4 STRENGTH RETENTION OF ALKALI-RESISTANT GLASS FIBRES IN ALKALI EXPOSURE

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SUMMARY: The results of strength retention tests for alkali-resistant (AR) glass fibres exposed to cement related alkali environment are presented in this paper. Two types of fibres are examined, single filaments and strands. The alkali environment is simulated in terms of saturated $Ca(OH)_2$ solution, OPC mortar and sulfoaluminate mortar. The influence of fibre formation, cement type and source of sulfoaluminate cement on strength retention is discussed. The work aims to demonstrate the advantages and disadvantages of using sulfoaluminate cement in the GRC industry.
KEYWORDS: Alkali, AR glass fibres, filament, strand, strength retention, sulfoaluminate, tensile test.

INTRODUCTION

The development of glassfibres manufactured from alkali-resistant (AR) glass has led to the development of glassfibre reinforced concrete (GRC) composites, which is now a major worldwide industry. Although GRC has been establishing itself in the construction industry as an essential material with some very special advantages, its development has been slower than expected due to the high alkalinity of Portland cement matrices. As the reinforcement material, AR glassfibres are subjected to physical attack by calcium hydroxide crystals throughout the product's lifespan[1,2]. Hence, the durability of AR glassfibres is crucial to the strength and toughness of GRC elements.

This paper reports a study on strength retention of AR glassfibres after exposure to various alkali environments. Tests for tensile strength of single glass filament and 'strand in cement' (SIC)[3,4] were conducted. Alkali environments were simulated both in saturated $Ca(OH)_2$ solution and in a hardened cement mortar environment. Four types of cement were used. One was ordinary Portland cement (OPC) and the other three were calcium sulfoaluminate cements. The three calcium sulfoaluminate cements were a low-alkalinity type and a rapid-hardening type from China as well as a UK product. Results, in terms of weight loss and tensile strength retention, are presented here.

EXPERIMENT PROGRAMME AND RESULTS

Weight loss

A balance (Figure 1) with precision to the fifth decimal place was used to measure the mass of fibres. The initial mass was recorded before fibre strands were soaked in the alkali solution. Then the fibres were immersed in a saturated $C_a(OH)_2$ solution: 1.2g $C_a(OH)_2$ in 1 litre of distilled water[5], and kept in a water bath at 80°C for 200h at 100% relative humidity (RH) (Figure 2). Next, the fibres were rinsed in distilled water and placed in a ventilated drying oven (Figure 3) adjusted to 80°C (± 5°C) until a constant mass was attained, i.e. until the difference between two weighing results 24h apart was less than 0.1%. The change of the solution alkalinity along with time and total weight loss is summarised in Table 1.

Figure 1 - Digital balance

Figure 2 - 80°C water tank

Figure 3 - Ventilated oven

Table 1 - Alkalinity of $C_a(OH)_2$ and final weight loss

pH of $C_a(OH)_2$				Weight loss (%)
0h	24h	96h	200h	
13.33	12.65	12.63	12.30	1.41

Tensile strength test of fibres as manufactured

Specimen preparation

Considering the small size of the fibre specimen and the availability of the grips, mounting tabs (plain A4 paper for single filament and chrome paper for strands) were adopted to fix the specimens. The dimension of the tabs is shown in Figure 4.

1. Approximately 2m of roving from the roving package were cut. Individual strands from the roving were selected and carefully removed from the 2m roving.
2. For each strand, 20cm was cut off as the test specimen and 1m from the remaining length was measured off for the next test. A single strand was also kept and carefully separated in order to obtain single-filament specimens from it.
3. The specimen was lightly stretched and centred over the tab slot. A small amount of LOCTITE super glue was carefully placed on the specimen, on either edge of the slot to bond the specimen to the mounting tab. For the strand specimen, ARALDITE PRECISION was applied from the gauge length marker to the grip area (including the grip area) to bond the strand on the tab and also to strengthen the grip area (Figure 4).

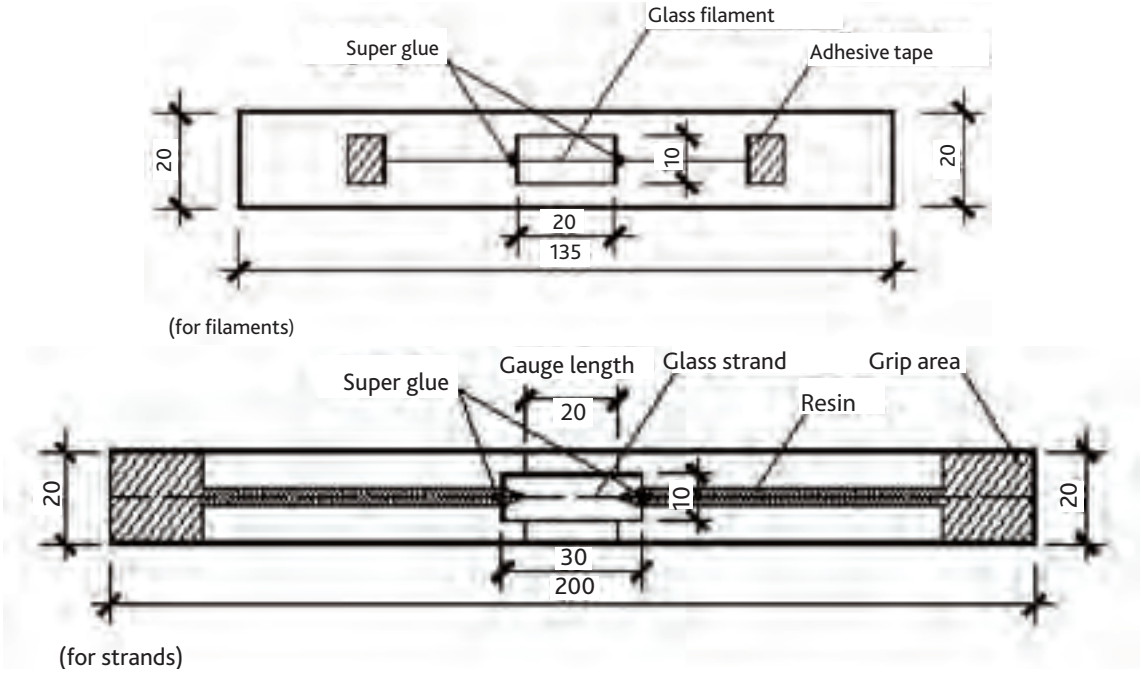


Figure 4 - Mounting tab dimension and specimen mounting method

Specimen testing

The test specimen was grasped at both ends (grip area) with the face of the stationary grips of the Hounsfield Universal Test Machine (Figure 5). The set-up of the grips and load cells are shown in Figure 6. The potential full scale of the load cell is 10N for the single filament specimen and 1kN for the strand. Next, both sides of the tab were carefully cut at mid-gauge with the mounting tab unstrained. The specimen was then tensed at the cross-head speed of 0.52mm/min for the single filaments and 1mm/min for the strands. The failure test load was recorded.

Figure 5 - Hounsfield Universal Test Machine

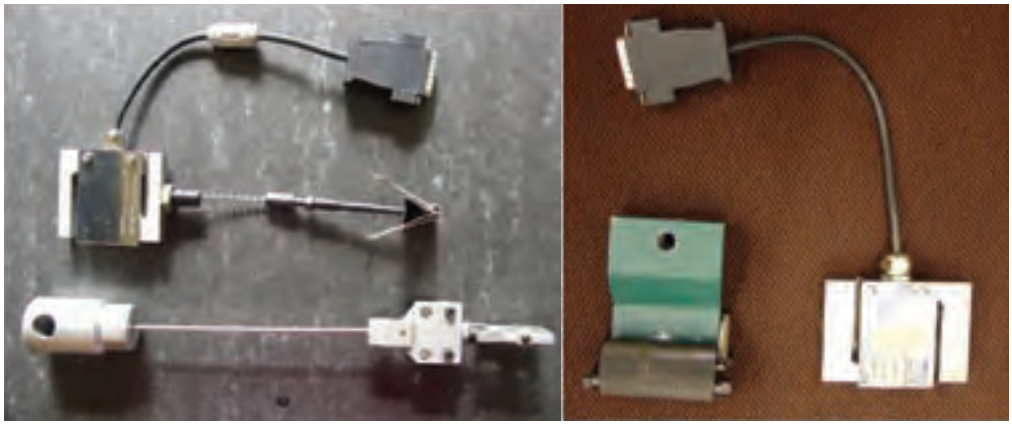


Figure 6 - Load cell and grips

TENSILE STRENGTH TEST OF FIBRES AFTER ALKALI EXPOSURE

In this section, the alkali environment was simulated in terms of saturated $C_a(OH)_2$ solution, OPC mortar and sulfoaluminate mortar. The three types of calcium sulfoaluminate cements used were the low-alkalinity type and rapid-hardening type from China, as well as a UK product. The alkalinity of each solution is summarised in Table 2.

Table 2 - Alkalinity of different solution

	Saturated $C_a(OH)_2$ solution	OPC	Low-alkalinity cement	Rapid-hardening cement
pH	13.33	13.29	10.5[6]	11.5[6]

Approximately 20mm of roving was cut from the roving package and soaked in the saturated $C_a(OH)_2$ solution. This was cured at the condition as stated in the weight-loss test section. After that, the test specimen was prepared and tested with the same method described in the previous section.

For the SIC test, a mould (Figure 7) was constructed according to GRCA-S-0104/0184[4].

Figure 7 - Mould for preparing SIC test specimen

1. Strand specimens were mounted on the mounting tabs as in the previous section, but cellophane film was used to resist the high humidity in the water tank.
2. Side edges of the mounting tabs were cut off and the ARALDITE PRECISION-impregnated parts of the strands on both ends of the gauge length were covered with a rubber sealant grommet. Next they were placed across the wooden frame of the mould, as shown in Figure 7, by locating the gauge length in the middle of each mould slot.
3. The cement mortar slurry (cement : sand : water = 75 : 25 : 32), mixed in a plastic beaker, was used to fill the mould slots. The mould was then immediately transferred to the mist room to be cured at 20°C and 100% RH. The cement was allowed to harden for 24h.
4. The specimens were then stripped (Figure 8) and put in the same water bath mentioned above for the same period. After removal of the specimens from the water bath, they were immersed in water at ambient temperature to cool for 15min. Following that they were tested using the previously mentioned test machine under the same conditions that the strand specimens were subjected to.

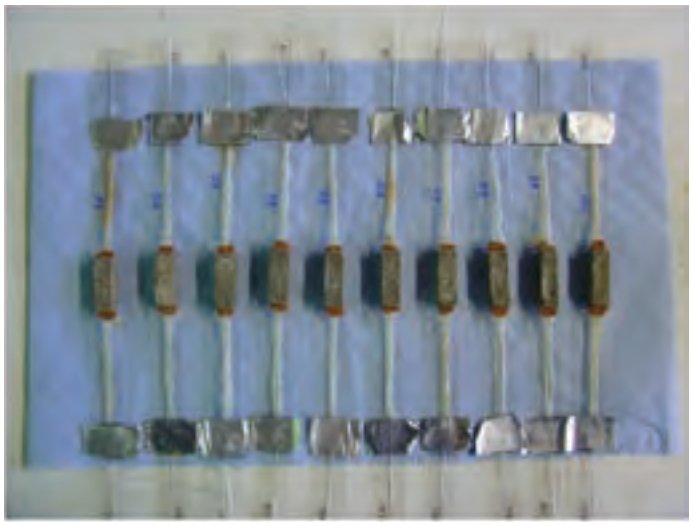
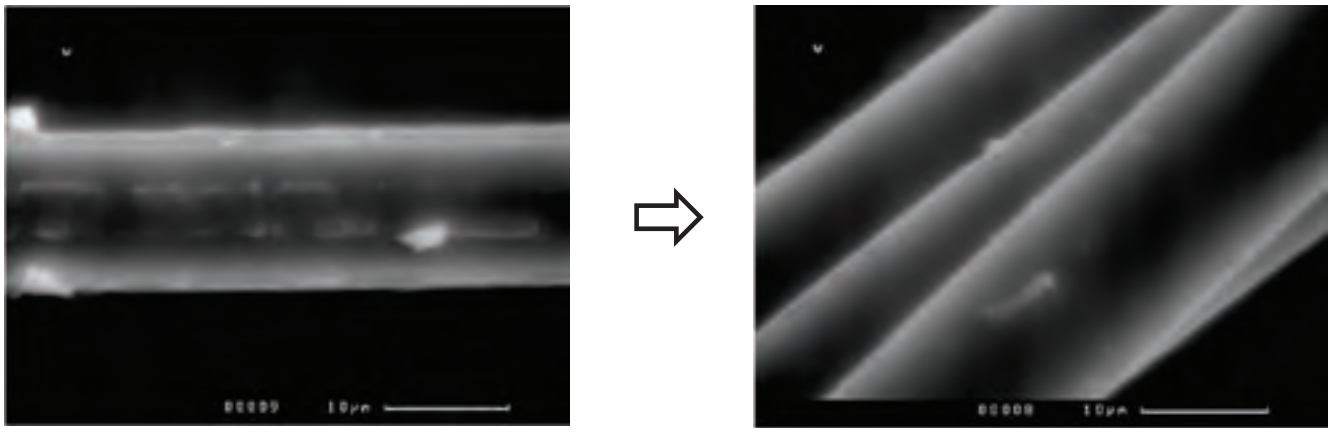


Figure 8 - Finished specimens

MEASUREMENT OF CROSS-SECTIONAL AREA

Single filaments

The average specimen area for a test group was determined by measuring a certain number of filament diameters, as shown on photomicrographs (Figure 9) prepared by scanning electron microscope, Cam-Scan II (Figure 10).



Filament separated from strand

Held at 80°C for 192h in saturated $C_a(OH)_2$ solution

Figure 9 - Photomicrographs prepared by Cam-Scan II (Magnification: 2500)

Figure 10 - Cam-Scan SEM

Strands

At the 'Tensile strength test of fibres as manufactured' section, right after step 2, the measured 1m strand was coiled up and weighed on the balance shown in Figure 1. After correcting for sizing content the weight was then divided by the density of the glassfibre to get the cross-section area.

The final results of strength retention are summarised in Table 3.

Table 3 - Strength retention

Variety	Single filaments	Strands				
	$C_a(OH)_2$	$C_a(OH)_2$	OPC	Low	Rapid	UK
Strength retention	30.3%	82.7%	36.5%	56.4%	52.4%	58.1%

DISCUSSION

The determination of tensile strength is straightforward. Even when filaments are as thin as around 15μm in diameter, they can be easily fitted on a paper tab and tensile tests can be performed in a simple way.

Glassfibres have defects introduced during manufacturing, processing and from handling, such as ultramicropores, fibril misalignments and impurities, which are the main source of crack initiation and failure in fibres[7]. These defects cause either lower or scattered strength values. As shown from the test results[8], this scatter is significant, and hence, a statistically large number of tests is indispensable.

After the alkalinity exposure, fibre strands exhibit softer characteristics than the original ones and filaments can be easily peeled off the strand. Also considering that the sizing weight (2%) is greater than the total weight loss (see Table 1), it is believed that a substantial part of the weight loss is due to damage to the sizing.

For the $C_a(OH)_2$ solution, the strength retention of strands is nearly three times as high as for single filaments, which means that it is better to keep the fibres in strands than to disperse them in the mix as single fibres.

In general, the strength retention in sulfoaluminate cements is 50% higher than that in OPC. This gives sulfoaluminate cement an advantage in design for long-term loading.

Saturated $C_a(OH)_2$ solution was used to simulate OPC because the measured alkalinity of both was almost the same. While the strength retention results are exceedingly different, it is thought that other chemical reactions occurring on the interface between glassfibres and concrete may also contribute to degradation of the glassfibres. Another possible explanation for the higher degradation is that there is a higher possibility of damage to fibres during the preparation of SIC samples than simply by immersing fibres in an alkali solution.

The strength in low-alkalinity cement is higher than that fromin rapid-hardening cement. This is in accordance with the alkalinity of the cements[6].

Sulfoaluminate cements from different sources give parallel results.

CONCLUSION

AR glassfibre strands demonstrate 50% higher strength retention in sulfoaluminate cements than in OPC. This is of particular interest to the GRC industry since this implies better long-term durability and the enhanced performance offers more safety to the design.

Experiments involving fibre strands in saturated $C_a(OH)_2$ showed much higher strength retention than in OPC of similar alkalinity. This means that the chemical attack on the glassfibre is more complicated than just an attack from the $C_a(OH)_2$ component of the cement. In addition, the protective effect of the sizing appears to have a greater effect on strands than on single filaments.

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