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Fatigue endurance of aged glass fibre reinforced cement

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The resistance to flexural fatigue of glass fibre reinforced cement (GRC) stored in water for six years, has been studied. Peak stresses of between 6.0 and 18.2 MN m^{-2} were used. At stresses of 10.0 and 18.2 MN m^{-2} the median times before failure were 1.95×10^5 and 2.0×10^3 cycles, respectively. At a stress of 8.1 MN m^{-2}, six out of sixteen samples tested survived 4.65×10^6 cycles. At a stress of 6 MN m^{-2}, all of the samples survived 1.75×10^6 cycles. An unreinforced mortar specimen was also studied and its fatigue endurance showed greater scatter than the GRC samples.

1. Introduction

Fatigue in glass fibre reinforced cement (GRC) composites up to 1 year old and in asbestos cement was studied by Hibbert and Grimer [1]. In this work the investigation has now been extended by performing fatigue tests on GRC samples which have lost most of their ductility as a result of storage under water at about 16° C for six years. An unreinforced OPC mortar was also included in the present work.

2. Experimental procedure

The equipment used in this work, previously described by Hibbert and Grimer [1] was used to apply a positive flexural stress with a haversine waveform to sixteen GRC samples (coupons) simultaneously. The coupons were of dimensions 150 mm by 50 mm by 8.6 mm. Static flexural strength tests were carried out using an Instron 5-tonne Universal Testing Machine. In both dynamic and static tests, four-point bending with a major span of 135 mm and a minor span of 45 mm was employed.

The distribution of the load among the sixteen stations of the fatigue rig and the effect of the sudden failure of one of the test coupons was studied by placing a steel bar with strain gauge in each of the stations in turn and recording the signals on an ultra-violet (high-speed type) recorder. The distribution of the loads varied about the mean value with a standard deviation of 3%. The effect of the sudden failure of one of the coupons was simulated by dropping a test coupon out of the rig at various phases of the load cycle and observing the signal on the ultra-violet recorder. The effect was slight, even between adjacent stations, amounting to a small reduction in load of duration less than one cycle.

3. Results and discussion

Relevant details of the different samples are given in Table I together with values of the static flexural strength (MOR) and the limit of proportionality stress (LOP). Two specimens studied by Hibbert and Grimer were included for a comparison with the present work.

The six-year-old GRC samples were cycled at average peak stresses of 6, 8.1, 10, 14 and 18.2 MN m^{-2}. The unreinforced OPC samples were cycled at an average peak stress of 7.25 MN m^{-2}. No failures occurred in the GRC samples at 6 MN m^{-2} after 1.75×10^6 cycles. The endurances, in cycles, of the samples fatigued at the remaining stresses are shown plotted against the probability of failure in Fig. 1. The probability of failure, p, assigned to each coupon is given by

$$p = i/(1+n), \quad (1)$$

where $i = 1, 2, \ldots r$, r is the number of failed coupons, and n = the number of coupons in the group (usually 16). Reasonably straight lines were obtained at average peak stresses of and

TABLE I Composition and properties of GRC and mortar boards

Board number	De-watered board		Composition of the matrix		Storage conditions	Age at time of test (years)	LOP ($MN\,m^{-2}$)	MOR ($MN\,m^{-2}$)
	Content of 32 mm Cem–FIL (wt %)	Water/cement ratio (w/w)	OPC (wt %)	Sand (wt %)				
1 (from [1])	4.6	0.31	100	–	Water at 20°C	0.25	13.2	42.0
7 (from [1])	4.9	0.26	100	–	Water at 20°C	0.5	16.7	27.9
9	5.1	0.31	100	–	Water at ≈ 16°C	6	14.0	21.8
10	–	0.23	65	35	Natural weathering	1	9.8	10.4

above 10 $MN\,m^{-2}$ showing the expected normal (Gaussian) distribution of fatigue endurance. However, at an average peak stress of 8.1 $MN\,m^{-2}$ the distribution is markedly non-linear above 50% probability of failure, suggesting two separate modes of failure.

Estimates of the median times-before-failure, taken from Fig. 1, together with some results from [1], are plotted on a peak stress–number of cycles before failure plot in Fig. 2. The endurances of the six-year-old GRC samples were all above 10^5 cycles at the LOP stress. The endurances of the eleven unreinforced OPC mortar coupons showed considerable variation, one failing after only 10^3 cycles and six surviving 1.26×10^6 cycles at 7.25 $MN\,m^{-2}$.

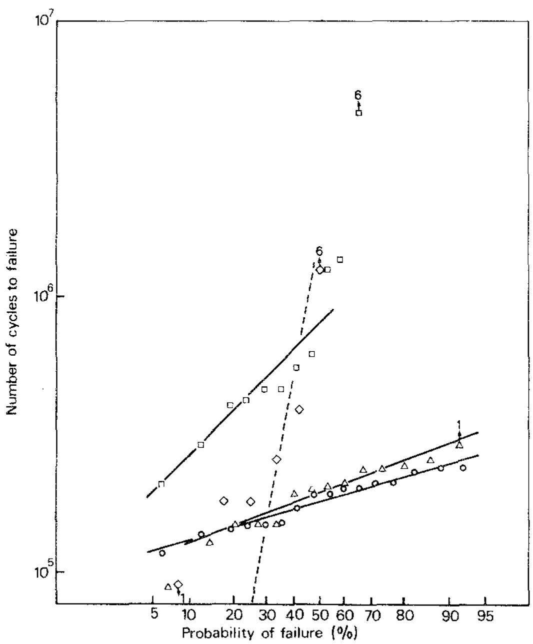

Figure 1 Cycles to failure against probability of failure in flexural fatigue. Peak stresses for GRC stored for six years in water are as follows: □ = 8.1 $MN\,m^{-2}$, △ = 10.0 $MN\,m^{-2}$ and ○ = 12.3 $MN\,m^{-2}$. Each symbol represents one failed coupon from a total of sixteen. Peak stress for eleven unreinforced mortar coupons correspond to the broken line: ◇ = 7.25 $MN\,m^{-2}$, tested after natural weathering for one year. Where coupons survived up to the end of the test, the symbol has an arrow above it and a number indicating the number of surviving coupons.

Below about 10^6 cycles, a normal distribution of fatigue times-before-failure was observed but above it the endurance is unexpectedly high. This discontinuity may mark the transition between two modes of failure associated with the presence or absence of stress-induced microcracks in the composite matrix. In the former case, fatigue endurance is controlled by a combination of matrix, fibre and interface properties, whereas, in the latter case, fatigue endurance is predominantly controlled by the matrix properties. In this work on GRC the transition between the two modes of failure occurs at a peak stress of about 8 $MN\,m^{-2}$. It seems likely that at this stress some of the coupons could contain cracks on the tensile surface as this corresponds approximately to the LOP stress in direct tension. This would suggest that the LOP stress in bending, which in this case was 14.0 $MN\,m^{-2}$, is not a good indicator of the formation of stress-induced micro cracks.

The mode of fatigue fracture consisted of a single plane crack initiating normal to the surface, interrupted by one or more steps parallel to the surface. The step feature was present to some extent in all the fatigue failures, but was not common in the static failures, which also failed with a single, plane crack. Fibre pull-out length at the fracture surface was small, as expected for aged GRC, amounting to only a few fibre diameters.

This work shows that fatigue is unlikely to im-

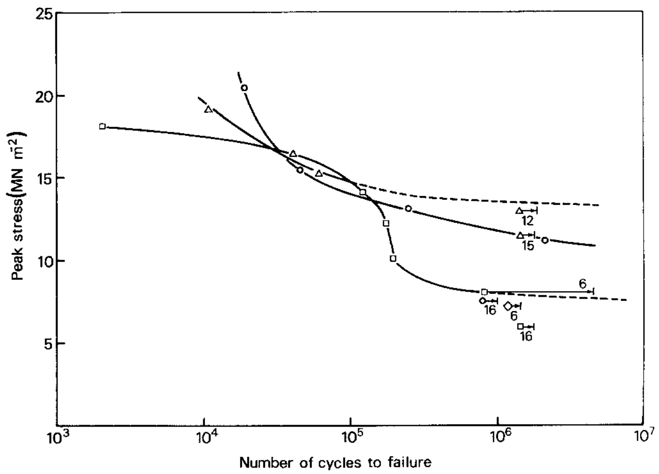

Figure 2 Median flexural fatigue lives of sixteen GRC coupons stored in water for (○) 3 months, (△) 6 months, and (□) 6 years. ◇ indicates termination of the test on eleven unreinforced mortar coupons which had been naturally weathered for 1 year. Where coupons survived to the end of a test, the number surviving is given beneath an arrow leading to the cut-off.

pose a significant limitation on current usage of GRC [2]. At a stress level of 6 MN m^{-2} no failures occurred after 1.75×10^6 cycles. Even at a peak stress of 12.3 MN m^{-2}, the GRC has a probability greater than 90% of surviving 10^5 cycles.

Acknowledgement
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2. Design guide: Glass fibre reinforced cement, Pilkington Bros Ltd, St. Helens, 1977, p. 24.

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