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Effects of Ageing and Weathering on the Tensile Strength of Glass Fibre Reinforced High-Alumina Cement

H. C. CHAN, W. A. PATTERSON
Department of Civil Engineering, The Queen's University of Belfast, Belfast, UK

The results of experimental studies on the variation of the tensile strength with time of high-alumina cement sheeting reinforced with glass fibres are presented. Over a period of one and a half years no significant deterioration has been found in specimens stored under either laboratory or outdoor conditions. Sheeting subjected to a severe artificial weathering cycle over a period of five months has shown some decrease in strength.

1. Introduction

Fibrous composites, both natural and man-made, are commonly used in the construction industry. A good example is asbestos cement which was introduced at the beginning of this century and is still widely used as a cladding material today. Owing to the short length of the fibres, asbestos cement has a rather low fracture toughness and after being in use for some years it can become further embrittled. Furthermore, the production of suitable asbestos fibre is, for physical and political reasons, unlikely for an indefinite period to be able to meet the increasing world demand for asbestos cement, which is at present running at a rate of ten million tons per year.

The use of glass fibre reinforced plastic has increased considerably in the last two decades, particularly in some special structures, e.g. pipes, tanks, roof lights, etc. But certain deficiencies inherent in the organic resins used, such as low durability, creep, poor fire resistance and not least cost, have prevented it from having a more general application to building structures.

Fibre glass reinforced cement, in which the comparatively short fibres of asbestos cement are replaced by long glass fibres and the organic resin by a cement matrix, appears to be a good compromise. This should eliminate some of the deficiencies of the two materials mentioned previously. Research in this type of composite material was first reported in Russia by Biryukovich [1] and in this country by the Building Research Station [2, 3] and Maries and Tseung [4] of the City University, London. From these previous studies it would appear that Portland cement has adverse effects on the long term strength of the composite, owing to the corrosion of the glass fibres by high alkalinity of the cement paste. This does not seem to be so conclusive in the case of high-alumina cement.

In order to apply this type of new material safely to any structural use, its mechanical properties have to be fully investigated. This report limits itself to the effects of ageing and weathering (natural and artificial) on the tensile strength of glass fibre reinforced high-alumina cement. The work described forms part of a research programme which is being carried out in this Department.

2. The Composite

The high-alumina cement used in this fibrous composite was Ciment Fondu and the reinforcement used was E glass chopped strand mat. The mat is made up from strands containing 204 filaments, chopped into 50 mm lengths and sprayed to form a randomly orientated mat of 460 gms/m^2. The resulting laminate should be essentially isotropic. The multi-component size in the mat, which protects the fibres from abrasive damage and acts as binder and coupling agent for use with resins, was leached by immersing the mat in running water for 24 h. The weight loss after leaching was approximately 2 %.

The fibrous composite was produced in sheet form by a hand lay-up method similar to that widely used in fibre reinforced plastics technology

[5]. A thin layer of high-alumina cement paste with water/cement ratio of 0.4 was spread over a steel mould and a sheet of chopped strand mat was then placed on top. Using a roller and a trowel the cement paste was gradually induced to rise up through the mat and fill the voids. Three layers of mat were used giving the final product a thickness of around 5 mm.

Immediately after casting, the sheet was covered with polythene. After 24 h the mould was removed and the sheet was cured in water for thirteen days, except in the case of specimens tested after seven days. It was then removed and stored under the conditions required by the different tests.

The weights of the chopped strand mats used and the weights of the final products were recorded. From these the glass contents were calculated by weight to be approximately 15% in all cases.

3. Tests and Results

Plain tensile tests were carried out on a Hounsfield W-type Tensometer and strain was measured by a clip-on Hounsfield Extensometer. Test specimens were cut to comply with B.S. 18 [6] except for the width which was increased from 12.7 to 25.4 mm, as the narrower specimens proved to be too fragile for handling. On any particular test day three samples were picked at random and the mean result taken.

The test programme called for three different treatments on the material, namely:

(i) Storing in air: after curing, the specimens were stored in the laboratory until required for testing.

(ii) Exposure to weather: specimens were treated as in (i) up to the age of twelve weeks when they were placed horizontally in an exposed position on the roof.

(iii) Exposure to artificial weathering cycles: after normal curing the specimens were subjected to weathering cycles as detailed below (table I).

This process was designed to subject the material to the full extremes of climatic conditions in this country.

Two results are presented: the ultimate tensile stress and the "idealised cracking stress". The first term is self explanatory; the second is defined with reference to a typical stress-strain diagram for this composite, fig. 1, as corresponding to point B, the intersection of tangents drawn to the two distinct regions OA and CD.

Figs. 2 and 3 are results for specimens treated

TABLE I Weathering cycle.

Treatment	Duration (h)
Stored in: Water at 20°C	1
Oven at 30°C	46
Water at 20°C	2
Refrigerator at − 5°C	46
Water at 20°C	1
Period of cycle	96

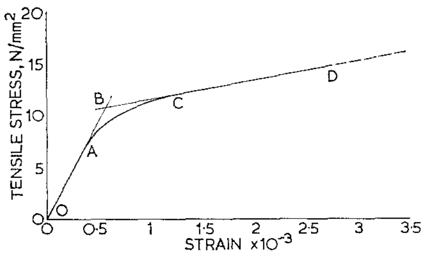

Figure 1 Stress-strain diagram.

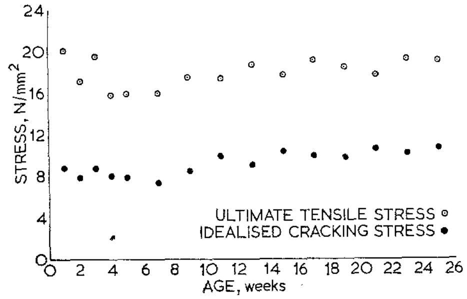

Figure 2 Relationship between (a) the ultimate tensile stress; and (b) the idealised cracking stress; and age (group 1).

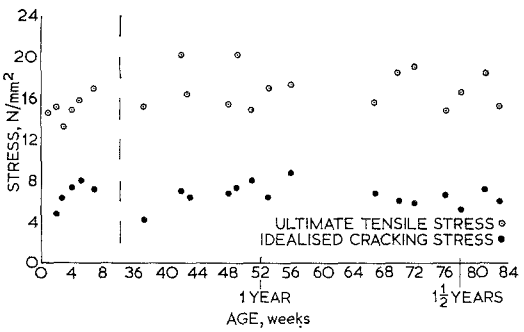

Figure 3 Relationship between (a) the ultimate tensile stress; and (b) the idealised cracking stress; and age (group 2).

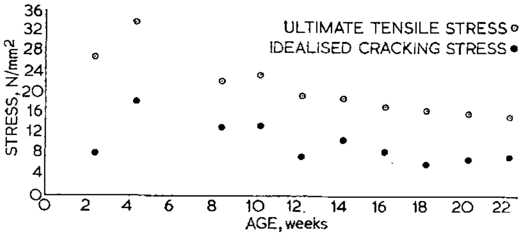

Figure 4 Effect of artificial weathering on the idealised cracking stress and the ultimate tensile stress.

TABLE II

Time of tensile test	"Idealised cracking stress" N/mm^2	Ultimate tensile stress N/mm^2
After normal curing but before placing on roof	7.38	17.09
After 1 year on roof	8.18	16.36
After 1.65 years on roof	7.33	17.44

by method (i). Table II and fig. 4 are results for specimens treated by methods (ii) and (iii) respectively.

4. Discussion

The "idealised cracking stress" presented in the previous section is thought to be of structural significance for its resemblance to the yield point of mild steel. This may be illustrated with reference to the stress-strain diagram in fig. 1. In region OA the composite behaves linearly elastically while in the region ACD there is a certain amount of irreversible deformation. It is suggested that initially in the region OA, the fibres act as crack arrestors restraining the internal flaws from propagating, and at the same time share the load with the cement according to the simple law of mixtures. Due to this stabilizing effect of the fibres on the internal flaws, stress at point A (7 N/mm^2) is considerably higher than the ultimate tensile stress of unreinforced cement (2.5 N/mm^2). In region AC the initial microcracks start to propagate and there is a gradual transfer of load from the matrix to the fibres. This process ceases at point C and from then on the matrix serves only to transfer load and maintain positional geometry but adds no significant strength of its own. From C, deformation continues partly due to elongation of fibres and to a greater extent due to slipping between fibres and cement and between individual fibres within the strands. A certain amount of slipping is thought to be useful as it serves to release stress concentration and gives the material a pseudo plastic character which is responsible for the relative high fracture toughness of the material. Values of 17.5 kN/m have been observed [7] as compared to 875 N/m in the case of asbestos cement. Final failure of the composite occurs as a result of a combination of pullout and fracture of the fibres. See fig. 5.

Figure 5 A micrograph illustrating a combination of pull out and fracture of fibres at failure (× 60).

The effect of ageing has been examined over a period of one and a half years with more than 100 tensile tests completed. An analysis of variance [8] carried out on all the individual test results, represented in figs. 2 and 3, is shown in the Appendix. This analysis indicates that there is no significant difference between the means of ultimate tensile stress, assuming normal distribution of tensile strength and the same population standard deviation for all times.

It is fair to say that the overall trend does not show any appreciable adverse effect of ageing on either the ultimate tensile stress or the "idealised cracking stress". The slight difference in magnitude in the tensile strength in figs. 2 and 3 is due to the fact that the composite was manufactured by two different operators in the two series of tests. A point to be borne in mind is that when using this simple hand lay up method, the absolute value for the tensile strength of the composite (which is not within the scope of this report) depends to a considerable extent at present on the human factor.

It has been suggested previously that the initial role of the fibres is to stabilize the internal flaws. The effectiveness of this action, reflected in the "idealised cracking stress", depends largely on the bond strength developed between fibres and matrix. The ultimate tensile stress, from the nature of the failure of the composite, depends on both the interfacial bond strength and the individual fibre strength. Any damaging chemical activity which reduces the interfacial bond strength would be reflected by a decrease in the "idealised cracking stress" and any reduction in the individual fibre strength and/or the bond strength would result in a decrease in the ultimate tensile stress. As no variation of either value has been observed it is concluded that chemical changes in the fibre matrix interface or on the surface of the fibres, if any, do not cause appreciable reduction in the effectiveness of the fibre reinforcement.

The specimens exposed to the weather endured fairly severe treatment and on several occasions were covered with snow. On inspection after one and a half years there were no obvious signs of physical degradation except for a few marks caused by penetration of water. Results for these specimens shown in table II also do not indicate any deterioration in the tensile strength.

Fig. 4 shows the effect of artificial weathering on the "idealised cracking stress" and the ultimate tensile stress. After having undergone 35 cycles continuously in a period of five months, the material still retains 60% of the two week tensile strength. The decrease in strength is probably due to certain debonding at the interface of the fibres and matrix as a result of thermal cycling, since glass and cement have quite different coefficients of thermal expansion. Another possible cause would be the chemical changes in high-alumina cement in the presence of water at temperature above 25°C [9]. These changes would affect the matrix strength and possibly the bond strength. Visual examination shows a higher proportion of fibres being pulled out as the weathering cycles increase. However, it is felt that this accelerated ageing process is more than sufficient to simulate the normal life span of a structural component in service.

From these results it appears that the durability of high-alumina cement reinforced with glass fibre is reasonably good and that such a material would be suitable for constructional use.

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Appendix

The results of an analysis of variance carried out on all the individual ultimate tensile stress results represented in fig. 2 is shown in table A1. The corresponding results for fig. 3 are shown in table A2.

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TABLES A1 and A2 on next page

TABLE A1

Source of variation	Degrees of freedom d(f)	Sum of squares (ss)	Mean square $ms = \frac{ss}{df}$	Variance ratio $F = \frac{\text{ms between times}}{\text{ms within times}}$
Between times	14	79.04	5.65	1.15 < F0.05, 14,30
Within times	30	147.65	4.92	
Total	44	226.69	—	

TABLE A2

Source of variation	Degrees of freedom (df)	Sum of squares (ss)	Mean square $ms = \frac{ss}{df}$	Variance ratio $F = \frac{\text{ms between times}}{\text{ms within times}}$
Between times	20	209.82	10.49	1.09 < F0.05, 20,41
Within times	41	395.23	9.64	
Total	61	605.05	—	

where for example in table A1:
(a) the total number of individual tests carried out = $N = 45$.
(b) the number of batches of tests carried out = $K = 15$.
(c) degrees of freedom for total corrected sum of squares (for all test results) = $N - 1 = 44$.
(d) degrees of freedom for between times (number of batches) = $K - 1 = 14$.
(e) degrees of freedom for within times (results within each batch) = $(N - 1) - (K - 1) = 30$.

The variance ratio found for this case is 1.15, which is less than 2.03, the 5% points of variance ratio distribution given in reference [8] for values of $K - 1 = 14$ and $N - K = 30$.