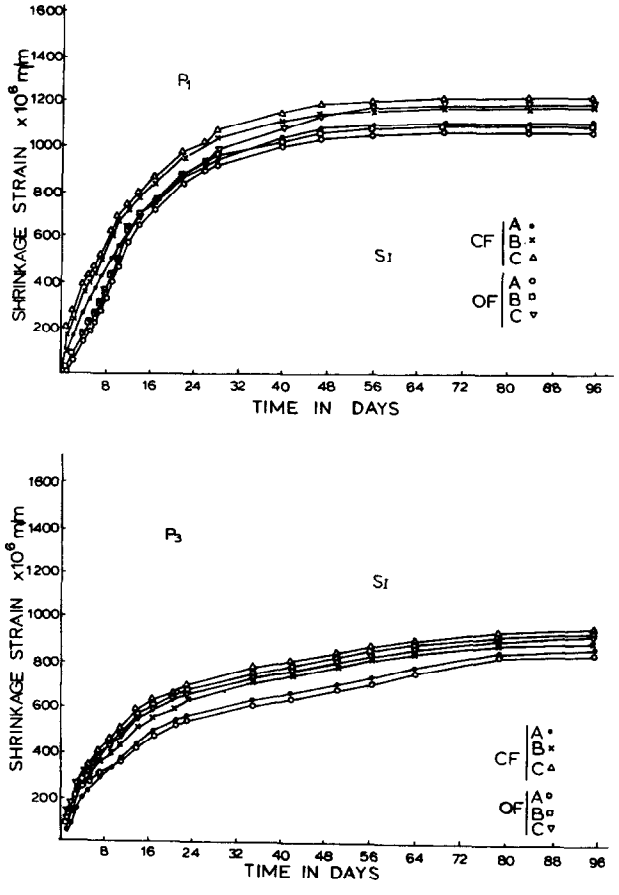

Fig. 4. Shrinkage strains of GRC sheets, Series I, Panels P_1 and P_3, t=16 mm, gauge length=200 mm, curing P_1: ULC, P_3: CTR.

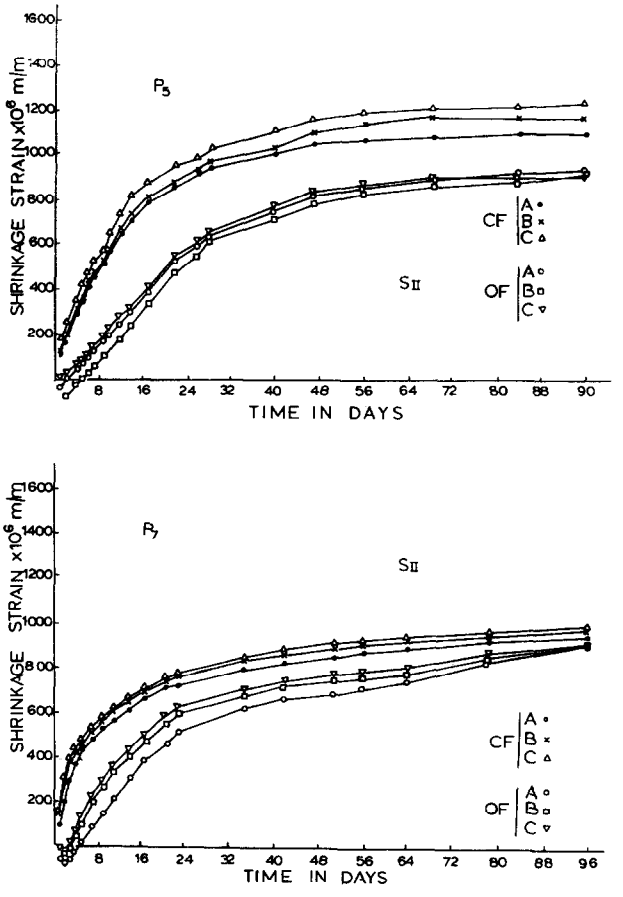

Fig. 5. Shrinkage strains of GRC sheets, Series I, Panels P_5 and P_7, t=16 mm, gauge length=200 mm, curing P_5: ULC, P_7: CTR.

Table 5. Shrinkage strains of GRC sheets at 96 days, Series I (microstrains)

Curing	*Mix*	*Plate No.*	*Thickness (mm)*	*Specimen A (300 × 300 mm)*				*Specimen B (300 × 600 mm)*				*Specimen C (600 × 600 mm)*					
				Cast face		*Other face*		*Cast face*		*Other face*		*Cast face*			*Other face*		
				100 mm	*200 mm*	*100 mm*	*200 mm*	*100 mm*	*200 mm*	*400 mm**	*100 mm*	*200 mm*	*400 mm*	*100 mm*	*200 mm*	*400 mm*
Uncont. LAB cond	Premixed	1	16	1100	1120	1010	1080	1200	1192	1180	1120	1110	1130	1250	1236	1210	1270	1220	1208
Uncont. LAB cond	Premixed	2	11	1270	1220	1100	1100	1290	1282	1245	1220	1192	1165	1280	1258	1255	1260	1268	1220
Uncont. LAB cond	Spray	5	16	1170	1090	940	930	1140	1160	1140	890	912	890	1200	1236	1205	900	904	900
Uncont. LAB cond	Spray	6	11	1250	1312	1000	1024	1270	1318	1315	1040	1060	1065	1320	1356	980	1010	1050	
CTR	Premixed	3	16	890	868	920	848	970	900	930	960	936	880	1000	964	940	960	930	930
CTR	Premixed	4	11	1030	1016	1020	996	1050	1072	1085	1030	988	995	1090	1072	1110	1090	1000	995
CTR	Spray	7	16	950	536	860	896	970	962	950	850	880	895	1010	998	965	870	902	912
CTR	Spray	8	11	1120	1060	940	930	1190	1096	1115	950	960	930	1160	1096	1098	960	980	945

*Only one reading.

for the shrinkage of specimens under dry conditions. From Figs 2–5 it can be seen that the difference between swelling and shrinkage strains is higher in panels cured in a constant temperature room than in those cured in the laboratory because of the increased relative humidity of the constant temperature room.

Test results show that panels of the same type of GRC under the same curing conditions but of different thickness showed different values of shrinkage; the thicker the specimen the less the strain of shrinkage.

Series II–IV

In Series II the same test procedure was used as in Series I, i.e. absorption for 45 days and drying shrinkage for 96 days. In Series III there was absorption for 16 days and shrinkage for 20 days, while in Series IV there was absorption for 8 days. The test results are shown in Figs 6–10. From the test results it can be seen that almost the same critical conclusions as in Series I can be drawn for the behaviour of GRC panels. The differences observed in behaviour

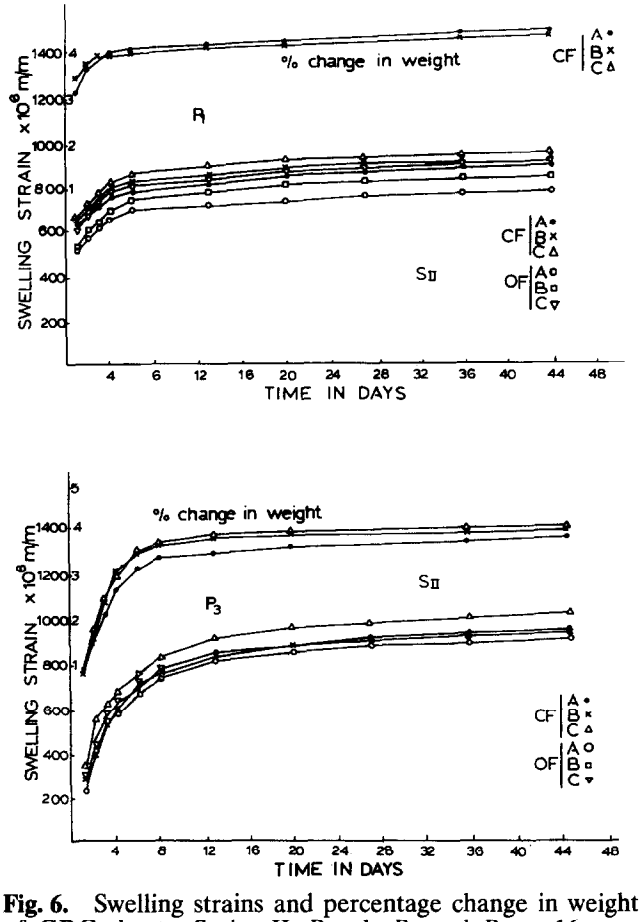

Fig. 6. Swelling strains and percentage change in weight of GRC sheets, Series II, Panels P_1 and P_3, t=16 mm, gauge length=200 mm, curing P_1: water, P_3: 1000 RH.

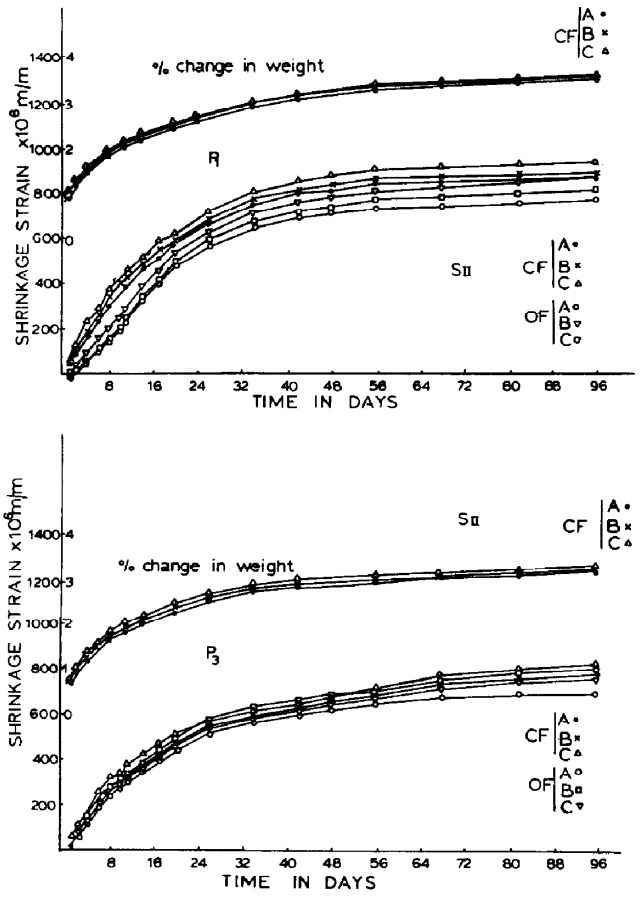

Fig. 7. Shrinkage strains and percentage change in weight of GRC sheets, Series II, Panels P_1 and P_3, t=16 mm, gauge length=200 mm, curing P_1: ULC, P_3: CTR.

of GRC panels during the repeated wet and dry process pertain (a) the values of swelling and shrinkage strains, which are lower when compared with the strains in Series I, and (b) that both swelling and shrinkage strains stabilize earlier in Series I than in the next series.

In Figs 6–9 the change of weight of each specimen with time as a percentage of the initial weight at the beginning of any particular curing condition is shown. These figures show that the form of the curves of the change of weight is similar to the form of swelling and shrinkage curves. Table 6 shows the change in weight for all specimens due to swelling or shrinkage. This table shows that the change of weight is higher in thinner specimens; the size of specimen does not largely affect the change of the initial weight. It is also shown that the change of weight is higher for specimens soaked in the water than in specimens cured in the 100% humidity room.

CONCLUSIONS

From the results reported here the following conclusions can be drawn regarding the moisture absorption and drying shrinkage of glass fibre reinforced cement panels:

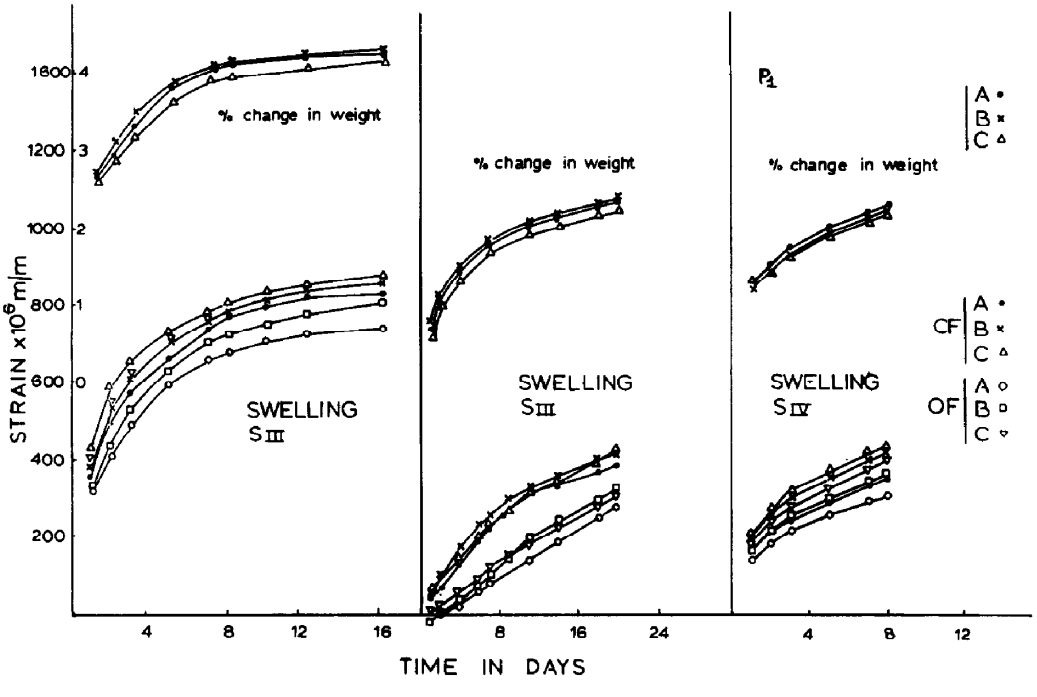

Fig. 8. Swelling and shrinkage strains of GRC sheets, Series III and IV, Panel P_1, t=16 mm, gauge length=200 mm, curing: water — ULC.

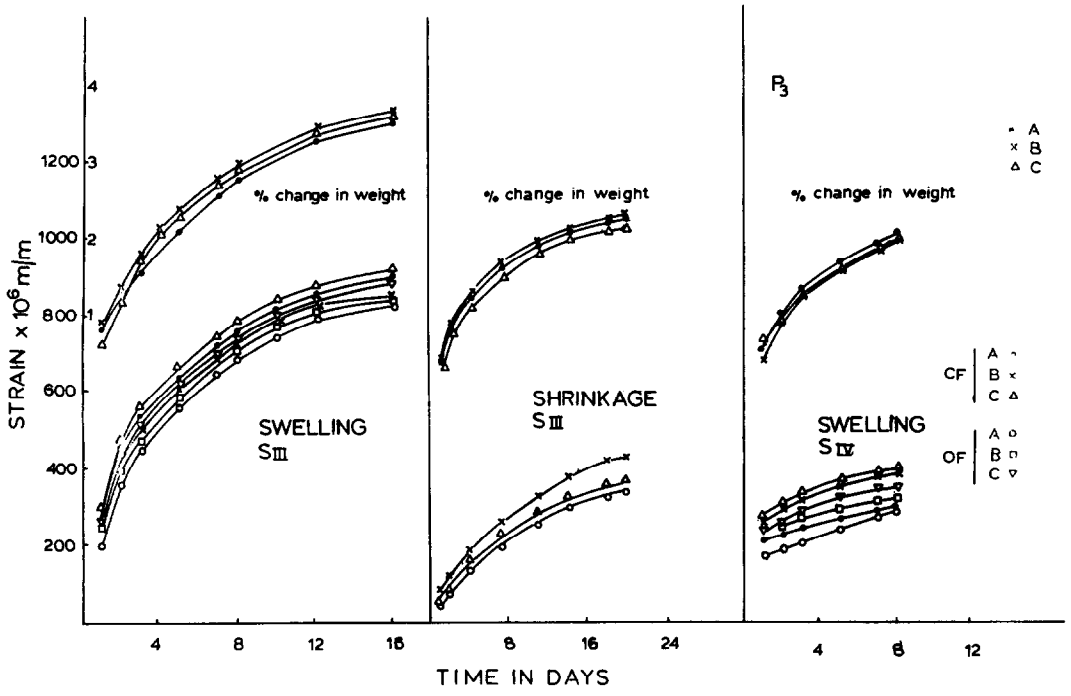

Fig. 9. Swelling and shrinkage strains of GRC sheets, Series III and IV, Panel P_3, t=16 mm, gauge length=200 mm, curing: 100% RH — CTR.

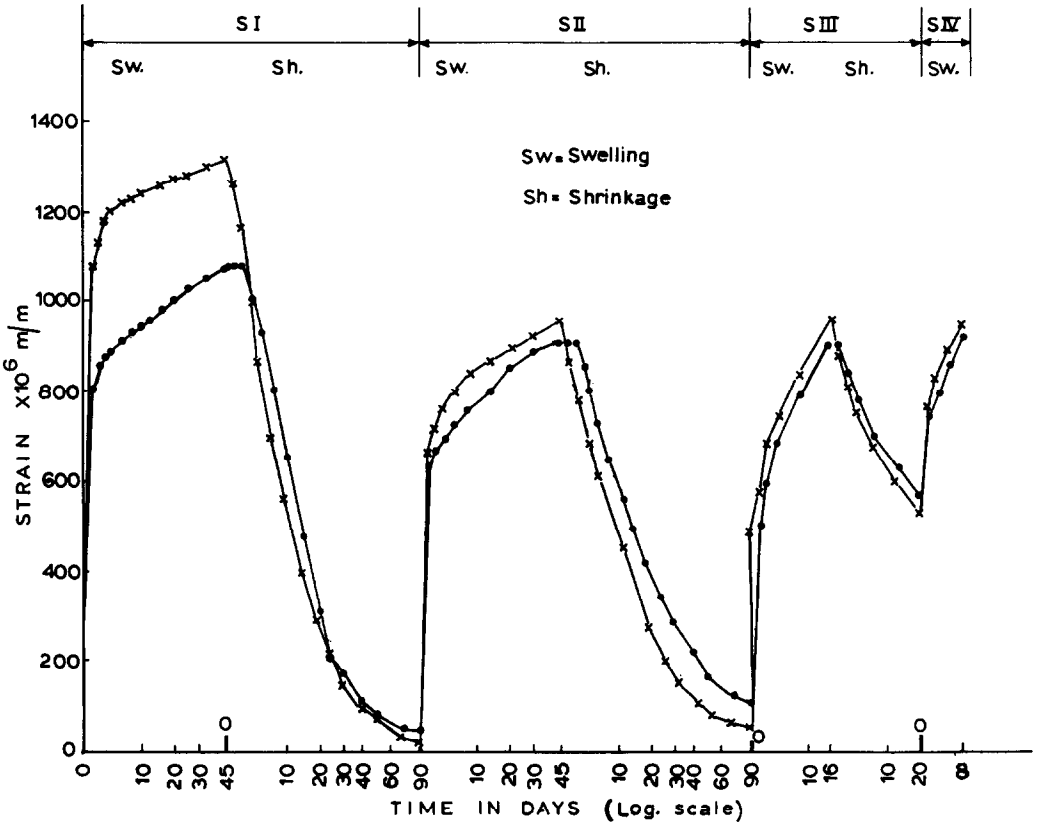

Fig. 10. Swelling and shrinkage strains of GRC sheets, Series I–IV, Panel P_5, t=11 mm, gauge length=200 mm, curing: water — ULC.

Table 6. Percentage change of the initial weight of the specimens due to wet and dry process

	Plate No.	*t (mm)*	*Series II Swelling for 45 days*			*Series III Swelling for 16 days*			*Series IV Swelling for 8 days*		
			A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Absorption											
Water	P1	16	4·39	4·30	4·37	4·30	4·32	4·22	2·33	2·31	2·25
	P2	11	4·91	4·67	4·63	4·80	4·60	4·70	2·67	2·72	2·75
	P5	16	4·51	4·32	4·68	4·45	4·42	4·58	2·44	2·41	2·48
	P6	11	4·85	4·90	4·88	4·80	4·72	4·67	2·85	2·80	2·70
100% RH	P3	16	3·61	3·82	3·91	3·51	3·57	3·61	2·10	2·01	2·08
	P4	11	4·00	3·96	4·22	3·95	3·68	3·79	2·22	2·17	2·28
	P7	16	3·79	3·85	4·00	3·65	3·70	3·67	2·02	2·08	2·13
	P8	11	4·15	3·95	4·39	4·50	3·80	3·92	2·17	2·12	2·21
			Shrinkage for 96 days			*Shrinkage for 20 days*					
Shrinkage											
ULC	P1	16	3·52	3·57	3·60	2·38	2·41	2·28			
	P2	11	3·90	3·94	3·80	2·60	2·56	2·44			
	P5	16	3·60	3·51	3·68	2·36	2·32	2·40			
	P6	11	3·98	4·21	3·94	2·79	2·65	2·80			
CTR	P3	16	3·13	3·20	3·29	2·29	2·38	2·18			
	P4	11	3·72	3·40	3·54	2·69	2·48	2·66			
	P7	16	3·10	3·10	3·34	2·10	2·05	2·10			
	P8	11	3·42	3·41	3·50	2·31	2·20	2·32			

(1) The rate of moisture absorption is higher when the specimens are soaked in the water than that when cured in the 100% relative humidity room.
(2) The swelling strains tended to stabilize earlier in the specimens soaked in water than in specimens cured in the humidity room.
(3) The specimen showed almost the same behaviour in the two orthogonal directions.
(4) The rate of moisture absorption is much higher than the rate of drying shrinkage in both types of GRC panels and in any specimen size.
(5) The thicker the specimen the less the swelling and drying shrinkage strains.
(6) There is no significant difference in the behaviour of different sizes of specimens.
(7) The swelling and drying shrinkage strains measured with different gauge length had almost the same values.
(8) Panels made with the spray suction method showed, in general, slightly less strains than those made with the premixing method. Specimens made with the spray method exhibited a slight warping during the drying shrinkage process.
(9) The casting face of specimens showed higher strains than the other face.
(10) The loss of moisture was less than the absorption of moisture.
(11) The swelling and drying shrinkage strains measured by repeatedly placing test specimens in wet and dry environments were less in those measured in Series I. The strains measured tended to stabilize earlier in Series I than in the next series.
(12) The increase in weight of the specimen due to absorption of moisture is about 4·0% while the decrease due to loss of moisture is about 3·5%. The change of weight is higher in thinner specimens and it is marginally affected by the specimen size.

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