METHODS FOR REDUCING THE TENDENCY TOWARDS EMBRITTLEMENT IN SISAL FIBRE CONCRETE

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Thin roofing sheets of sisal fibre concrete stored outdoors in a tropical climate become markedly embrittled within a period of 6 months. The reason has been found to be that the alkaline pore water in the concrete dissolves components in the fibres so that they become decomposed and loose their reinforcing capacity. Experimental results indicate that the most efficient way of counteracting the embrittlement of sisal fibre concrete is to reduce the alkalinity of the pore water. Use of various fibre impregnating agents have also reduced the embrittlement somewhat.

Keywords: Durability, fibre reinforced concrete, sisal, improvement of durability.

1. INTRODUCTION

Concrete reinforced with natural fibres has been studied in Sweden since 1971. The aim was to develop a low cost, appropriate and durable roofing sheet made of locally available materials. In collaboration with organisations in Tanzania, roofing sheets of sisal fibre concrete have been developed.

It was found that sisal fibre concrete becomes brittle in tropical climates. Obviously there was a need to study the durability of natural fibre concrete and in 1979 a joint venture research project on this subject was initiated between the Faculty of Engineering at the University of Dar es Salaam in Tanzania and the Swedish Cement and Concrete Research Institute (CBI).

2 WHY DOES SISAL FIBRE CONCRETE BECOME BRITTLE?

Nilsson /1/ among others found that natural fibres which had been conditioned in an alkaline solution lost in tensile strength. Investigations at CBI showed that sisal fibres conditioned in solutions with a pH value in excess of 12 are coloured yellow, see also Gram /2/.

This yellow discolouring of the fibres indicates a reaction between the buffer solutions OH-ions and the lignin in the sisal fibre. The primary cause of the change in the characteristics of sisal fibre in concrete has been found by the author to consist of a chemical decomposition of the lignin and the hemicellulose in the middle lamella. The alkaline pore water in the concrete dissolves the lignin and hemicellulose and thus breaks the link between the individual fibre cells, see Fig. 1. The long sisal fibre looses its reinforcing capacity in concrete, since it breaks down into numerous small units.

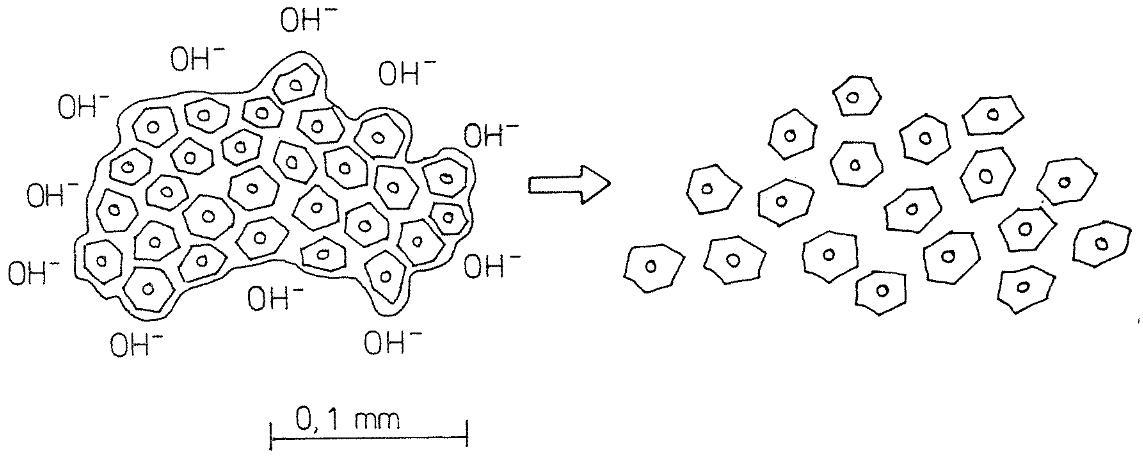

Fig. 1 Schematic sketch of the decomposition of sisal fibres in concrete. The middle lamella is dissolved by the alkaline pore water in the concrete.

The rate at which sisal fibre concrete is embrittled depends on the magnitude of the variation in the relative air humidity and temperature to which it is subjected. These variations initiate the transport of alkaline pore water to the fibre and the removal of decomposition products and neutralized pore water from the fibre - factors which are essential for the decomposition of the fibre components.

3. PRODUCTION AND CURING OF SPECIMENS, TEST METHODS

Specimens for durability experiments have been manufactured with a mortar composed of binder, aggregate and water with a weight ratio of 1:2:0.5 respectively. The share by volume of embedded fibre has been 2%. A thin layer of mortar has been placed on a plastic mould measuring 400 x 280 mm and 220 mm long sisal fibres have then been placed on the surface of the mortar, uniformly distributed and aligned parallell to the end of the mould. This layer of fibres was then worked into the mortar with the aid of a roller so that each individual fibre was surrounded by mortar.

A new thin layer of mortar was then placed on the fibre layer and a second layer of fibres was placed in position, oriented in the same direction as the fibres in the first layer. The last layer of mortar was then placed and levelled off and the mould was vibrated until the surface of the mortar became smooth and glossy. The 8-10 mm thick specimen was demoulded after it had been stored for 24 hours in a conditioning room with a temperature of +20°C and a relative air humidity of about 100%. After that the specimen was placed in a tube full of water for curing for at further 5-7 days. Up to the testing time or the storage in the intended environment (normally a further three weeks) the specimen was stored in a conditioning room with a temperature of +20°C and a relative air humidity of 50%.

Using knowledge about the influence of the external environment on the embrittlement of natural fibre concrete as a basis, a method has been produced for accelerating the ageing of natural fibre concrete in this respect. The method has been used to determine whether the measures taken to prevent the embrittlement of sisal fibre concrete have any effect.

The specimens have been stored in a climate cubicle, see Fig. 2, for 0, 3, 15 and 30 days. The specimens in the climate cubicle were subjected to moistening and cooling by spraying them with water from the sprinkler nozzles. The water which was transported into the climate cubicle maintained a temperature of +10°C. Each specimen was sprayed with 1.5 litres of water per minute for 30 minutes. A period of 30 minutes was selected on the basis of the capillary suction capacity of the concrete. The time available permitted the 8-10 mm thick specimens to have a considerable part of their capillary pore system filled. After the water spraying the heat and fan were started in the heat cubicle. The temperature in the cubicle was permitted to reach +105°C. The heat was switched on for five and a half hours before the water was sprayed into the climate box again. During the heating period, the capillary pore system in the specimens dried out. As a result, the capillary pore system of the specimens was both filled with and emptied of water during the conditioning cycle of six hours. This means that the fibres embedded in the specimens came in contact with the alkaline pore water of the concrete during the moistening phase and that any decomposition products which were formed as a result of the reaction between the fibre components and the pore water could be transported away from the fibre during the drying phase.

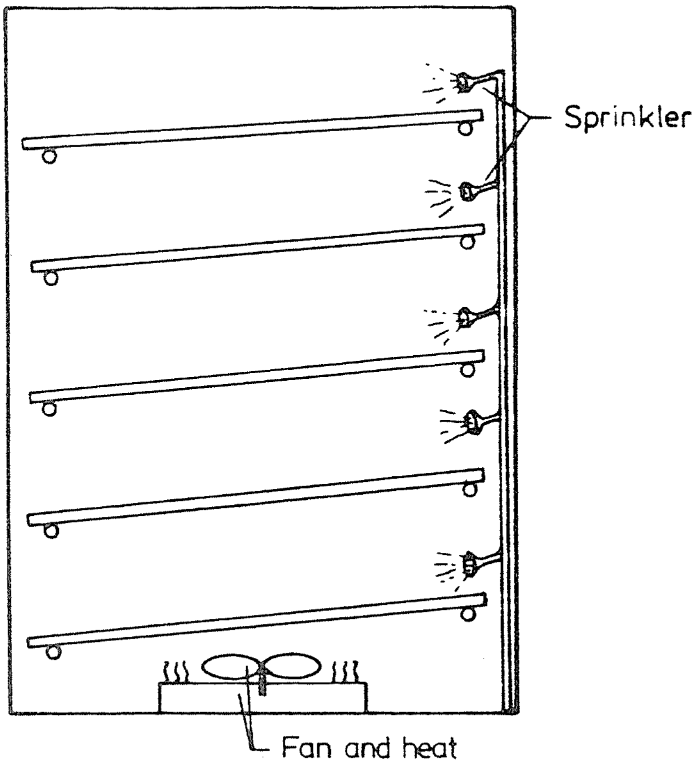

Fig.2 Schematic sketch of CBI climate cubicle.

Another method of accelerated ageing has also been tried, the BRE-method developed in conjunciton with the production of an alkali-resistant glass fibre in Great Britain, see for example

Litherland et al /3/. This method, where the specimens are stored in warm water, has no ageing effect on sisal fibre concrete.

The embrittlement of sisal fibre concrete has been studied by following the changes in the behaviour of the not aged or aged composite during bending. Beams measuring 55-60 x 230-280 x 8-10 mm were sawn out and subjected to flexural strength tests with a load set-up shown in Fig. 3.

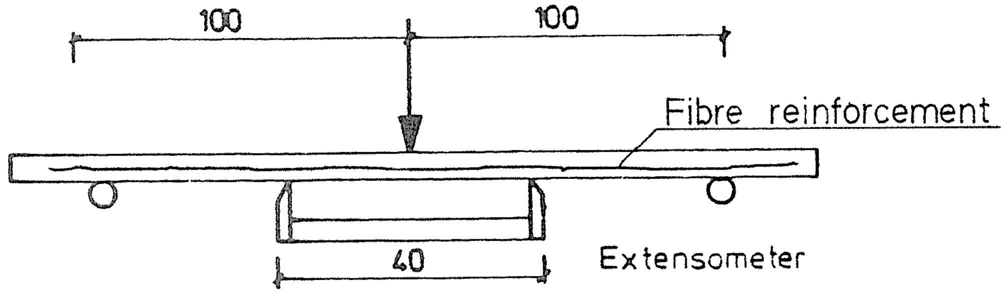

Fig. 3 Load set-up when bending natural sisal fibre concrete beams.

The stress-strain curve was produced with the aid of a XY-plotter and had two different layouts in principle as illustrated in Fig. 4.

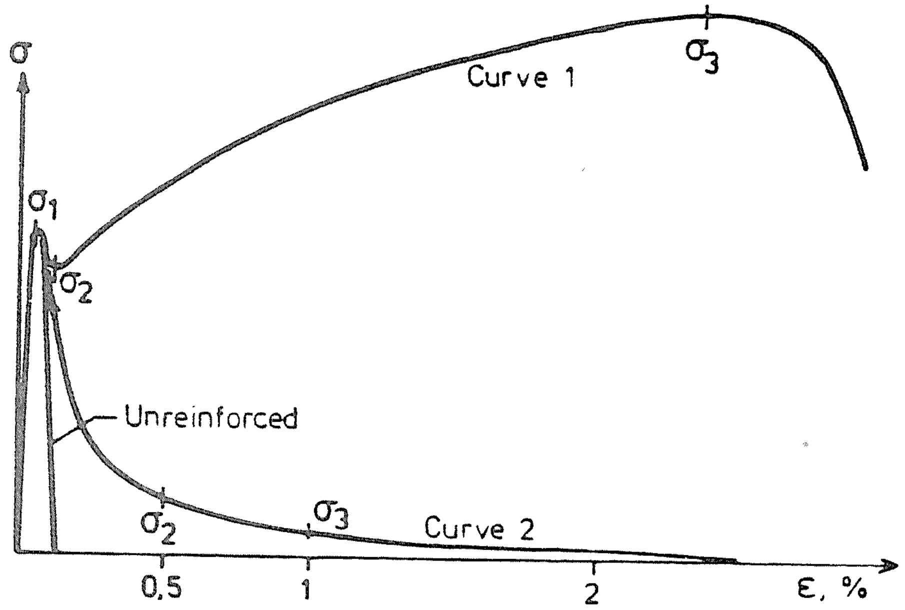

Fig. 4 Principle layouts for stress-strain curve during tests of flexural strength of sisal fibre concrete beams.

Either the stress, having passed the proportionality limit (σ_1) and a possible drop (σ_2), increased again to a maximum value (σ_3) according to Curve 1 or else the stress decreased the entire time with an increase in the deformation according to curve 2. For a sequence in accordance with Curve 2, σ_3 has been selected as the stress which prevails at a deformation of 1%. The lower value of σ_3 the smaller the area under the stress-strain curve and, therefore, the toughness of the composite. The parameter σ_3 has been selected as a criterion of the toughness of the composite.

Fig. 5 shows stress-strain curves for specimens of sisal fibre concrete aged 0, 4, 8 and 120 cycles in the CBI climate cubicle.

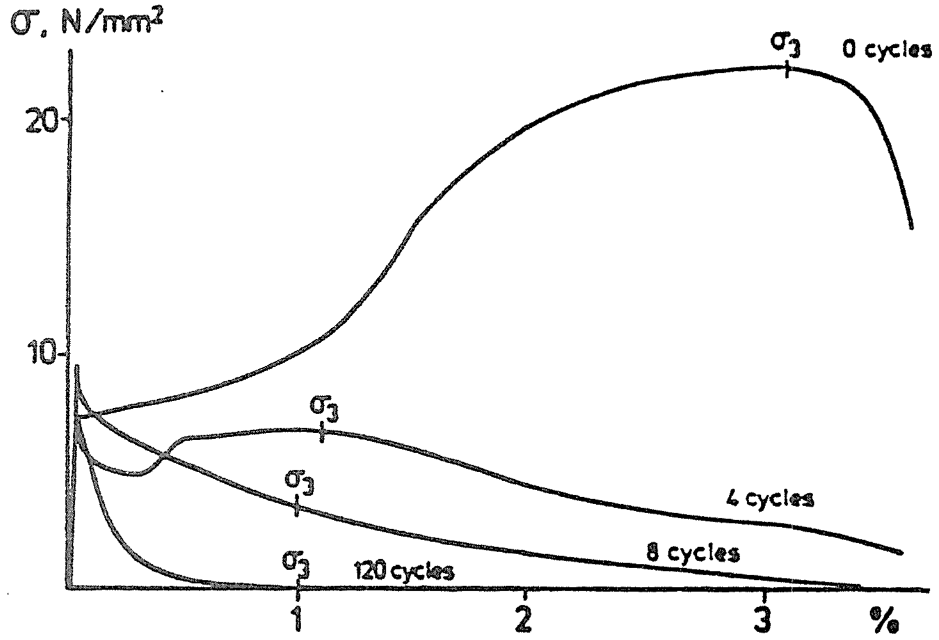

Fig.5 Stress-strain curves for specimens of sisal fibre concrete aged 0, 4, 8 and 120 cycles in a climate cubicle.

4. COUNTERMEASURES AGAINST THE EMBRITTLEMENT OF SISAL FIBRE CONCRETE

Different approaches to prevent the observed embrittlement of sisal fibre concrete have been tested.

One approach was to use embedded bundles of sisal fibres in concrete instead of individual fibres. The fibres which are in direct contact with the matrix can be broken down with time while the inner fibres retain their strength. A mesh of fabric consisting of sisal fibres with about 30 fibres in the weave threads was embedded in a concrete matrix and aged in the climate cubicle. When specimens which had gone through 0 cycles were subjected to bending tests it could be seen that the interaction between the mesh reinforcement and the matrix was not at all as good as was the case when individual fibres were embedded and completely surrounded by the matrix, see Fig. 6.

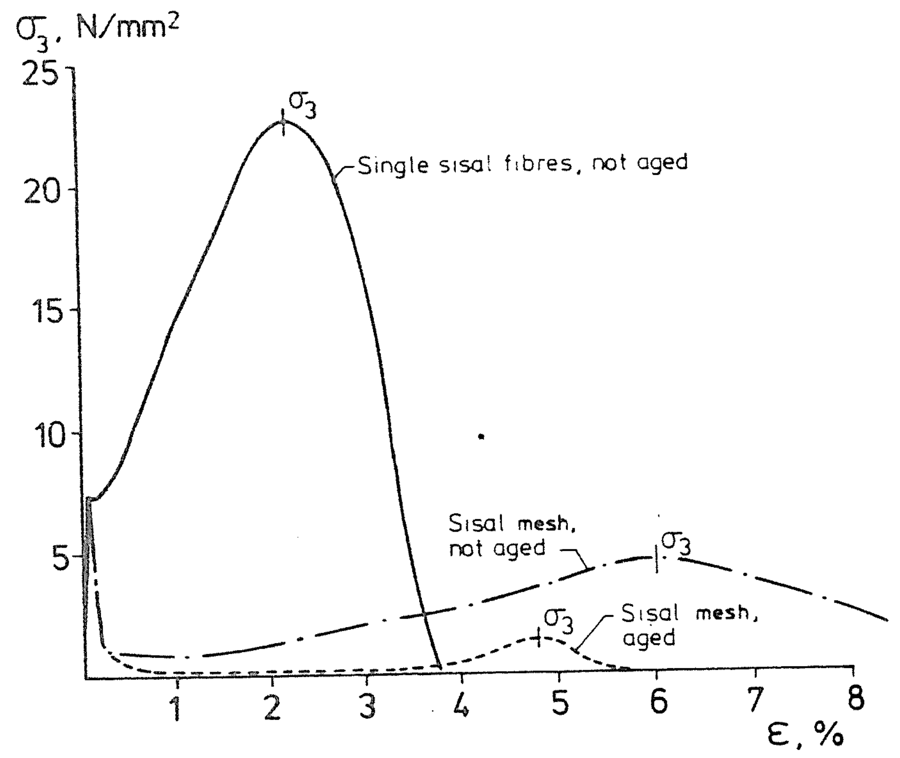

Fig. 6 Stress-strain curves for concrete reinforced with sisal mesh which had been subjected to 0 and 12 cycles in the CBI climate box, and unaged concrete with individually embedded fibres.

As can be seen from Fig. 6, the value for σ_3 achieved when the reinforcement was embedded in the form of mesh reinforcement was not at all high. σ_3 occurs at a far greater deformation, in this case at a deformation of about 6% compared with a normal value of 2-3%. The displacement of σ_3 is due to the fact that the individual fibres in the mesh have a far longer anchorage length since they are not in continous contact with the matrix at the same time as they are not tensioned to the same extent.

As can be seen from Fig.6, the toughness was considerably reduced when the composite had been aged.

Earlier it was noted that the decomposition of the sisal fibre in concrete is due to the fact that the fibre is attacked chemically by the alkaline pore water in the concrete. One way of avoiding or delaying this decomposition could be to impregnate the fibre with agents which react with certain fibre components and build up compounds which are difficult to dissolve in an alkaline environment.

Table 1 presents some of the investigated impregnation combinations as well as the values for σ_3 for specimens cast with impregnated sisal fibres aged for 0, 12, 60 and 120 cycles in the climate cubicle.

Table 1. Values for σ_3 after a different number of cycles in the climate box for specimens reinforced with sisal fibres which have been impregnated with blocking and water-repellent agents.

Impregnating agent	Number of cycles and σ_3 (N/mm^2)			
	0	12	60	120
Unimpregnated sisal	32.8	2.8	0.9	0.4
Boric acid and PVC_2	0	-	-	-
Borax and chromium stearate	16.1	-	-	3.3
Formine and stearic acid	16.7	-	7.7	4.2;6.3
" "	17.4	3.8	7.2	5.3
" "	13.6	9.7	9.5	5.6
Potassium nitrate and stearic acid	14.0	-	6.4	3.0;4.1
Magnesium sulphate and PVC_2	4.8	-	0.8	0.6
Sodium chromate and fluorine-carbon-hydrogen-stearate	18.2	-	3.9	3.7

As can be seen from Table 1, impregnating the sisal fibre with blocking and water-repellent agents causes the value for σ_3 for unaged specimens to be lower than for specimens with unimpregnated fibre. Impregnating the sisal fibres reduces the embrittlement, however, after ageing in a climate box. Fibres impregnated with formine and stearic acid, potassium nitrate and stearic acid, sodium chromate and fluorine-carbon-hydrogen-stearate, and borax and chromium stearate give values for σ_3 after 120 cycles which exceed 3 N/mm^2.

Table 2 presents the values for σ_3 for specimens conditioned outdoors in Dar es Salaam or Stockholm.

Table 2. Values for σ_3 for specimens reinforced with sisal fibres which have been impregnated with blocking and water-repellent agents and which have been stored outdoors in Dar es Salaam or Stockholm.

Impregnating agent	Locality	Number of days and σ_3(N/mm^2)		
		0	135	200
Unimpregnated	Sth	10.7	-	6.9
"	Dar	12.4	-	0.3
Boric acid and PVC_2	Dar	0 1)	1.8	-
Formine and stearic acid	Dar	11.4	-	6.9
Barium nitrate and stearic acid	Sth	18.2	-	12.2
"	Dar	14.1	-	9.7

1) The 0-value has been taken from Table 1.

The results in Table 2 confirm the results achieved with specimens aged in the climate box. Impregnating sisal fibres with formine and stearic acid or barium nitrate and stearic acid has a favourable effect and leads to a retardation of the embrittlement tendencies in the composite.

The transport of alkaline pore water to the fibre and the removal of neutralized water with the decomposition products from the fibre which occur when the temperature and moisture conditions of the composite are changed might be reduced or eliminated completetly by sealing the pore system in the matrix in some way. This would delay or perhaps completely eliminate an embrittlement of sisal fibre in concrete.

Among the methods which have been tested for sealing the pore system of the concrete matrix can be mentioned the use of aggregate with a higher proportion of fines, a lower water-cement ratio, replacing a part of the cement with fly ash or slag, changing the binder from ordinary Portland cement to finely ground blast furnace slag which is activated with powerfully alkaline admixtures, admixture of polymer micro-particles and admixing wax beads. None of the methods which were tested for changing the pore system of the concrete matrix proved capable of completely eliminating the embrittlement of sisal fibre concrete. However, interesting results in the laboratory tests were obtained with the admixture of small beads of wax in the fresh mortar. When the concrete had hardened and dried out, the composite was heated so that the wax melted and flowed out in the pore system. The sealing by means of wax made the absorption of water much slower and specimens with wax amounting to 6.5% of the cement weight do not lose their toughness after 120 cycles in the climate cubicle.

Sisal fibre concrete with a wax-sealed pore system becomes brittle when it is conditioned outdoors in Dar es Salaam. One possible reason for the difference observed in the experimental results for specimens conditioned outdoors in Dar es Salaam may be that the moisture content in the Tanzanian concrete was excessively high, when the pore system was sealed by melting the wax. The wax may have had difficulty in penetrating water-filled pores and the moisture which may have been enclosed when the pore system was sealed was, perhaps, capable of transporting OH-ions to embedded fibres. Further experiments with wax-sealed sisal fibre concrete should shed light on the suitability of this method for preventing embrittlement.

The last approach tested to prevent the embrittlement of sisal fibre concrete has been to reduce the alkalinity of the pore water of the concrete matrix. Attempts to carbonate the composite rapidly have been carried out, but were not successful. The alkalinity in the pore water in the matrix can be reduced considerably by using high alumina cement as a binder instead of ordinary Portland cement. Table 3 presents values for σ_3 for specimens manufactured with high alumina cement and aged in the climate box.

Table 3. Values for σ_3 after different numbers of cycles in the climate box for specimens manufactured with ordinary Portland cement or high alumina cement and reinforced with sisal fibres.

Binder	Number of cycles and σ_3 (N/mm^2)			
	0	12	60	120
Ordinary Portland cement	32.8	2.8	0.9	0.4
High alumina cement	30.8	21.3	21.4	13.5

As can be seen from Table 3, specimens manufactured with high alumina cement retain some of their toughness even after they have been subjected to ageing in the climate box. The value for σ_3 after 120 cycles is 13.5 N/mm^2. The tendency of the composite to become brittle can thus be reduced, although not completely eliminated, by using high alumina cement as a binder instead of ordinary Portland cement.

The pH value for the pore water in the matrix is reduced by replacing some of the ordinary Portland cement with a highly active, ultra-fine silica fume. It was noted when carrying out investigations of the alkalinity of pore water that the pH value for the pore water decreases from 13.2 for a matrix with ordinary Portland cement only as a binder to 12.9 and 12.0 for matrixes in which 17% and 33% respectively of the binder consisted of silica fume.

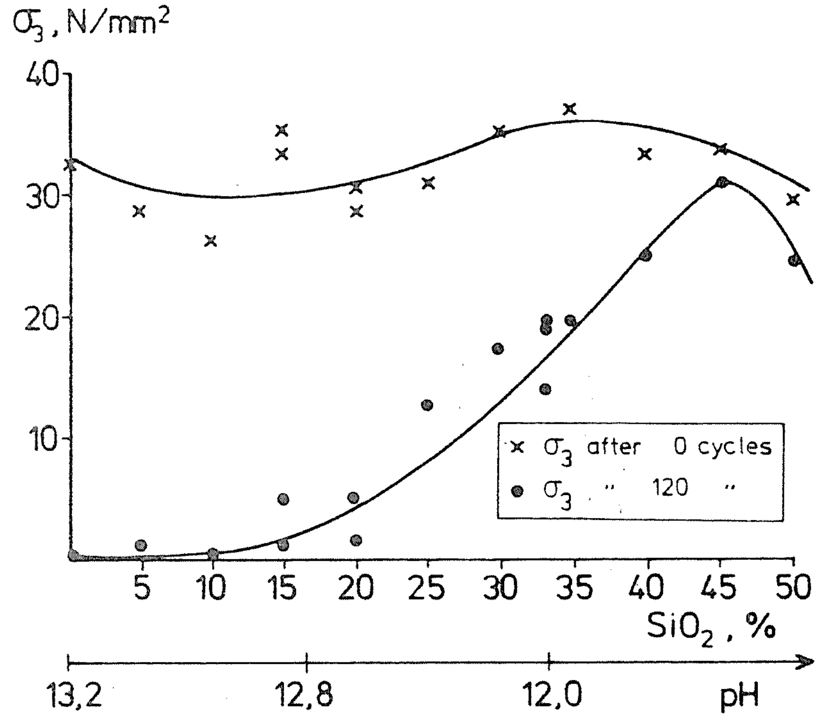

Fig 7. The stress σ_3 (mean value for three specimens reinforced with sisal fibres) after 0 and 120 cycles in the climate box as a function of the percentage silica fume of the binder weight.

As can be seen from Fig. 7, specimens in which up to 20% of the binder weight consisted of silica fume received comparatively insignificant or moderate increases in the value for $_3$ after 120 cycles compared with specimens without an admixture of silica fume. When 30-50% of the cement is replaced with silica fume, a dramatic improvement is obtained in the toughness of the composite after ageing.

REFERENCES

/1/ Nilsson L: Reinforcement of concrete with sisal and other vegetable fibres. Swedish Council for Building Research, Document D14:1975. Svensk Byggtjänst, Stockholm, pp 1-68.

/2/ Gram H-E: Durability of natural fibres in concrete. CBI-research Fo 1:83, Swedish Cement and Concrete Research Institute.

/3/ Litherland K L, Oakley D R, Proctor B A: The use of accelerated ageing procedures to predict the long term strength of grc composites. Cement and Concrete Research, Vol 11, pp 455-466, 1981.