Properties of fibre glass reinforced cement composites

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Caractéristiques du béton renforcé de fibres de verre

Eigenschaften von mit Glasfasern bewehrtem Beton

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SUMMARY
The paper deals with the testing of long term resistance of fibre glass in the alkaline medium of Portland cement. The applied Czechoslovak alkali resistant fibre glasses were incorporated into the Portland cement matrix. The long term ageing process was studied. Some of the specimens were stored in water, and the rest were dry cured. The modulus of rupture was determined at the age of 28, 90, 180, and 360 days. The composite texture was studied by the SEM method.

RÉSUMÉ
L'étude examine la résistance à longue durée des fibres de verre dans le milieu alkalin du ciment Portland. Les fibres de verre tchécoslovaques ont été utilisées pour renforcer la matrice de ciment Portland. La résistance à longue durée a été examinée sur des éprouvettes. Une partie de celles-ci était stockées dans l'eau, une autre partie dans un environnement sec. La résistance à la flexion a été déterminée aprés 28, 90, 180, 360 jours. La microstructure des ciments à fibres de verre a été étudiée par la méthode SEM.

ZUSAMMENFASSUNG
Dieser Beitrag befasst sich mit der Untersuchung der Langzeitbeständigkeit von Glasfasern in der alkalischen Portlandzement-Matrix. Verwendet wurden tschechoslowakische, alkalibeständige Glasfasern, die in die Zementmatrix eingebettet wurden. Die Langzeitbeständigkeit wurde an Prüfkörpern untersucht. Ein Teil dieser Prüfkörper wurde im Wasser, ein anderer Teil wurde trocken gelagert. Die Biegezugfestigkeit wurde im Alter von 28, 90, 180, 360 Tagen ermittelt. Das Verbundwerkstoffgeffgefüge wurde mittels der SEM Methode untersucht.

1. INTRODUCTION

The extension of fibre reinforced cement composites /FRC/ to the field of building materials plays a peculiar role of its own in the already wide and wellestablished area of application for composite materials. Glass fibre reinforced cement and concrete GRC/, with its rapidly increasing applications in construction /e.g.clading panels, permanent formwork, small components, hydraulics and marine applications/, is a composite material consisting of a cement or concrete matrix reinforced by a small proportion of glass fibres.

The function of the fibres in the relatively brittle cement matrix is to delay and control the tensile cracking of the material so that an unstable and uncontrolled tensile crack growth is transformed into a slow controlled crack growth. It is this unique characteristic of fibre reinforcement that gives the composite properties of post-cracking tensile resistance, increased tensile strain capability and enhanced energy absorption.

The basic problem of GRC application is the attack by the alkalies associated with hydrating cements. This problem is being solved either by applying alkali resistant glass fibres provided with effective coating materials, e.g. Cem-FIL 1 and Cem-FIL 2 fibres of following composition: SiO_2= 62.5%; ZrO_2= 16.3%; NaO_2 = 14.8%; Al_2O_3= 0.85%; CaO = 5.05%; K_2O = 0.3%, produced by Pilkington Brothers Ltd in Great Britain, or by decreasing the alkalinity of the cement matrix, e.g. the procedure developed by l´Industrielle de Préfabrication in France, which enables the application of E-glass fibres.

In Czechoslovakia much attention has been paid to the problem of alkali resistance of glass fibres, and the result of these studies was the development of two types of alkali resistant glass fibres. Glass fibres REZAL and ESAP are of low zirkonium dioxyd content, SVÚS 16 belongs to the high zirkonium dioxyd content.

In our previous work [1] we studied the suitability of several methods of determining the chemical resistance of glass fibres in alkaline media. These investigations have shown that the autoclave test method has a more severe effect on the glass fibres than the standard method. The most deterious effects were obtained with a NaOH and Na_2CO_3 mix as the reacting solution. The submitted paper, which is a continuation of the above study, deals with the long-term alkali resistance of Czechoslovak glass fibres incorporated in the cement matrix.

2. EXPERIMENTAL PROGRAMME

2.1. Materials and mixes

A Portland cement type 400 was used to manufacture the cement paste. The physico-mechanical properties of the applied cement fulfilled the requirements of the Czechoslovak Standard ČSN 722121. As fibre reinforcement REZAL, ESAP, and SVÚS 16 alkaliresistant glass fibres were applied. Their chamical composition is given in Table 1. The fibre length was 36 mm. The water/cement ratio of the cement paste was 0.370. The following fibre weight fractions of glass fibres were incorporated into the cement paste: 0.4; 1.0; 1.6; 2.2; 3.3; and 4.4 per cent. The batches were mixed in

Components in weight% / Fibre Type	SiO_2	ZrO_2	BaO	Na_2O	Al_2O_3	CaO	Fe_2O_3	TiO_2
REZAL	59,29	4,97	9,94	10,4	5,10	10,3	–	–
ESAP	65,70	4,95	6,80	10,5	4,60	7,3	0,15	–
SVUS16	58,30	11,40	–	14,3	–	8,6	–	7,4

Table 1 Glass fibre chemical composition

laboratory pan mixer, and the fibres were incorporated into the cement paste in such a way to ensure an uniform and random distribution in the cement matrix.

2.2. Casting, curing and testing

The mixes were compacted in steel moulds on a vibrating table /50 Hz; 0.35 mm/. Three specimens 40x40x160 mm could be manufactured simultaneously in these moulds. Together with the fibre reinforced specimens, plain specimens were cast. For each investigated parameter six specimens were manufactured. The obtained values are the mean strength values determined on these specimens.

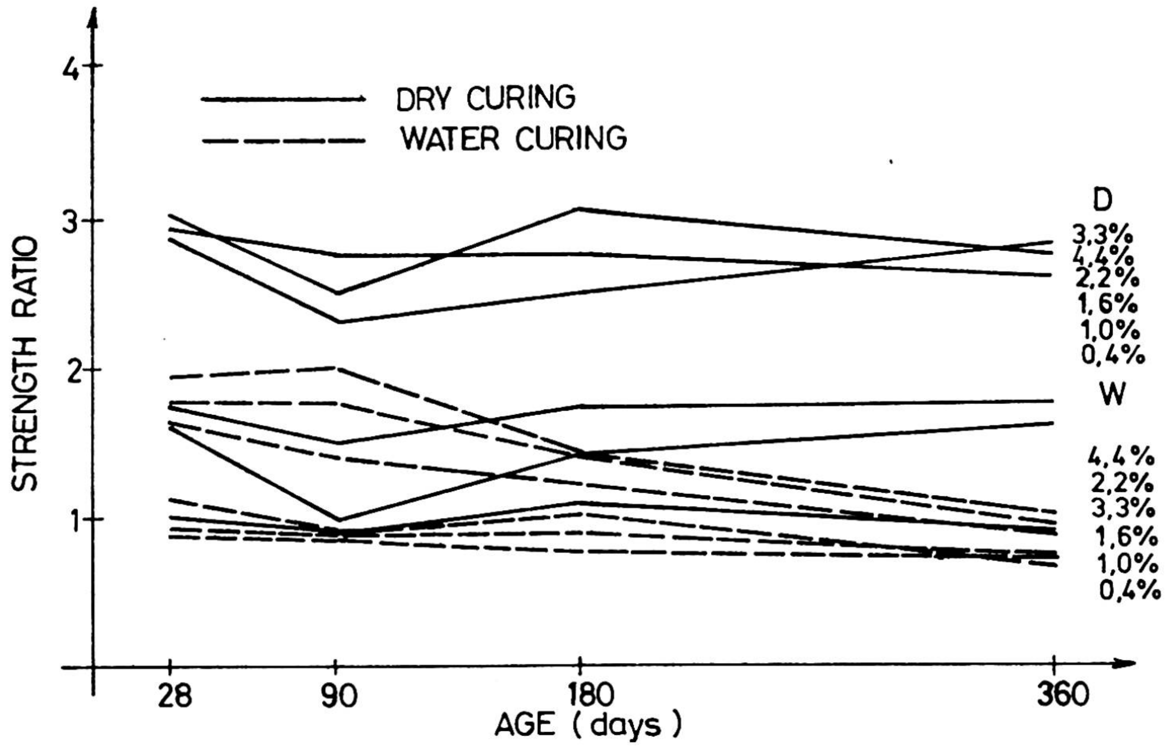

Fig. 1 Strength ratio versus composite age relationship - fibre typ: REZAL

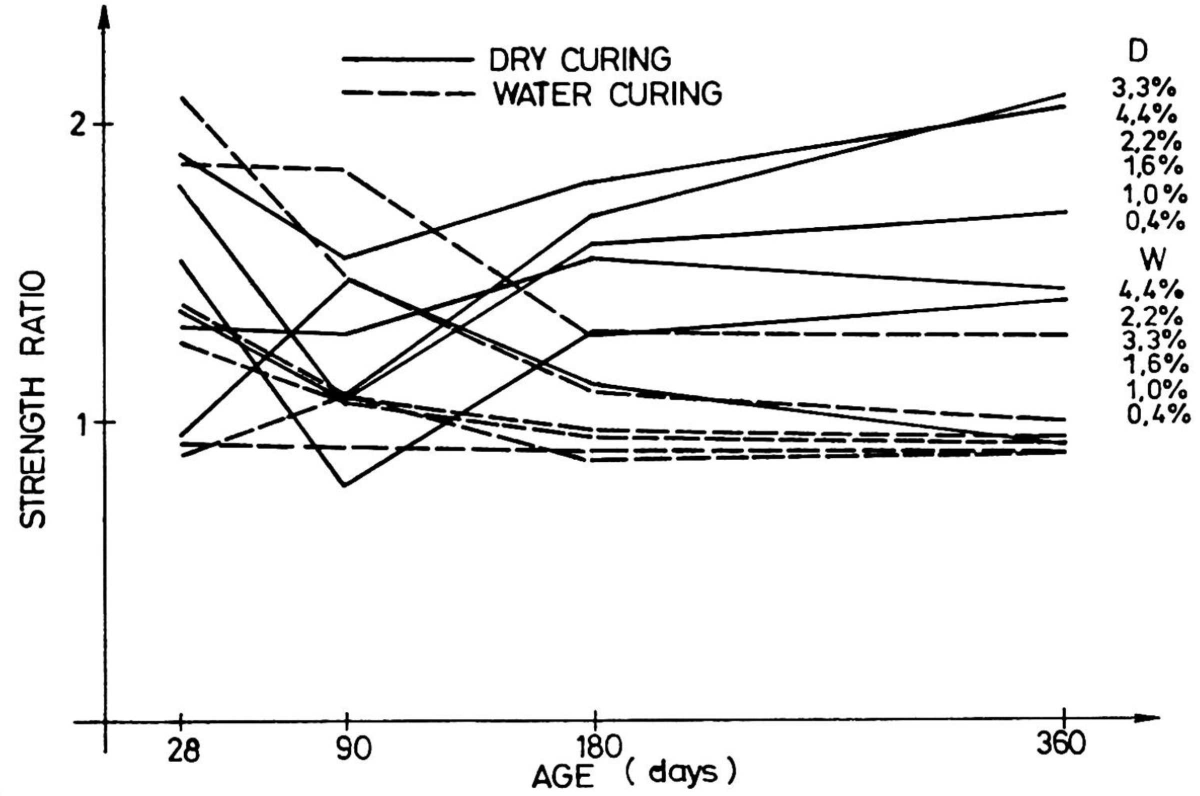

Fig. 2 Strength ratio versus composite age relationship - fibre type: ESAP

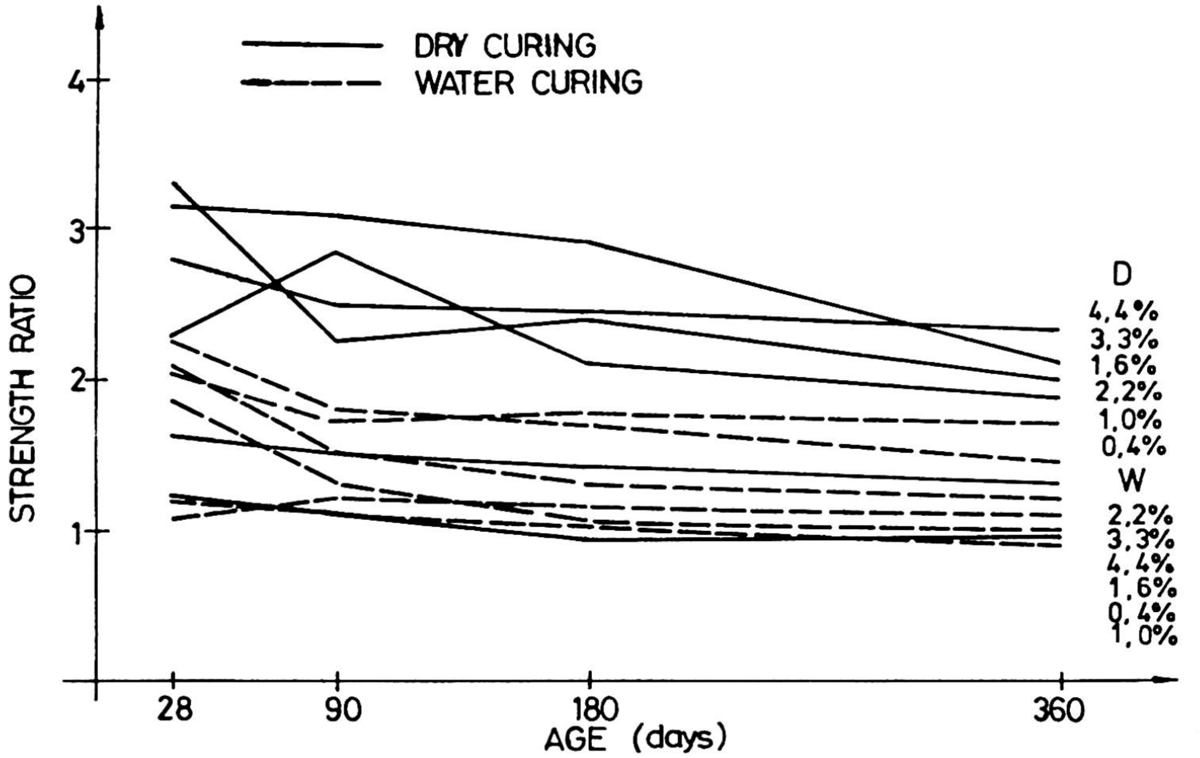

Fig. 3 Strength ratio versus composite age relationship - fibre type: SVÚS 16

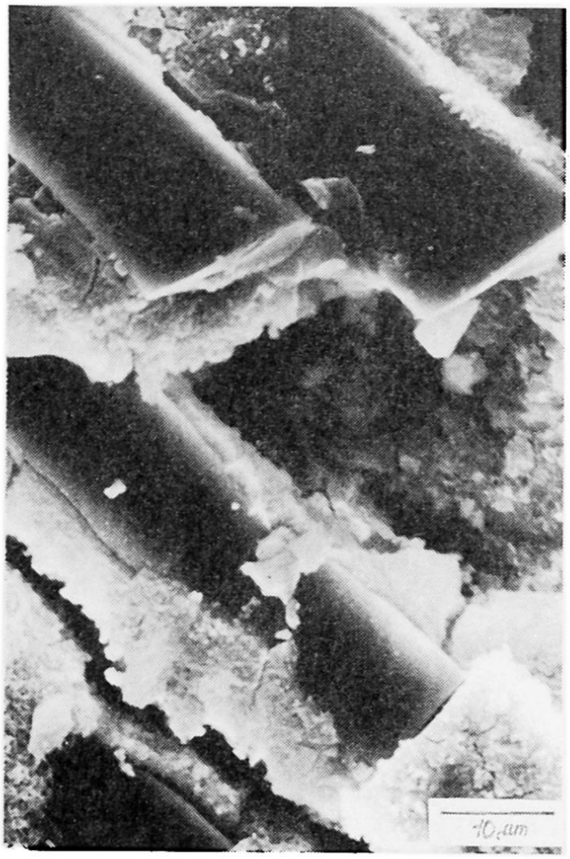

Fig. 4 SEM of REZAL fibres in the cement matrix /360 days, water curing, fibres: 4.4%/

One half of the manufactured specimens was dray cured, and the second half cured in water.

After casting the specimens were cured in moulds for 48 hours in a moist room /20°C, 90 per cent R.H./, and after the moulds were removed, one half of specimens was stored in dry environment /20°C, 60 per cent R.H./, and the second half was stored in water /20°C/. The specimens were tested at the age of 28, 90, 180, and 360 days. The specimens were tested in flexural strength /three point loading being used/. A 25 kN testing machine with a constant loading rate of 6 mm/ min. was applied.

2.3. Results and discussion

The results of investigations carried out are summarized in Fig. 1 to 3. In These figures the relationship between the flexural strength ratio and the age of the tested specimen reinforced with a fibre weight fraction of 0.4; 1.0; 1.6; 2.2; 3.3; and 4.4 is plotted. The flexural strength ratio is the ratio

$$\frac{\text{strength of reinforced matrix}}{\text{strength of plain matrix}}$$

The investigations carried out have shown that the specimens stored in water exhibit considerably lower strength than specimens dry cured. The strength of composites of low glass fibre content, stored for 360 days in water, can decrease to the strength of the cement matrix. This phenomenon is in good agreement with results published abroad, as well as with our results obtained earlier [2]. The obtained results show - more pronounced in the case of dry curing - that with the raise of fibre weight fraction, we obtain an increase in the composite strength. The drop

Fig.5 SEM of ESAP fibres in the cement matrix /360 days, water curing, fibres: 4.4%/

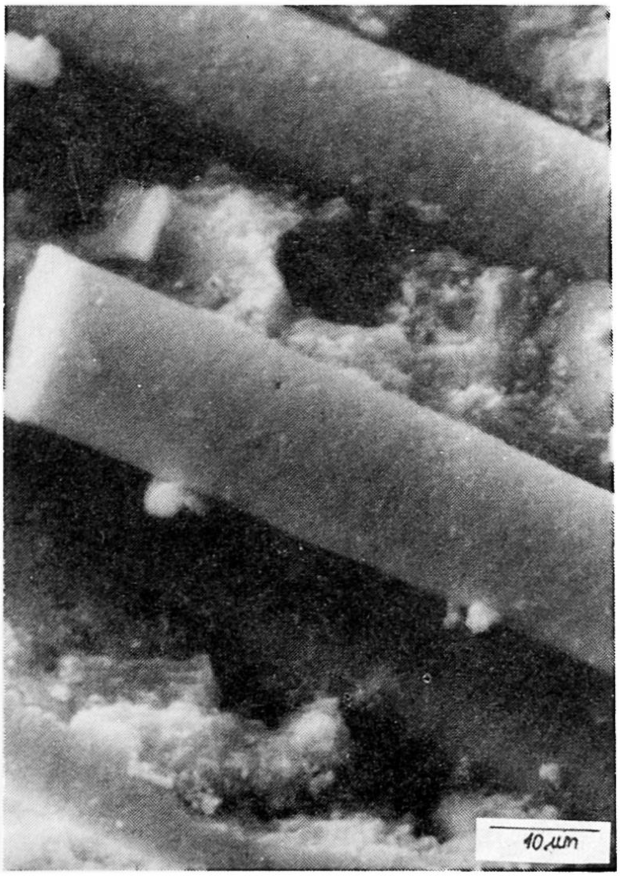

Fig. 6 SEM of SVÚS 16 fibres in the cement matrix /360 days, water curing fibres: 4.4%/

of strength around the composite age of 90 days, in the case of dry curing /see Fig.1 and 2/, can be effected by non uniform shrinkage, or by partial debonding in the fibre-matrix interface, iniciated also by the shrinkage process.

After the strength tests were carried out, samples were taken in order to be investigated under the SEM. According to these investigations we may say that the fibre shape remained unchanged, even in the case of water curing, and that the fibre surface is covered with smaller and larger particles of hydration products /see Fig.4 to 6/.

3. CONCLUSIONS

The investigated glass fibre types have shown a considerably high alkali resistance. Within the testing period of one year glass fibres of low as well as of high zirkonium dioxyd content show similar behaviour in the cement matrix. Only further investigations, now being carried out, can clear all the problems connected with the alkali resistance of the tested glass fibres.

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