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Creep Characteristics of Glass Reinforced Cement Under Flexural Loading

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Abstract

Tests are reported on the flexural creep behaviour and flexural strength characteristics of mortar specimens reinforced with 5·0% by weight glass fibres. The specimens were cut off from flat sheet materials produced by premixing and spray suction casting processes. It is shown that fibre reinforcement reduced the deflections under sustained flexural load. The results show unmistakably a very significant influence of the fibre reinforcement in reducing creep strains. Fibres were generally more effective in controlling compression creep than tensile creep. Strength reductions were observed with time which were insignificant in specimens produced with the spray suction method.

Keywords: Flexural creep, fibre reinforcement, casting process, casting face, other face, sustained load, deflection characteristics, long term behaviour, creep recovery, absorption, drying shrinkage, strength characteristics.

INTRODUCTION

It is now well established that in many respects fibre cement composites possess better performance characteristics than conventional cement-based construction materials. One of the important factors to be considered in the design and usage of these new materials is, therefore, their long term behaviour. The ability of these materials to withstand the effects of time may be considered to depend on two aspects.

First is the durability and strength retention properties of the composites under various environmental and exposure conditions. Second is the ability of the material to accommodate time dependent deformations occurring within the composite. Both these factors have considerable significance even for non-load-bearing elements since movements occurring within a structure as a whole can cause stress to be transferred to such elements. It is therefore important to know the time-dependent deformations of fibre–cement composites.

There is only limited published data on the time-dependent deformations of fibre cement composites. The available test results show that both shrinkage and creep are influenced by the presence of fibre reinforcement.[1–9] In this paper tests are reported on flexural creep behaviour of fabricated flat sheet materials made with glass fibre and cement paste. The effect of sustained load on deflecton, tensile and compressive creep are discussed. Creep recovery, absorption and drying shrinkage as well as strength characteristics of the creep specimens are also presented.

TEST PROGRAMME

Specimen details

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

(1) On plates made by the premixing method.

(2) On plates made by the spray suction method.

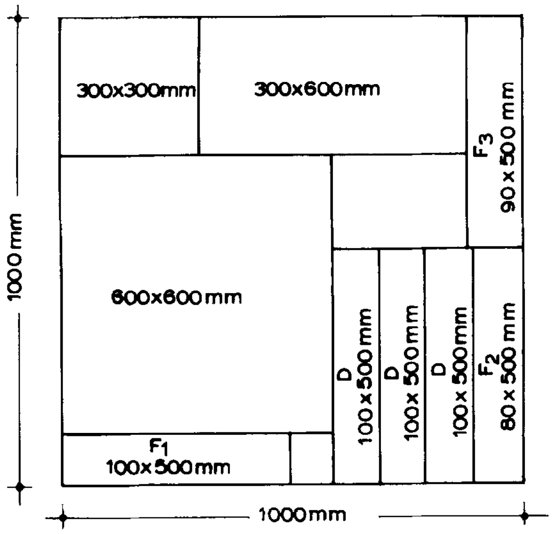

Fig. 1. Sizes of GRC test specimens.

Eight panels of $1{\cdot}0\ m^2$ were provided. All panels had 5·0% by weight of glass fibres. The specimens used in the tests were obtained by cutting off each panel as shown in Fig. 1. Specimens D and F1, F2 and F3 were used either as creep or accompanying shrinkage specimens. The width and thickness of each specimen were obtained as the average of readings measured at the centre-span and at two positions located at 80 mm from the centre of the specimen.

Test details

All the tests were carried out under indoor, uncontrolled environmental conditions. The temperature and humidity during the test conditions varied from 15 to 23°C and 50 to 60% RH, respectively. The flexural strength of each panel was determined from two plates.

The flexural creep tests were carried out on plate specimens $100 \times t \times 500$ mm, where t is the thickness of the particular panel used. The specimens were under two point loading over a span of 450 mm. The test rig was spring loaded and each rig contained two specimens loaded back-to-back, as shown in Fig. 2. Deflections were obtained at the mid-span of each specimen and the supporting points of specimen B. All strains of creep specimens and companion shrinkage specimens were measured with a mechanical extensometer over a gauge length of 100 mm. The initial stress applied to all test specimens and the percentage of the ultimate strength (stage I) are shown in Table 1. When the flexural creep under this load had stabilised, the load was increased to a higher percentage of the ultimate strength (stage II).

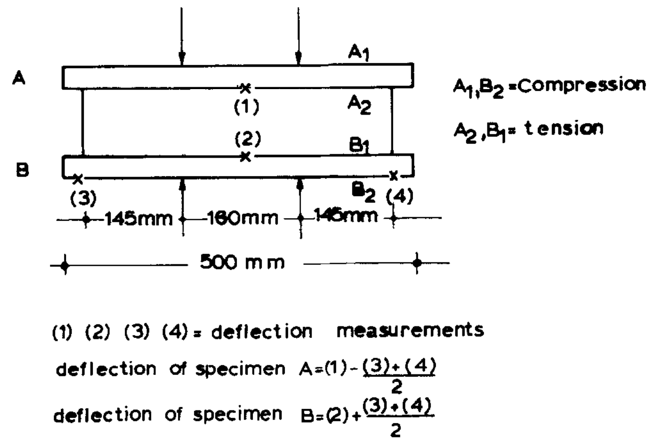

Fig. 2. Creep test details.

TEST RESULTS AND DISCUSSION

Deflection characteristics

Typical deflection characteristics of GRC specimens reinforced with 5·0% by weight glass fibres are shown in Figs 3(a) and 3(b). The maximum deflection under each load increment and the span–deflection ratios are shown in Table 2.

The results show that the deflections are substantially small for all fibre-reinforced specimens. At flexural loads of 15–20% of the ultimate strength, the span–deflection ratios varied from about 1000 to 1700 whereas for loads of 35–50% of the ultimate flexural strength these values ranged from 500 to 700. These are far higher than the generally accepted values of 250–400 for normal concrete members and confirm the beneficial effects of fibre reinforcement on the stiffness characteristics of the resulting composite. Table 2 shows that for almost the same applied loads the span–deflection ratio decreases with decreasing thickness of specimens (plates 5 and 6).

It was found that similar specimens in the same test rig showed variations of about 15% in the observed deflections between them. This is somewhat higher than the variations between specimens of conventional concrete but is generally typical of variations observed in fibre reinforced specimens[10] because of the non-uniform fibre distribution.

FLEXURAL CREEP CHARACTERISTICS

For the flexural creep tests two specimens for the same glass-reinforced panel were subjected to the same load in each rig. Because of the

Table 1. Applied stress of creep specimens

Method	Plate No.	Creep specimens	Thickness (mm)	Flexural strength (N/mm²)	Stage I		Stage II	
					Applied stress	% of the ultimate	Total stress (N/mm²)	% of the ultimate
Premixing method	1	A	16·28	15·60	2·769	17·75	6·794	43·55
		B	15·92		2·895	18·56	7·103	45·53
	2	A	9·77	15·15	7·698	50·75	—	—
		B	10·10		7·193	47·48	—	—
	3	A	15·34	17·38	3·118	17·94	4·931	28·37
		B	15·53		30·4	17·49	4·81	27·66
	4	A	12·08	16·27	5·028	30·90	6·489	39·88
		B	10·52		6·631	40·75	8·558	52·60
Spray method	5	A	14·92	20·00	3·296	16·48	7·129	35·65
		B	15·44		3·078	15·39	6·657	33·29
	6	A	12·57	23·09	4·644	19·60	7·344	31·00
		B	11·98		5·113	21·58	8·086	34·13
	7	A	15·27	25·54	3·147	12·32	4·98	29·48
		B	16·24		2·782	10·89	4·400	17·22
	8	A	11·38	33·43	5·66	16·95	6·976	20·89
		B	11·25		5·79	17·34	7·146	21·37

different thickness of the specimens, this load yields a different applied stress for each specimen. Each flexural test was accompanied by a shrinkage specimen kept side-by-side with a test rig.

The bending creep results for four typical sets of specimens are shown in Figs 4 and 5. Figure 4 shows the results for plates of different thickness made by the premixing method and Fig. 5 shows the results for plates of different thickness made by the spray suction method. The figures show both compressive and tensile creep in bending initially at stage I and subsequently at stage II (see Table 1).

The results of all creep tests are shown in Tables 3–5. Tables 3 and 4 show the elastic strain and the modulus of elasticity of the fibre reinforced specimens, respectively. Table 5 shows the creep strain, specific creep and creep coefficient of the fibre composites. There was no increase in load at stage II for specimens of plate 2 whereas specimen B of plate 4 broke down immediately after the application of the increased stress.

From Figs 4 and 5 it can be seen that the compressive creep tended to stabilise slightly earlier than the tensile creep. From Table 5 it can be seen that the compressive creep is generally less than the tensile creep in bending. This behaviour is different from that of conventional concrete in which compressive creep is much higher than tensile creep,[11] but similar to that of fibre concrete.[8] From the specific creep column (Table 5) it can be seen that the thicker the specimen, the less the specific creep irrespective of the method of casting. It can also be seen that for plates of the same thickness, the plates made by the spray suction method showed better flexural creep characteristics.

The results showed that for specimens cut off from identical plates (for example plates 1 and 3 or 5 and 7) the relation between compressive and tensile creep strains depends on which face (casting face or other face) of specimen is in tension or in compression. The casting face of specimens was generally slightly less effective than the other face.

CREEP RECOVERY, ABSORPTION AND SHRINKAGE TESTS

After the creep tests were completed, the specimens were unloaded and elastic and creep

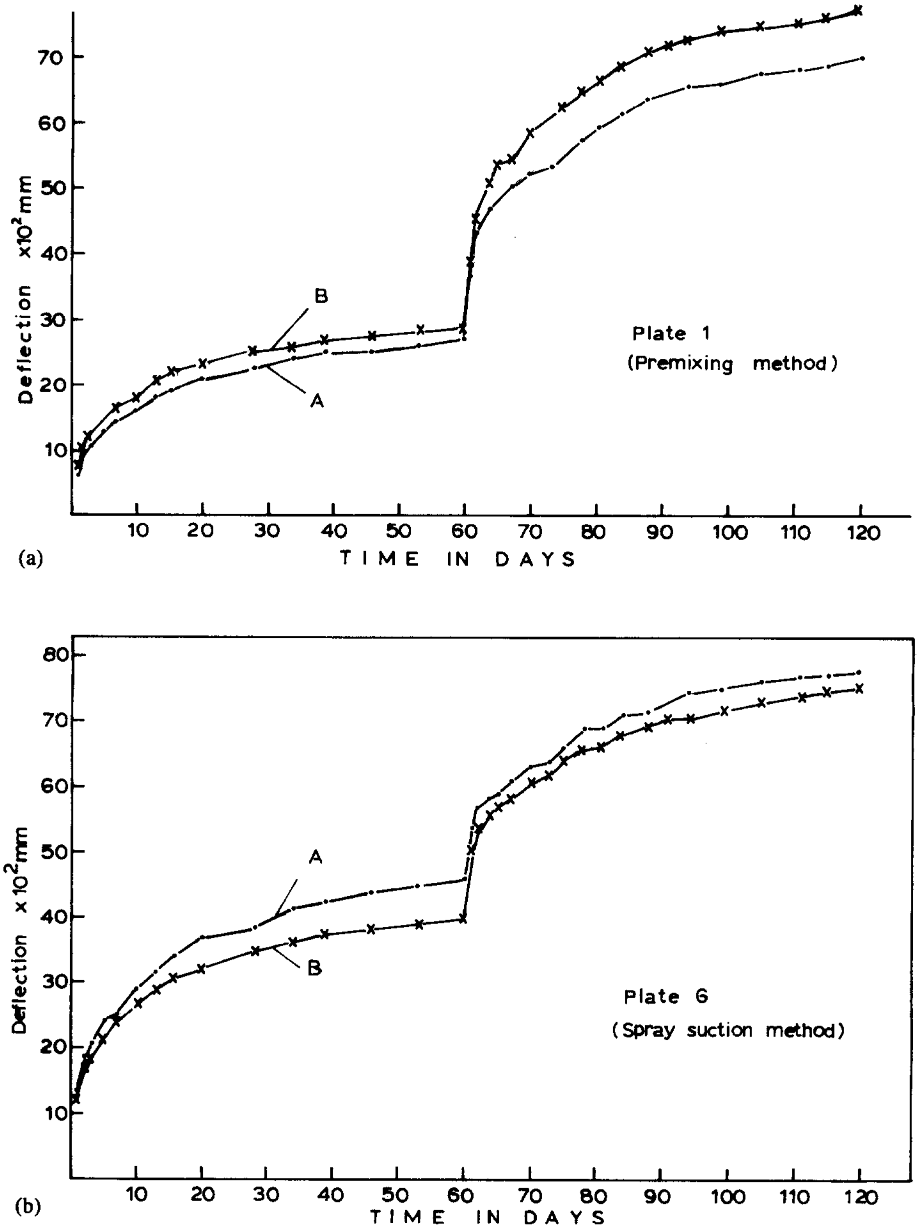

Fig. 3. Deflection characteristics of GRC plates: (a) plate 1; (b) plate 6.

Table 2. Maximum deflection and effective span/deflection ratios of test specimens

Plate No.	*Creep specimen*	*Load*† *(%)*	*Max. deflection (mm)*	*Eff. span/ deflection* $(\times 10^{-3})$	*Load*† *(%)*	Max. *deflection (mm)*	*Eff. span/ deflection* $(\times 10^{-3})$
1	A	17·75	0·28	1·61	43·55	0·76	0·59
	B	18·56	0·27	1·67	45·53	0·69	0·65
2	A	50·75	0·92	0·49	—	—	—
	B	47·48	0·80	0·56	—	—	—
5	A	16·48	0·31	1·45	35·65	0·68	0·66
	B	15·39	0·26	1·73	33·29	0·62	0·73
6	A	19·60	0·40	1·12	31·0	0·75	0·60
	B	21·58	0·46	0·98	34·13	0·78	0·58

† % of ultimate flexural strength.

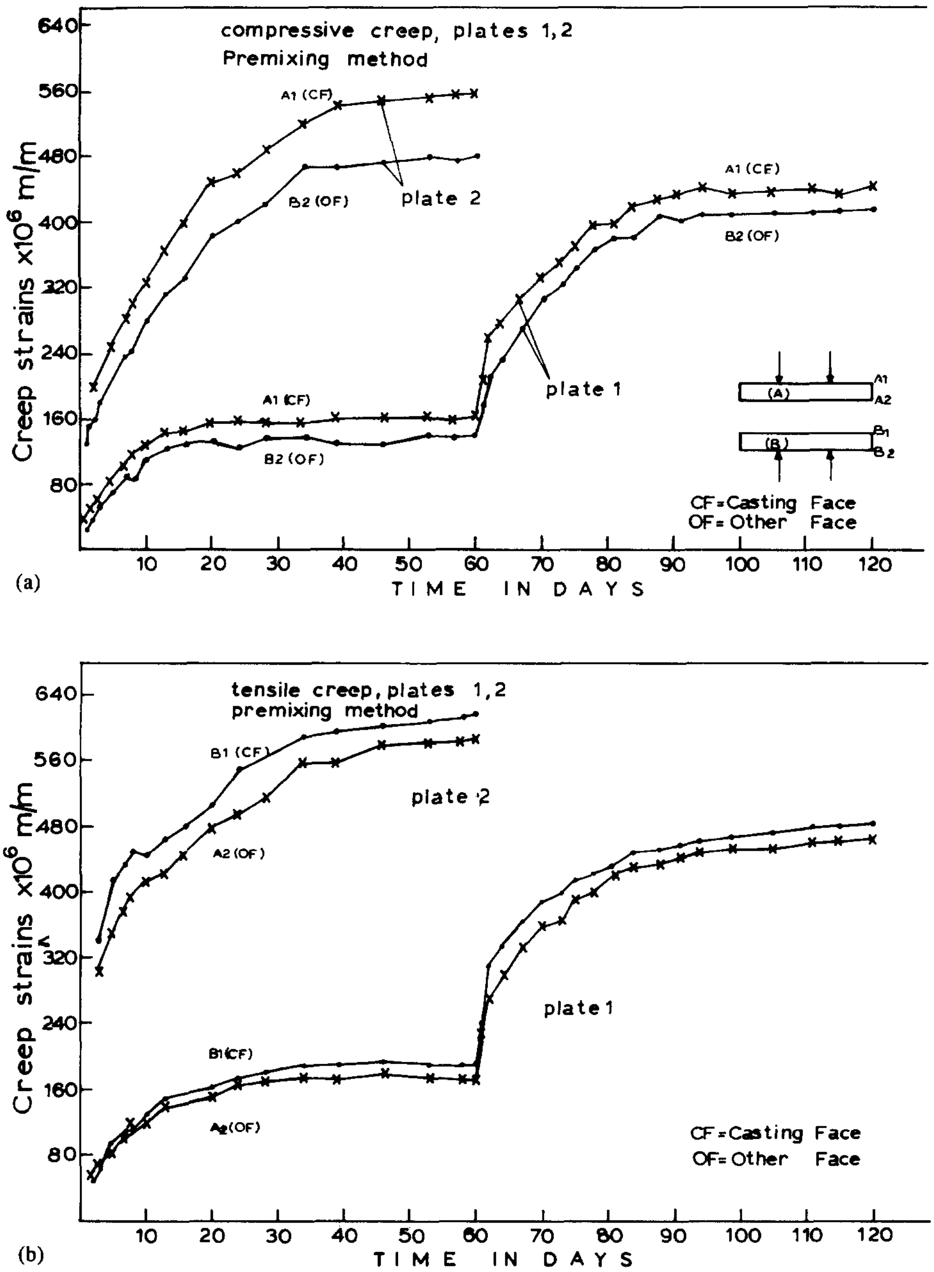

Fig. 4. Flexural creep behaviour of GRC plates (plates 1 and 2): (a) compressive creep; (b) tensile creep.

recovery strains were measured for 22 days. Then the creep specimens (A and B) and the companion shrinkage specimens (S) were soaked in water for 20 days and then the specimens were left to shrink for another 20 days under uncontrolled environmental conditions. Table 6 shows the elastic and creep recovery strains after removing the applied load from the tests rigs. It can be seen that the creep recovery strains on tension sides of all specimens are higher than the strains on the compression sides. Table 7 shows the absorption and drying shrinkage strains as well as the change in the weight of specimens as a percentage of the initial weight. Figure 6 shows the creep recovery, absorption and shrinkage strains of plates 1 and 2. Figure 7 shows the change in the weight of A, B and S specimens of all plates.

The results show that at 20 days the absorption strain is higher than the shrinkage strain; the rate of absorption is also greater than the rate of drying shrinkage.

STRENGTH CHARACTERISTICS

The strength characteristics of glass fibre-reinforced panels are shown in Tables 8(a)–8(c).

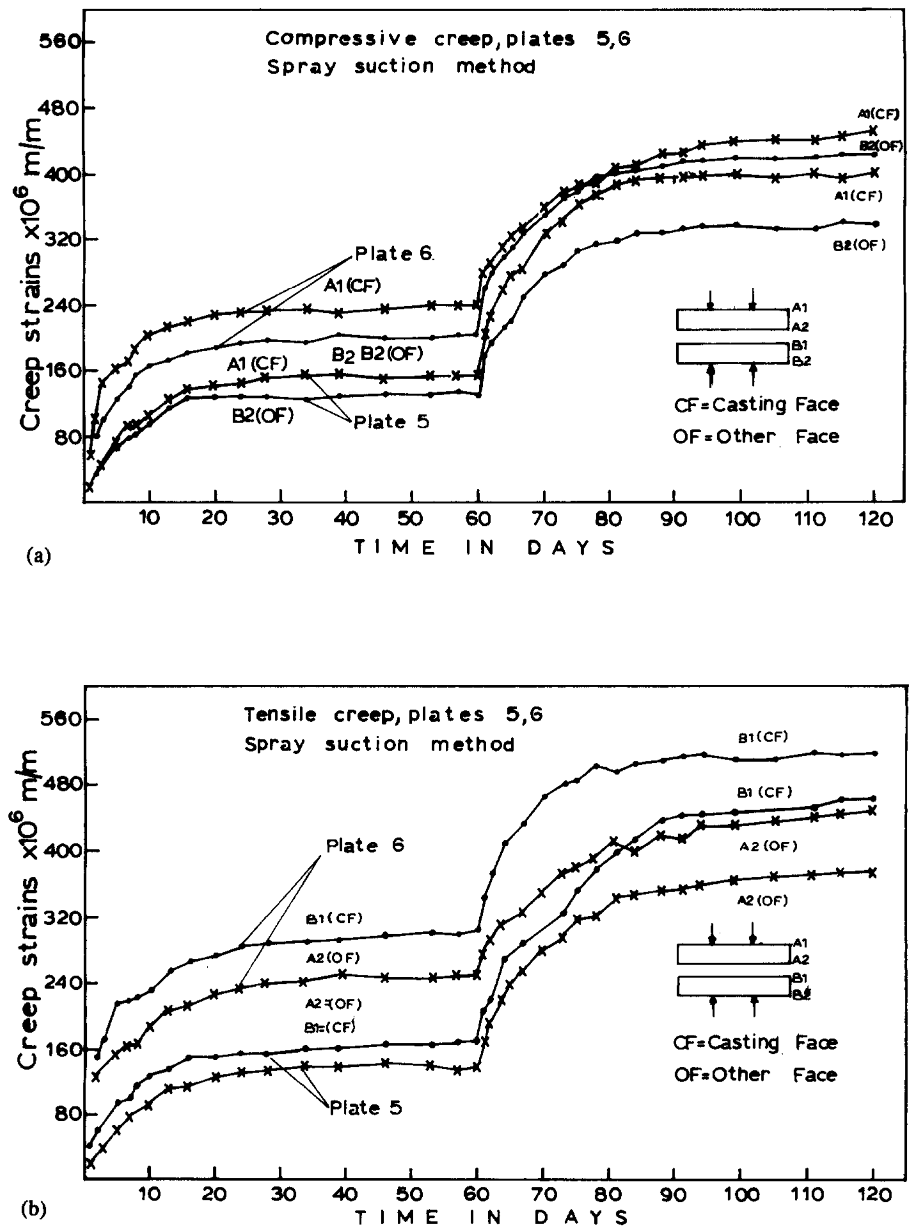

Fig. 5. Flexural creep behaviour of GRC plates (plates 5 and 6): (a) compressive creep; (b) tensile creep.

Table 8(a) shows the modules of rupture of each panel at the beginning of the test. It can be seen that the presence of 5·0% by weight glass fibre gave flexural strengths 15–17 N/mm^2 in the case of the premixing method and 20–33 N/mm^2 in the case of the spray suction method. These values are much higher than those of the conventional unreinforced concretes. In Table 8(b) the modulus of rupture of the panels is shown after 18 months, whereas in Table 8(c) the modulus of rupture of creep and shrinkage specimens is shown.

It can be seen that while the reduction in strength in the spray suction panels has a maximum value of about 20%, this reduction reaches a value of 60% in the premixing panels. The reduction in strength might be due to deterioration in bond between glass fibres and cement paste because of the progressive hydration of cement paste.

CONCLUSIONS

From the results reported here the following conclusions can be drawn:

(1) Glass fibre reinforced specimens showed substantial reductions in deflection when compared to plain concrete members under sustained flexural loading. At flexural loads of

Table 3. Elastic strains — 10^6 m/m

Method	*Stage I*						*Stage II*				
	Plate No.	*Applied stress (N/mm^2)*	A_1	A_2	B_1	B_2	*Applied stress (N/mm^2)*	A_1	A_2	B_1	B_2
Premixing	1	A 2·769 B 2·895	130	140	150	140	4·115 4·208	170	210	220	200
	2	A 7·688 B 7·193	400	390	380	360	— —	—	—	—	—
	3	A 3·118 B 3·04	140	150	160	150	1·813 1·77	70	70	80	70
	4	A 5·028 B 6·631	340	390	820	750	1·461 1·927	100	150	1200	680
	5	A 3·296 B 3·078	130	150	150	200	3·833 3·579	150	140	180	160
Spray method	6	A 4·644 B 5·113	240	250	280	220	2·7 2·973	170	150	170	160
	7	A 3·147 B 2·782	120	140	160	120	1·833 1·918	70	80	80	70
	8	A 5·66 B 5·798	270	330	320	250	1·316 1·348	70	70	80	70

Table 4. Modulus of elasticity — kN/mm

Plate No.	*A1*	*A2*	*B1*	*B2*	*A1*	*A2*	*B1*	*B2*
1	21·3	19·8	19·3	20·7	24·2	19·6	19·1	21·0
2	19·3	19·7	18·9	20·0	—	—	—	—
3	22·3	20·8	19·0	20·3	25·9	25·9	22·1	25·3
4	14·8	12·9	8·1	8·9	14·6	9·8	1·6	2·8
5	25·4	21·9	20·5	15·4	25·5	27·4	19·9	22·4
6	19·4	18·6	18·3	23·2	15·9	18·0	17·5	18·6
7	26·2	22·5	17·4	23·2	26·2	22·0	20·2	23·1
8	21	17·6	18·1	23·2	18·8	18·8	16·8	19·3

A1, B2: Compression sides.
A2, B1: Tension sides.

15–20% of the ultimate strength, the span–deflection ratios varied from 1000 to 1700.

(2) Similar specimens in the same test rig showed variations of about 15% in their observed deflections.

(3) Fibre-reinforced specimens showed generally less compressive creep than tensile creep for the same intensity of loading. The compressive creep generally tended to stabilise earlier than the tensile creep.

(4) Specimens of about 16 mm thickness showed better creep characteristics than specimens of about 11 mm thickness.

(5) Specimens from panels made by the spray suction method showed better behaviour under sustained loading than those made by the premixing method.

(6) The casting face of specimens was generally slightly less effective in resisting shrinkage and creep than the other face.

Table 5. Creep properties of test specimens

Plate No.		*Stage I — age 60 days*					*Stage II — age 120 days*					
		Applied stress (N/ mm²)	*% of ultimate strength*	*Creep strain (10^{-6} m/m)*	*Specific creep (10^{-6} m/m/N)*	*Creep co-effi-cient*	*Applied stress (N/ mm²)*	*Total applied stress*	*% of ultimate strength*	*Creep strain strain*	*Specific creep creep*	*Creep co-effi-cient*
1	A_1 CF	2·769	17·75	162	58·5	1·25	4·115	6·794	43·55	440	64·8	1·47
	A_2 OF			175	63·2	1·25				460	67·7	1·31
	B_1 CF	2·895	18·56	190	65·6	1·27	4·208	7·103	45·53	485	68·3	1·31
	B_2 OF			140	48·4	1·00				415	58·4	1·22
2	A_1 CF	7·688	50·75	550	71·5	1·38	—	—	—	—	—	—
	A_2 OF			585	76·1	1·50				—	—	—
	B_1 CF	7·193	47·48	620	86·2	1·63	—	—	—	—	—	—
	B_2 OF			480	66·7	1·34				—	—	—
3	A_1 CF	3·118	17·94	175	56·1	1·25	1·813	4·931	28·37	325	65·9	1·55
	A_2 OF			202	64·8	1·35				390	79·1	1·77
	B_1 CF	3·04	17·49	190	62·5	1·19	1·77	4·81	27·66	365	75·1	1·52
	B_2 OF			170	55·9	1·13				315	65·5	1·43
4	A_1 CF	5·028	30·90	360	71·6	1·06	1·461	6·489	39·88	—	—	—
	A_2 OF			390	77·6	1·00				—	—	—
	B_1 CF	6·631	40·75	720	108·6	0·88	1·927	8·558	52·60	—	—	—
	B_2 OF			410	61·8	0·55				—	—	—
5	A_1 CF	3·296	16·48	155	47·0	1·19	3·833	7·129	35·65	400	56·1	1·43
	A_2 OF			140	42·5	0·93				375	52·6	1·29
	B_1 CF	3·078	15·39	170	55·2	1·13	3·579	6·657	33·29	465	69·9	1·41
	B_2 OF			130	42·23	0·65				340	51·1	0·95
6	A_1 CF	4·644	19·60	240	51·7	1·00	2·70	7·344	31·0	450	61·3	1·10
	A_2 OF			250	53·8	1·00				445	60·6	1·11
	B_1 CF	5·113	21·58	305	59·7	1·09	2·973	8·086	34·13	520	64·3	1·49
	B_2 OF			205	40·1	0·93				425	52·6	1·12
7	A_1 CF	3·147	12·32	130	41·3	1·08	1·833	4·98	19·48	250	50·2	1·32
	A_2 OF			180	57·2	1·29				345	69·3	1·57
	B_1 CF	2·782	10·89	165	59·3	1·03	1·618	4·40	17·22	320	72·7	1·33
	B_2 OF			125	44·9	1·04				250	56·8	1·32
8	A_1 CF	5·66	16·95	280	49·5	1·04	1·316	6·976	6·976	370	53·0	1·09
	A_2 OF			345	61·0	1·05				445	63·8	1·11
	B_1 CF	5·798	17·34	365	63·0	1·14	1·348	7·146	21·37	475	66·5	1·19
	B_2 OF			265	45·7	1·06				345	48·3	1·11

Plates 1–4: premixing method.
Plates 5–8: spray method.

Table 6. Elastic and creep recovery strains

	Plate No.	Elastic creep recovery				Creep recovery at 22 days			
		A_1	A_2	B_1	B_2	A_1	A_2	B_1	B_2
Premixing	1	180	280	360	380	110	130	200	140
	2	320	290	380	350	160	200	260	180
	3	240	200	220	200	130	180	140	120
Spray	5	320	360	380	360	110	150	180	120
	6	420	440	420	460	150	175	220	160
	7	220	230	200	170	100	140	140	90
	8	330	360	350	300	180	200	210	190

A1, B2: compression side.
A2, B1: tension side.

Table 7. Absorption and Shrinkage strains, change in weight of creep and accompanied Shrinkage specimens at 20 days

Plate No.	Curing	A		B		Shrinkage specimen		Change in weight[†]		
		A_1	A_2	B_1	B_2	S CF	CF	A	B	S
1	Absorption[‡]	990	700	620	960	860	830	6·18	6·31	6·22
	Shrinkage[§]	510	440	520	480	580	420	2·92	2·77	2·90
2	Absorption	940	810	690	980	920	860	6·38	6·29	6·60
	Shrinkage	790	630	610	580	700	650	3·32	3·61	3·44
3	Absorption	960	700	640	950	850	820	6·79	6·57	6·92
	Shrinkage	580	610	580	520	560	510	3·33	3·35	3·42
5	Absorption	900	590	530	810	800	720	6·60	6·45	6·47
	Shrinkage	550	470	450	400	600	510	3·31	3·22	3·09
6	Absorption	1000	630	610	990	890	880	6·89	6·67	6·95
	Shrinkage	560	570	530	510	570	530	3·65	3·52	3·63
7	Absorption	990	690	740	880	940	870	6·34	6·49	6·52
	Shrinkage	640	600	580	—	670	630	2·82	3·02	3·11
8	Absorption	1030	800	620	1040	1000	910	6·52	6·71	6·60
	Shrinkage	670	730	540	660	710	680	3·20	3·13	3·25

[†] Change in weight as percentage of the initial weight.
[‡] Absorption in water for 20 days.
[§] Shrinkage in uncontrolled laboratory conditions for 50 days after soaking in water.

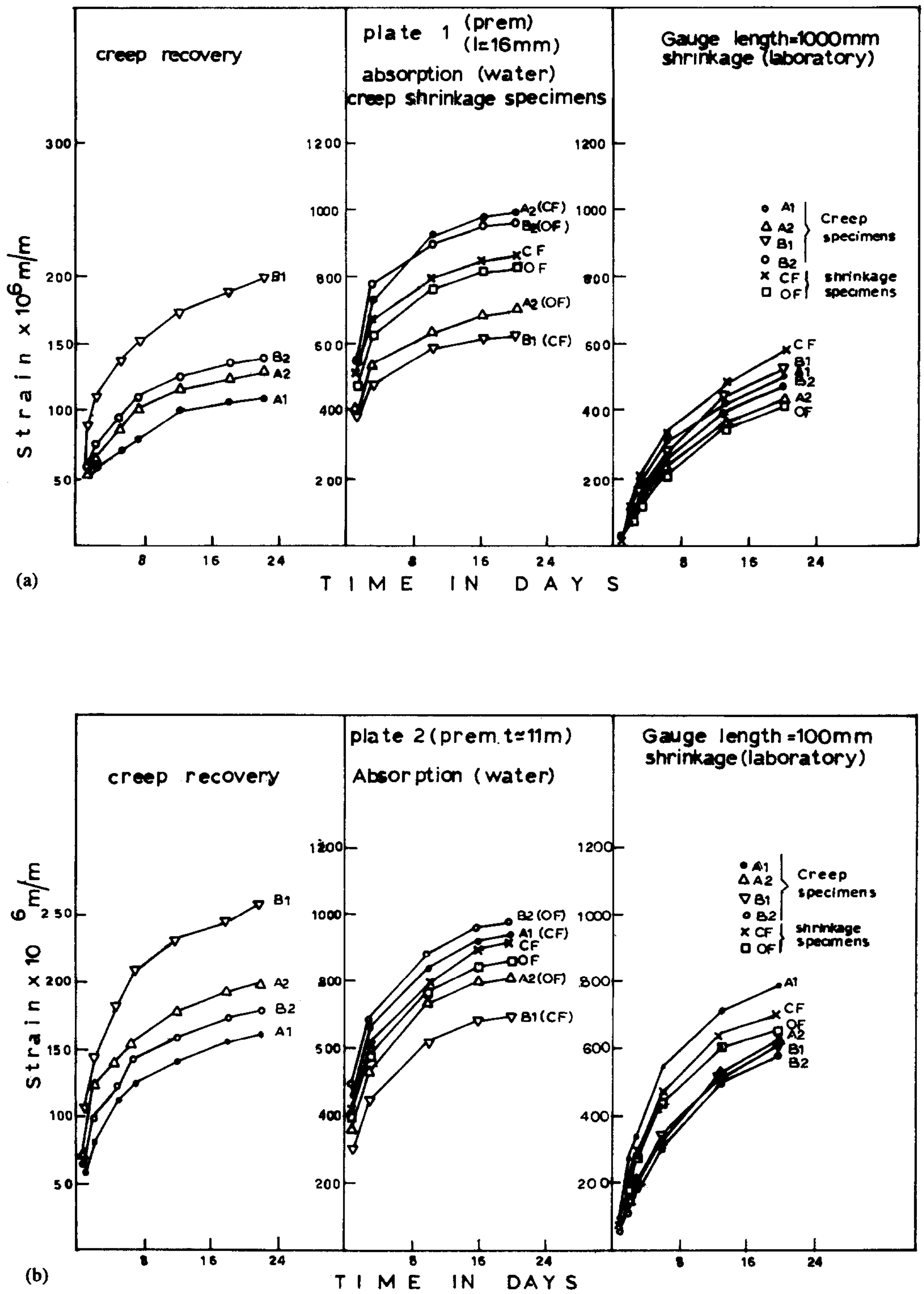

Fig. 6. Creep recovery, absorption and shrinkage strains: (a) plate 1; (b) plate 2.

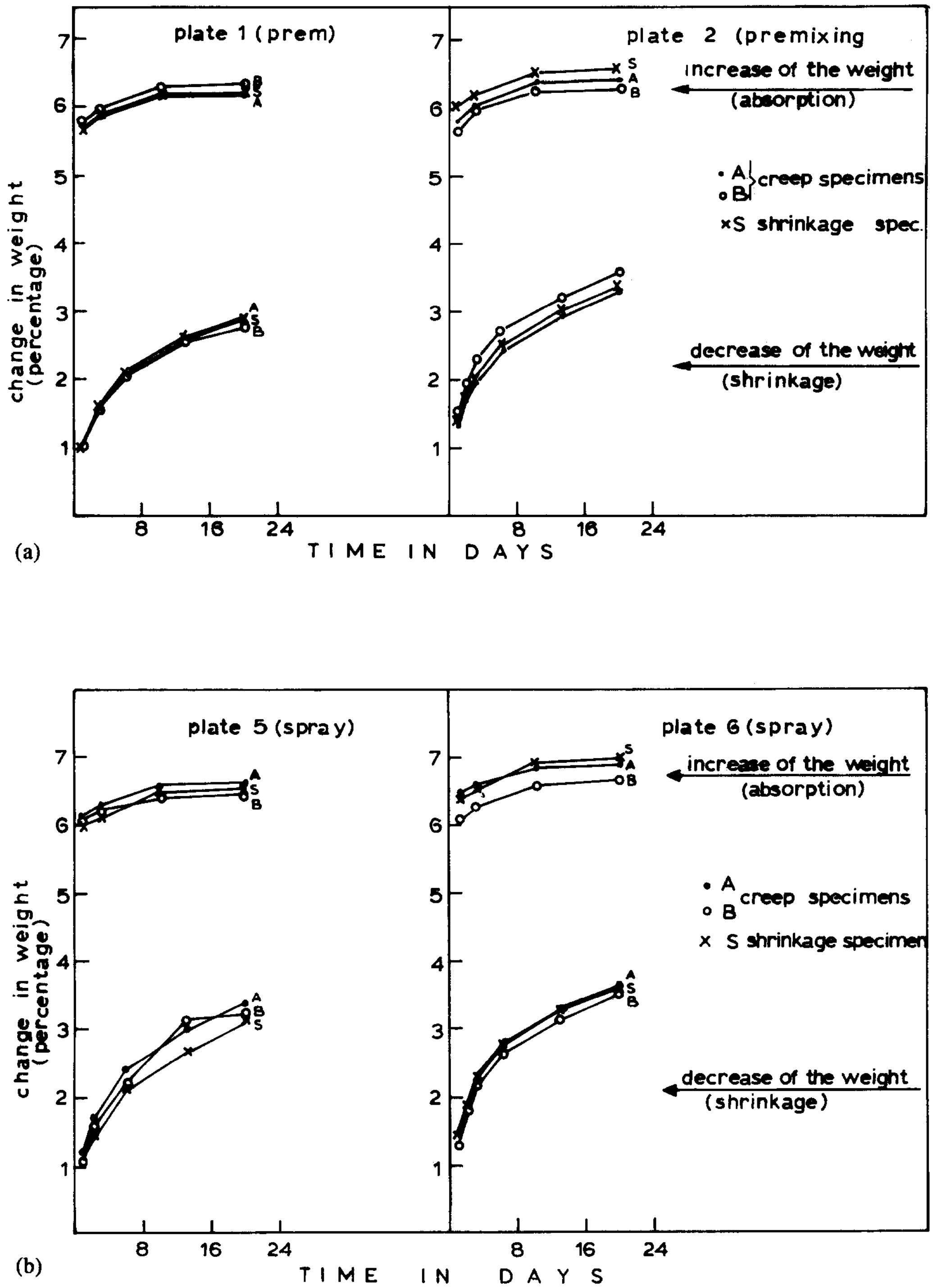

Fig. 7. Change of the initial weight of GRC plates: (a) plates 1 and 2; (b) plates 5 and 6.

Table 8.
(a) Modulus of rupture at the beginning of the tests

Plate No.	*Specimen No.*	*Thickness t (mm)*	*Width b (mm)*	*Description of test: tensile face*	*GRC*	*Modulus of rupture (N/mm²)*	*Average modulus of rupture (N/mm²)*
1	F2	15·4	87	CF†	Premix	14·78	15·60
	F3	16·7	100	CF		16·42	
2	F2	10·52	85	CF	Premix	14·46	15·15
	F3	10·88	100	CF		15·84	
3	F2	15·3	88	OF‡	Premix	15·60	17·38
	F3	14·9	99	OF		19·18	
4	F2	10·4	90·5	OF	Premix	15·94	16·27
	F3	11·5	101	OF		16·60	
5	F2	15·85	85	CF	Spray	20·49	20·00
	F3	16·42	100	CF		19·51	
6	F2	11·10	92	CF	Spray	23·43	23·69
	F3	11·15	101	CF		23·95	
7	F2	15·60	88	OF	Spray	25·96	25·54
	F3	15·60	100	OF		25·12	
8	F2	11·15	89	OF	Spray	31·67	33·43
	F3	11·2	100	OF		35·20	

† CF=casting face.
‡ OF=other face.

(b) Modulus of rupture (at 18 months)

Plate No.	*Specimen No.*	*Thickness t (mm)*	*Width b (mm)*	*Description of test: tensile face*	*GRC*	*Modulus of rupture (N/mm²)*
1	F1	15·82	100	CF	Premixing	10·50
2	F1	10·20	100	CF	Premixing	10·32
3	D	15·32	100	OF	Premixing	12·72
4	D	10·80	100	OF	Premixing	9·86
5	F1	15·75	96	CF	Spray	19·90
6	F1	11·90	100	CF	Spray	20·40
7	D	12·7	100	OF	Spray	21·32
8	D	9·95	100	OF	Spray	26·50

(7) The creep recovery strains of the tensile side of specimens are higher than the strains of the compression sides.

(8) The rate of absorption of water is greater than the rate of drying shrinkage.

(9) The presence of 5·0% by weight of glass fibres in the cement paste produced flat sheets with flexural strength varying from 15 to 33 N/mm^2.

(10) The reduction in flexural strength of the glass reinforced flat sheets after about 2 years after the time of casting was about 20% and 60% for premixing and spray suction methods, respectively.

(c) Modulus of rupture of shrinkage and creep specimens

Shrinkage specimen						*Creep specimens*		
Plate No.	*Thickness t (mm)*	*Width b (mm)*	*Description of test: tensile face*	*GRC*	*Modulus of rupture (N/mm^2)*	*Specimen No.*	*Description of test: tensile face*	*Modulus of rupture (N/mm^2)*
1	16·0	100	CF	Prem.	9·92	A	OF	12·80
						B	CF	12·02
2	9·85	101	CF	Prem.	9·45	A	OF	15·80
						B	CF	13·96
3	15·10	102	OF	Prem.	14·72	A	CF	12·90
						B	CF	17·80
4	11·10	101	OF	Prem.	9·38	A	—	—
						B		
5	16·0	102	CF	Spray	18·29	A	OF	19·9
						B	CF	21·0
6	12·1	100	CF	Spray	20·8	A	OF	22·66
						B	CF	21·76
7	13·3	100	OF	Spray	23·06	A	CF	26·25
						B	CF	27·90
8	10·8	99	OF	Spray	25·8	A	CF	27·32
						B	CF	26·42

(11) The glass fibre-reinforced panels made by the spray suction method showed generally better flexural creep and strength characteristics than those made by the premixing method.

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