Studies of Durability of Cement-based Composites Made with Different Types of Fibres

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Abstract

On a world-wide basis the use of cement-based composites is increasing rapidly. The properties of these composites can be varied by using inorganic or organic fibre types or a combination of both types. Effects of different types of fibres on the durability of these composites, especially in northern climates, have not yet been well documented; the only exception being composites made with the alkali-resistant glass fibres.

This paper reports the results of an investigation addressed to the above problem. In this investigation samples of composites, made with different types of fibres, have been subjected to accelerated freezing-thawing and drying-wetting cycles. The effects of these cyclings on the samples were monitored by means of length-change, ultrasonic sound velocity and strength measurement techniques. The degrading processes are illustrated by means of photo-micrographs.

Key words: Fibre, Composite, Durability

Introduction

Cement-based, fibre reinforced composites have a number of very advantageous properties e.g. toughness, relatively low cost etc., and as a result the use of these composites is increasing on a world-wide basis. This increase in use has been reflected on the types of fibres, both organic and inorganic, being made available for the manufacture of these composites. Unfortunately, however, data on the effects of different types of fibres on the durability of these composites are not always well documented; only exception being the composites made with alkali-resistant glass fibres. This lack of durability data is particularly true for northern climates where composites may be exposed to both drying-wetting and freezing-thawing cycles. The importance of these data cannot be over-emphasized, as these will determine the choice of fibre type for any given exposure condition. The present investigation has been addressed to this question.

The durability of these materials may be evaluated either by exposing samples to natural weathering or by subjecting samples to accelerated weathering tests. In the present investigation both these approaches have been adopted; however, only the results of accelerated tests are reported in this paper.

Materials and experimental techniques

Fibres - In this investigation nine types of fibres were used. Table 1 shows both the chemical nature of the fibres and their identification marks. Only the fibre marked PY was 15 mm long; all other fibres were 12 mm long.

Mix porportion - In order to evaluate the efficiency of a fibre addition at different levels, it is necessary to maintain the workability of different mixes constant. This maintenance of workability was achieved by varying the sand content keeping the contents of other ingredients constant. After extensive experimentation the recipies shown in Table 1 were chosen. Though the recipies were developed mainly for polypropylene fibres they worked as well with other fibre types. However, DO and Ke fibres were difficult to mix even at 1.5% by volume addition level. In the case TIK fibres 5.5% by volume addition could be mixed without any difficulty; this is probably due to its larger fibre diameter. Altogether 19 mixes were used in this investigation.

Sample preparation - From each of the above 19 mixes a number of 1000 x 350 x 15 mm plates were cast. After 24 hours humid curing the plates were water cured for 7 days. The plates were then stored in the laboratory for further 4 months. For each mix, 22 test specimens of 40 x 350 x 15 mm size were cut out of these plates. These were divided into three groups.

Group a - Six specimens were left without any future processing. These were used to measure the initial bending strengths.

Group b - Two circular marks were drawn, at 200 mm apart, on the smooth surface of each of 12 specimens. The marks were for placing the transducers for the measurement of the velocity of ultrasound through the specimens.

Group c - Two reference stabs were glued, at 200 mm apart, on each 40 x 350 surfaces of the last four specimens. These stabs were used as reference points for the length change measurement.

Test methods - Both the groups were then dried at 40°C for 48 hours and cooled to room temperature (approx. 20°C). The six unprocessed specimens (group "a") were used to measure initial bending strength. Velocity of ultrasound through specimens of group "b" were measured. Individual length between reference stabs of each of the specimens of the group "c" were measured.

All the specimens of groups "b" and "c" were water soaked for 8 hours. Groups "b" and "c" were then divided into two sub-groups of 8 specimens; 6 from the group "b" and 2 from the group "c". One of these sub-groups was then frozen for 16 hours at -20°C and thawed in water at 20°C for 8 hours. The second sub-group was dried at 60°C for 16 hours and water soaked at 20°C for 8 hours. The specimens undergone altogether 100 cycles. At the end of every 50 cycles the specimens for both the sub-groups were dried at 40°C for 16 hours, and their length or velocity of ultrasound through them were measured. At the end of 100 cycles, specimens of the group "b" were used to measure bending strength.

At the end of durability testing one specimen of each type of testing of each mix was used to make thin section for petrographic examination. A specimen, having a bending strength near the mean value of the relevant mix, was used to make a thin section. During the petrographic examination special attention was paid to evaluate the degree of crack formation in the specimens.

Results and discussion

A) Visual inspection - None of the specimens undergoing drying-wetting cycles did show any visible sign of damage. Of the specimens undergoing accelerated freezing-thawing cycles only those containing polypropelene fibres i.e. KR, KEG and PY showed signs of distress in the form of surface flaking. Specimens containing steel fibres developed surface rusting.

B) Freeze-thaw cycling - The effects of freeze-thaw cycling on the properties of composite specimens are shown in Tables 3, 4 and 5. From Table 3 it can be seen that the time taken by ultrasound to traverse 200 mm in exposed specimens decreased. This will indicate that the elastic modulus of the specimens were increasing. This indication is further substantiated by a general increase in E value as shown in Table 5. This improvement occurred irrespective of type of fibre used with the exception of KR where E value decreased with treatment.

   Length change measurements (Table 4), on the other hand, show that specimens containing polypropylene fibres (KR, KEG and PY) expanded more than others and this expansion increased with the increase in fibre content.

   Bending strength measurements show that substantial drops in strength occurred in specimens containing 3.5 % KR, KEG and ARG fibres.

C) Dry-wet cycling - Table 3 shows that in some specimens e.g. KR, ARG the time of traverse increased, but in other specimens e.g. PY, TIK the time of traverse of ultrasound decreased; E modulus (Table 5) shows corresponding decrease and increase in the above specimens. Table 5 also shows that specimens containing 3.5% ARG and PY lost strength due to this treatment. The length change measurements (Table 4) show that fibre type has no marked influence.

D) Petrographic examination - Figs. 1 and 2 show representative micrographs of different specimens at the end of 100 cycles. From the figs. it can be seen that dry-wet cycling (V.T.) caused very little microcracking. Freeze-thaw cycling (T.F.), on the other hand, caused micro-cracking especially in specimens containing KR, KEG and PY fibres, and to a lesser extent in specimens containing DO and Ke fibres. Micro-cracking is most extensive in specimens containing KR fibres. Micro-cracking, in general, increases with the increase of fibre content.

Conclusion

From the results of the accelerated testing, it will appear that freeze-thaw cycling seems to be relatively more harmful to fibre reinforced composites than dry-wet cycling. But from the bending tests one can see that drying-wetting tests also affects the maximum bending strengths (S) and the tail of the stress strain curves (e), i.e. toughness. For many samples, except KR, this treatment seems to be the most damaging. It is also interesting to note that the damage of a well described fibre like ARG seems to follow the manufacturers description of the long term stable values of this fibre.

One plast fibre, the TIK-fibre, seems to be the only plastic fibre which keeps a high value in bending (S) in combination with high E and e-values after accelerated testing.

It will be of interest to compare these results to those of natural weathering. Work on this aspect is in progress and will be reported in due course.

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Recipies

Materials by weight \ Fibre amount by volume	1.5% vol.		3.5% vol.	
Cement, rapid	950		950	
Silica	143		143	
Superplasticizer Sikament Na/B	32.8		32.8	
Water	306		306	
Sand	1900		1000	
Fibre:				
Krenit	19.6	16.7(1)	34.2	32.2(1)
Polycrete	19.6		34.2	
Dolanit	25.0		44.2	
Kevlar	30.8		54.3	
TI-Kevlar	30.8		85.7(2)	
E-Glas	55.6	7.4(1)	98.2	5.6(1)
AR-Glas	55.6		98.2	
Steel	165.5		292.3	

Table 1. Recipies

(1) Ref. to KEG mixes, see further Table 2.
(2) 5.5% by vol. was examined instead of 3.5%

Identification mark	Type
KR	Treated Polypropylene Each strand has a thickness of 30 μm and a width of 100-300 μm
KEG	Fibre type KR containing 0.2% fibre EG For further information see KR and EG fibres
PY	Treated Polypropylene Each strand has a thickness of 80 μm and a width of 200-500 μm
DO	Polyacrylonitrile Individual filament diameter is 18 μm
Ke	Kevlar, PDR 49 Polyamide Individual filament diameter is 11.9 μm
TIK	Treated Kevlar, PDR 49 Aramide Each bundle diameter 500 μm
EG	Electrical borosilicate glass Individual filament diameter is 12 μm
ARG	Alkali-resistant glass Individual filament diameter is 13 μm
ST	Steel, mild type Each strand has a thickness of 300 μm and a width of 600 μm

Table 2. Type of fibre used in this investigation

Fibre Type	Time taken by ultrasound to traverse 200 mm length (in micro seconds)											
	Samples undergoing freeze-thaw cycles						Samples undergoing drying-wetting cycles					
	0		50		100		0		50		100	
% vol.	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
KR 1.5	42.2	0.8	42.9	0.8	40.9	0.4	41.7	0.2	44.2	0.5	45.4	0.9
KR 3.5	49.6	3.3	52.3	1.1	47.1	3.4	47.4	1.5	50.4	1.5	52.5	0.9
KEG 1.5	42.1	0.5	41.8	0.5	41.4	0.2	42	0.3	46.2	0.6	46.6	0.3
KEG 3.5	49.7	1	49.5	1.7	47.9	1.9	49.9	1.4	50.6	1.4	48.6	2.5
PY 1.5	42.8	2.4	41.5	0.4	40.9	0.6	40.9	0.3	43.5	0.4	44.3	0.5
PY 3.5	49.3	0.5	46.5	0.7	43.7	0.5	49.3	0.7	50.	1.1	48.2	1.8
DO 1.5	41.5	0.2	41.6	0.3	40.9	0.2	42.	0.3	43.7	0.6	44.4	0.5
DO 3.5	47.9	0.5	47.6	0.6	46.3	0.5	47.5	0.6	50.8	0.4	50.6	2.1
Ke 1.5	42.4	0.4	42.0	0.8	40.4	0.4	41.8	0.4	43.9	0.4	43.5	0.2
Ke 3.5	46.7	0.3	46.9	1.2	44.	0.8	46.9	0.7	48.6	0.7	48.5	1.2
TIK 1.5	42.5	1.0	40.9	0.3	40.6	0.4	42.8	1.9	44.5	1.4	44.4	1.0
TIK 5.5	52.1	1.1	46.4	0.7	47.	1.5	51.7	1.1	51.1	0.7	48.7	2.2
EG 1.5	43.	0.7	41.3	0.3	40.5	0.2	43.0	0.5	43.6	0.7	43.7	0.5
EG 3.5	44.3	0.4	44.1	0.5	43.5	0.7	44.3	0.4	48.1	1.2	46.8	1.1
ARG 1.5	41.9	0.6	41.4	0.5	41.2	0.6	41.7	0.3	44.6	0.6	45.3	0.8
ARG 3.5	47.6	2.0	45.2	1.1	43.8	0.8	46.9	2.8	49.7	1.1	51.9	1.3
ST 1.5	47.5	1.6	45.0	2.0	43.1	1.2	48.2	2.7	47.6	1.8	48.8	2.6
ST 3.5	50.	1.7	48.	1.5	45.2	1	50.3	0.8	51.4	2.5	49.6	3.2

Table 3. Ultrasonic measurements of samples in accelerated testing.
$\bar{x}$ refers to the mean values and s to the standard deviation.

Fibre Type	Length change of samples in o/oo			
	Samples undergoing freeze-thaw cycles		Samples undergoing drying-wetting cycles	
	50	100	50	100
KR 1.5	0.80	0.81	0.22	0.24
KR 3.5	3.85	4.21	0.53	0.65
KEG 1.5	0.67	0.70	0.21	0.23
KEG 3.5	2.48	2.67	0.37	0.54
PY 1.5	0.15	0.17	0.28	0.19
PY 3.5	1.27	1.39	0.78	0.79
DO 1.5	0.11	0.12	0.17	0.06
DO 3.5	0.21	0.36	0.54	0.51
Ke 1.5	0.11	0.39	0.08	0.13
Ke 3.5	0.73	0.91	0.52	0.75
TIK 1.5	0.21	0.20	0.28	0.23
TIK 5.5	0.48	0.55	0.04	0.10
EG 1.5	0.20	0.19	0.16	0.33
EG 3.5	0.22	0.21	0.21	0.18
ARG 1.5	0.17	0.17	0.10	0.
ARG 3.5	0.28	0.30	0.41	0.37
ST 1.5	0.31	0.20	0.	0.
ST 3.5	0.60	0.97	0.81	0.85

Table 4. Length change of samples in accelerated testing.

Fibre Type	Initial bending test						Accelerated freeze-thaw tests						Accelerated drying-wetting tests					
	S MPa	V %	E MPa	V %	e 0/00	V %	S MPa	V %	E MPa	V %	e 0/00	V %	S Mpa	V %	E MPa	V %	e 0/00	V %
1.5% KR + REF.	10.3 1.00	7	34250 1.00	6	0.30 1.00	15	9.2 0.89	10	32900 0.96	10	0.36 1.22	17	10.1 0.98	10	32131 0.94	6	0.37 1.25	14
3.5% KR + REF.	8.3 1.00	11	21107 1.00	7	0.43 1.00	22	4.2 0.51	14	17906 0.85	21	0.48 1.13	21	6.6 0.80	9	18083 0.86	23	0.65 1.53	25
1.5% KEG + REF.	8.6 1.00	11	30584 1.00	12	0.30 1.00	13	10.3 1.20	11	40895 1.34	9	0.29 0.97	17	8.6 1.00	13	29229 0.96	17	0.36 1.20	11
3.5% KEG + REF.	7.5 1.00	12	18516 1.00	7	0.45 1.00	18	6.0 0.81	18	20136 1.09	19	0.60 1.33	38	7.2 0.97	8	23652 1.28	23	0.56 1.24	45
1.5% PY + REF.	9.3 1.00	12	34782 1.00	7	0.22 1.00	50	10.3 1.11	6	39102 1.12	5	0.46 2.14	85	10.3 1.11	9	34477 0.99	5	0.33 1.53	15
3.5% PY + REF.	9.0 1.00	19	22184 1.00	9	5.79 1.00	146	9.0 1.00	2	32517 1.47	6	1.19 0.21	170	6.4 0.71	5	17990 0.81	30	2.93 0.51	166
1.5% DO + REF.	9.2 1.00	11	34670 1.00	7	0.23 1.00	47	10.1 1.10	11	37524 1.08	7	0.45 1.96	89	9.7 1.05	14	33139 0.96	4	0.41 1.78	15
3.5% DO + REF.	9.8 1.00	10	23329 1.00	9	0.60 1.00	51	8.8 0.90	6	25655 1.10	12	0.42 0.71	29	8.0 0.82	6	19868 0.85	13	0.70 1.18	23
1.5% Ke + REF.	10.1 1.00	8	34195 1.00	9	0.32 1.00	29	10.4 1.03	5	40936 1.20	3	0.26 0.83	19	10.9 1.08	7	34242 1.00	5	0.39 1.24	13
3.5% Ke + REF.	8.0 1.00	23	22862 1.00	11	0.48 1.00	62	9.4 1.18	10	24989 1.09	8	0.53 1.10	34	8.0 1.00	19	19818 0.87	8	0.61 1.27	34

Table 5. Continued...

Fibre Type	Initial bending test						Accelerated freeze-thaw tests						Accelerated drying-wetting tests					
	S MPa	V %	E MPa	V %	e 0/00	V %	S MPa	V %	E MPa	V %	e 0/00	V %	S Mpa	V %	E MPa	V %	e 0/00	V %
1.5% TIK +	10.1	24	33282	13	0.28	21	8.0	31	38280	10	0.36	28	7.6	28	32302	18	0.28	29
REF.	1.00		1.00		1.00		0.79		1.15		1.30		0.75		0.97		1.01	
5.5% TIK +	10.5	14	16869	1	3.05	84	10.0	11	29812	8	2.27	76	9.6	13	24631	11	1.28	100
REF.	1.00		1.00		1.00		0.96		1.77		0.75		0.92		1.46		0.42	
1.5% EG +	10.7	6	33145	7	0.46	14	11.0	9	47396	11	0.29	17	9.9	7	36305	11	0.31	23
REF.	1.00		1.00		1.00		1.03		1.43		0.63		0.93		1.10		0.68	
3.5% EG +	10.6	8	30536	15	0.47	20	11.2	21	32762	12	0.39	13	10.6	9	26765	13	0.48	13
REF.	1.00		1.00		1.00		1.06		1.07		0.84		1.00		0.88		1.03	
1.5% ARG +	11.3	19	33891	4	0.57	61	9.8	11	39854	7	0.28	14	11.3	11	31576	7	0.50	34
REF.	1.00		1.00		1.00		0.87		1.18		0.49		1.00		0.93		0.87	
3.5% ARG +	14.9	22	20486	5	3.56	76	12.8	21	31769	10	1.40	49	10.2	16	20783	14	0.75	20
REF.	1.00		1.00		1.00		0.86		1.55		0.39		0.68		1.01		0.21	
1.5% ST +	7.6	12	22887	17	0.55	59	9.4	17	37548	6	0.64	88	9.2	11	31560	13	0.56	43
REF.	1.00		1.00		1.00		1.25		1.64		1.16		1.22		1.38		1.02	
3.5% ST +	8.1	6	13481	19	2.60	62	8.8	11	29690	12	0.70	63	6.8	16	18172	19	0.69	13
REF.	1.00		1.00		1.00		1.09		2.20		0.27		0.84		1.35		0.27	

Table 5. Bending tests. Initial bending tests compared to accelerated test specimens after 100 cycles. S is the bending strength. E is modulus of elasticity and e is the tail of the stress-strain curve. V is standard deviation.

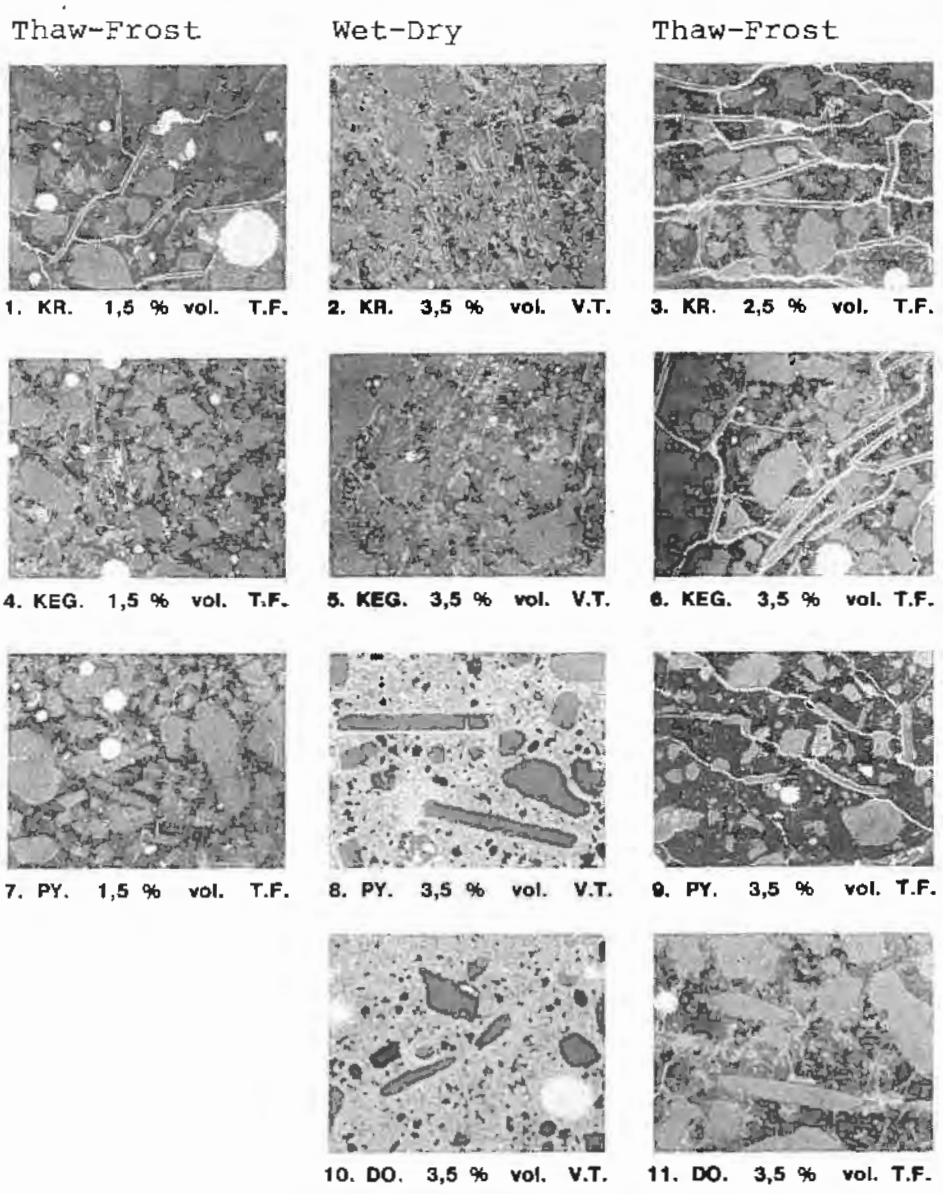

Fig. 1. Shows development of micro-cracks in fibre reinforced composites due to different exposure.

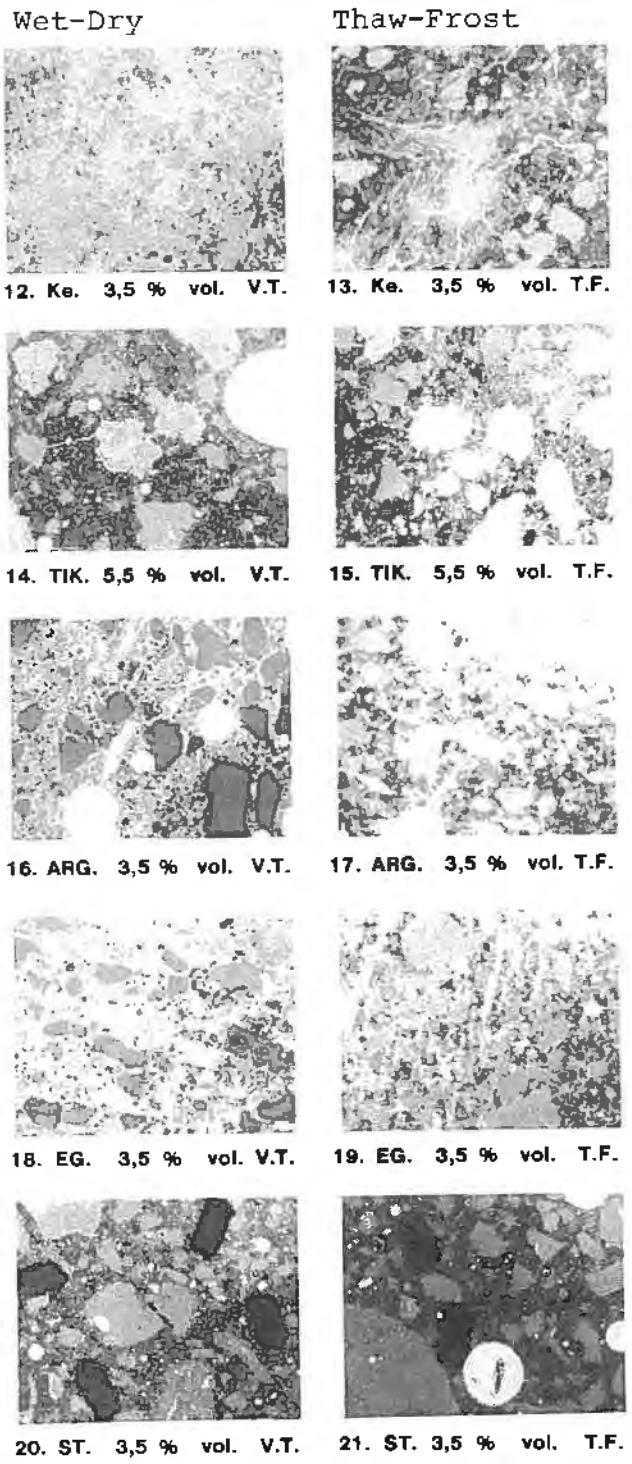

Fig. 2. Shows development of micro-cracks in fibre reinforced composites due to different exposure.