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THE USE OF GLASS FIBRE MAT IN THE SURFACE OF CONCRETE

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ABSTRACT

Deterioration of concrete structures due to penetration of aggressive species through the cover layer causing corrosion of the reinforcing steel is a major problem leading to premature failure of concrete structures throughout the world.

Samples have been made using chopped strand alkali-resistant glass mat as a shutter lining material and tests have been carried out to determine the effect of the glass on the potential durability of structures. The effect of the glass on fragmentation and flexural stiffness and strength has also been investigated.

The results indicate that this material promotes the formation of better concrete in the cover layer as well as inhibiting cracking. It therefore offers considerable potential for the construction of durable structures. It is also indicated that the glass improves flexural stiffness and inhibits fragmentation.

INTRODUCTION

The surface layer of concrete in a structure is the most critical part for durability because the cover is the barrier which protects the reinforcement from the environment. It is also likely to be formed of the poorest quality concrete due to effects such as premature water loss caused by imperfect curing (1) and depletion of aggregate (2). Any method which has the potential to enhance the properties of the surface layer is of interest for use in structures. This paper describes the use of chopped strand glass fibre mat in the surface.

Glass fibre has been used in concrete with some considerable success for many years. It has, however, generally been added to the mix before placing and thus been randomly distributed throughout the concrete as placed. There are many reasons why the glass fibre should be expected to be more effective when placed in the surface of concrete, some of these are as follows:

- 1 The surface layer of concrete is the most critical part of a structure when determining durability. In particular any material which can inhibit the transport processes in the cover layer has the potential to achieve substantially improved protection to steel reinforcement.
- 2 When fibres are randomly distributed in a structure a substantial part of their load carrying capacity is wasted because their location or orientation does not coincide with the stresses. The probability of a fibre being in a position to carry a stress is far greater if the fibre is at the concrete surface and oriented in the plane of the surface.
- 3 The chemical environment in hardened concrete is highly alkaline and glass is not durable in an alkaline environment. Considerable progress has been made in developing Alkali Resistant glass for use in concrete but even this will typically lose up to 50% of its strength after 10 years of exposure to concrete pore solution (3). The bulk of the concrete will remain highly alkaline throughout the life of a structure but the process of carbonation will reduce the alkalinity of the surface layer. The results of this paper suggest that the glass will inhibit the progress of carbonation but the alkalinity of the outermost layer will certainly decline. This will inevitably help the durability of glass in the surface to some extent although some research (4) suggests that, after substantial initial losses, the strength subsequently remains relatively unchanged for a considerable time even in uncarbonated concrete.

Construction with glass fibre in the concrete surface.

Test samples were made by cutting the glass fibre mat to the appropriate shape and placing it in the moulds before casting. It was found that for a mix with a typical (100mm) slump a poor surface finish was obtained if the samples were just vibrated on the laboratory vibrating table but the use of a vibrating poker achieved an excellent finish with the paste penetrating fully through the mat to give a perfectly smooth finish. On close inspection the texture of the mat could be seen quite clearly in the surface of the best finish but it is the opinion of the authors that a textured finish of this type would not be detrimental to the appearance of concrete structures and could well enhance them. It was found that it was not possible to trowel the glass into the upper surface of concrete but it was possible to place the glass in the surface with a roller.

EXPERIMENTAL PROGRAMME

Experimental plan

The experimental programme was intended to give initial results to determine the potential benefits of using the glass in concrete structures. Tests were carried out to measure the effect of the glass on the potential durability and the mechanical properties of concrete. The tests which are reported here are as follows:

Initial Surface Absorption Test (ISAT)

Water Absorption Test

Figg test

Carbonation dept measurements

Flexural stiffness and strength test

Drop Ball fragmentation test

Production of Samples

Materials.

All samples were made with class 42.5N Portland Cement to BS12 1991 (5).

The aggregate was a mixed natural gravel containing flint, quartzite and metamorphic materials. The maximum aggregate size was 10mm. The mix designs are in Table 1.

Table 1 Mix Designs

Mix	Mix Proportions kg/m ³				Cube Strength
	Cement	Water	Fine Agg	Coarse Agg (10mm)	
A	360	225	775	985	45
B	465	220	680	975	50
C	500	230	665	955	65
D	690	230	560	875	70
E	300	210	815	1075	30
F	410	245	750	995	40

The cube strengths quoted are for 100mm cubes without glass mat cured in water for 28 days. The Glass Fibre Mat was supplied by Cem-FIL PLC (6) and was the only type of alkali resistant matt in production. The properties are given in Table 2 :

Table 2 Properties of Glass Fibre Mat

Fibre range Serial No	50/1
Colour	Pink
Filament Dia (μm)	14
Strand Tex (g/km)	76
No of strands per roving	32
Roving Tex (g/km)	2450
Av Fibre Length (mm)	50
Mass of mat (g/m^2)	180
Quoted cost £/m^2	0.7

The orientation of fibres in chopped strand mat is random. The mat was pushed into the corners of the moulds with a compacting bar. Compaction was initially carried out with the vibrating table and some mixes suffered from inadequate compaction because this method did not fully "wet" the glass in all samples. For mix C a poker vibrator was therefore used in all samples.

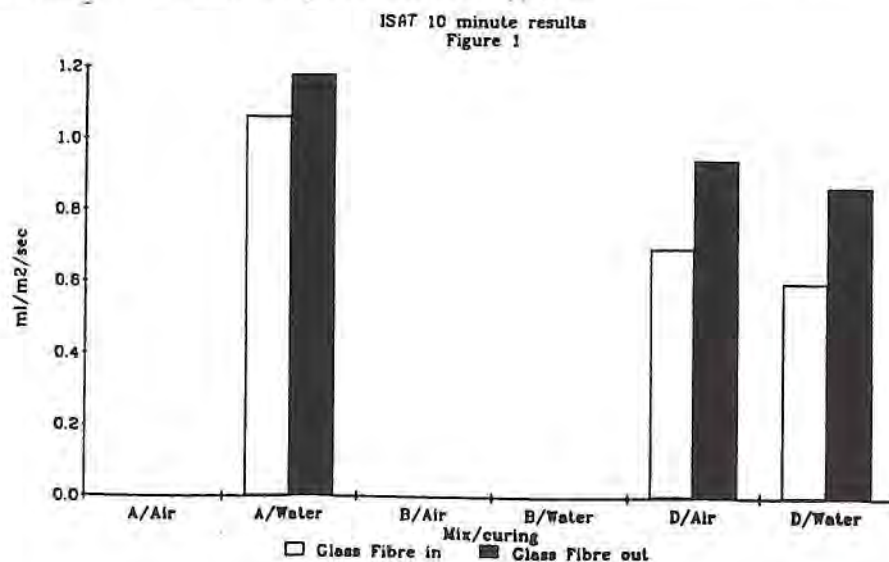
Curing

Two curing regimes were used: "Air Cured" samples were cured in the laboratory for 28 days. "Water Cured" samples were cured in a curing tank at 20°C for 28 days.

ISAT

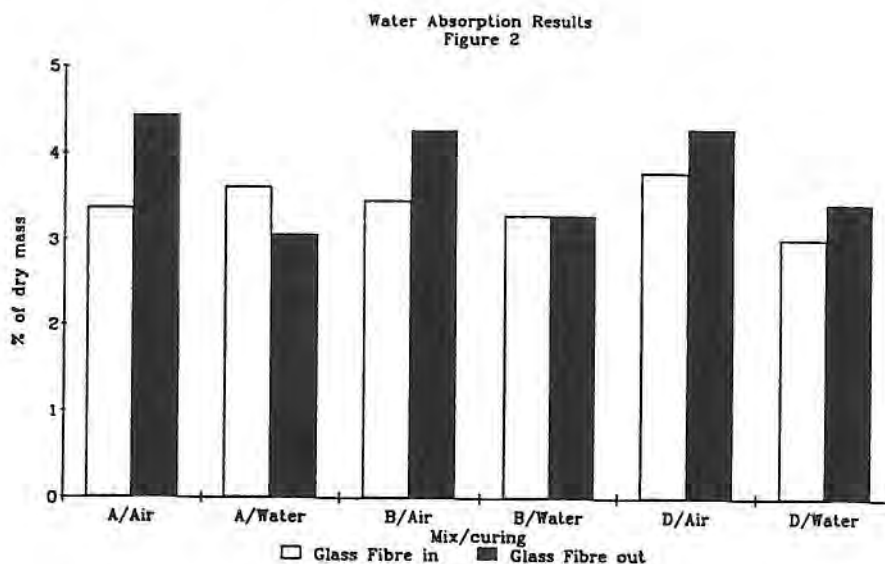
This test is covered by BS1881 part 5 (7) and this work was carried out in accordance with that standard on 150mm cubes. The samples were oven dried at 105°C for 72 hours prior to testing giving the weight loss requirement specified in the standard.

Readings were taken at 10,30 and 60 minutes. For this project the 120 minute reading was not found to be necessary. It was found that for a number of samples which had been vibrated on the vibrating table the surface quality was inadequate to form a seal around the cap and the test was therefore not carried out. The results which were obtained are in Fig 1.



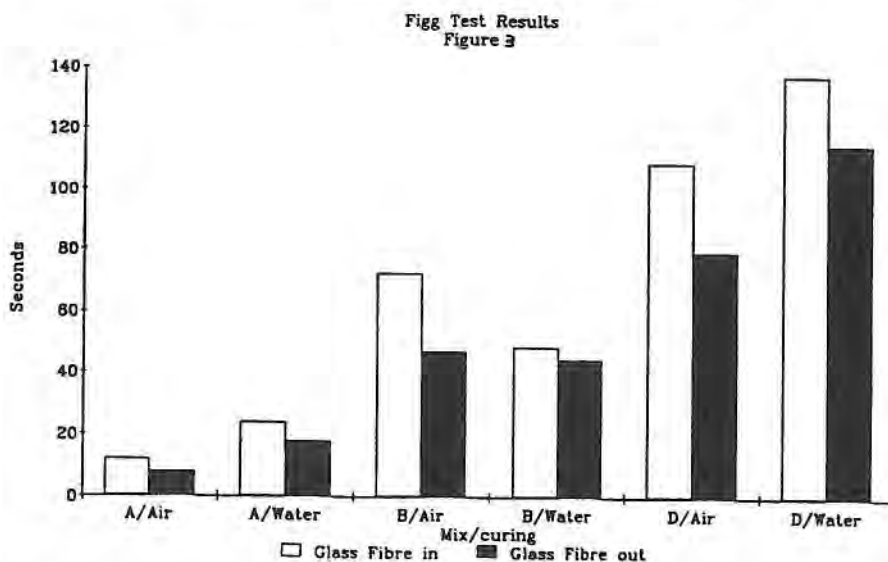
Water Absorption Test

The water absorption test in BS1881 Part 122 (7) was carried out on oven dry 100mm cubes. The cubes were immersed in water to a depth of 95mm and the weight gain over a period of 30 minutes was measured. Because the samples were not cylinders as recommended in the standard a correction factor given in the standard was used to allow for the surface area to volume ratio of the samples. The results are in Fig.2, each reading is an average of the results from two observations on replicate cubes.



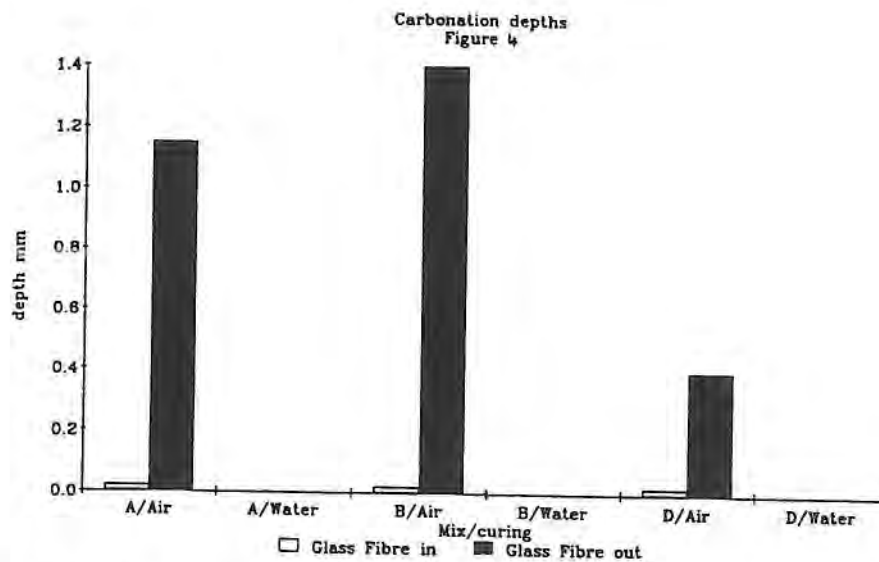
FIGG test

This test was carried out using the method of Cather et. al. (8). The samples were oven dried as for the ISAT. Two tests were carried out on each cube, the results are in Fig.3.



Carbonation measurements.

A small number of air cured test samples were placed on the balanced flue of a gas boiler. While this method cannot give absolute measurements of carbonation it provides a suitably aggressive environment for carbonation to give comparative readings. The warmth from the pilot burner on the boiler kept the samples dry at all times and the occasional use of the main burner exposed them to an atmosphere with a high carbon dioxide content. The carbonation depth was measured with phenolphthalein indicator on split samples. The results are in Fig.4



Flexural strength and stiffness tests

Twenty four plain concrete beams and eight reinforced concrete beams were tested in bending at 28 days, the results are given in Tables 3 and 4. All reinforced beams were of 75x175mm section, 1220mm and 920mm spans, made from mix B and wet cured. Reinforcement consisted of 2R10 longitudinal tension bars, 2R6 longitudinal compression/hanger bars and two-leg R6 links at 75mm spacing in the end thirds only.

Table 3. Plain concrete beams: modulus of rupture

Mix	Section size mm	Curing	Span mm	No of samples with glass	Modulus of rupture N/mm ²	No of samples without glass	Modulus of rupture N/mm ²
B	100×100	wet	400	1	5.73	1	5.64
B	100×100	dry	400	1	4.05	1	3.15
C	100×100	wet	400	4	4.18	3	3.26
D	100×100	wet	400	4	6.16	3	5.45
B	75×175	wet	1120	1	2.92	1	2.93

Table 4. Reinforced concrete beams

No. of samples with glass	Mean concrete cracking stress N/mm ²	Mean un-cracked concrete elastic modulus N/mm ²	No. of samples without glass	Mean concrete cracking stress N/mm ²	Mean un-cracked concrete elastic modulus N/mm ²
4	3.9	24.2	4	3.2	13.7

In all flexural tests, beams were loaded at third points. Reinforced beam strain profiles were obtained by 200mm long Demec gauge readings at mid span. Strain readings were taken at 3 kN load intervals (0.61 kNm and 0.46 kNm bending moment intervals, depending on span).

Steel resistance moments were calculated from steel strains linearly interpolated between Demec stud positions. Differences between these and applied moments were assumed to be resisted by linearly varying concrete tensile stresses, which were then tabulated for each loading interval. The concrete

cracking stress in table 4 was then taken to be the first clear drop in slope on tension edge stress/strain plots.

There was no significant difference in the ultimate strength of reinforced beams with and without glass mat.

Drop Ball Fragmentation Test

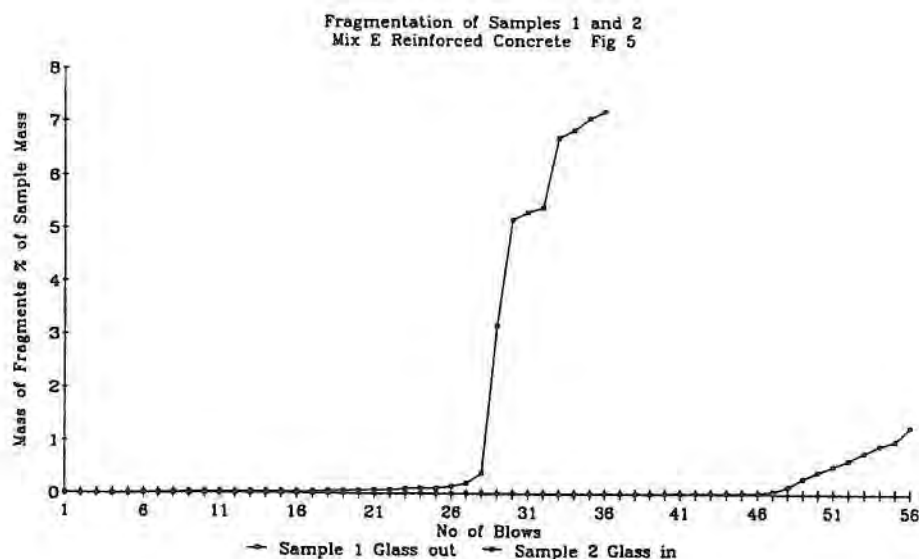
Four samples were cast as shown in Table 5:

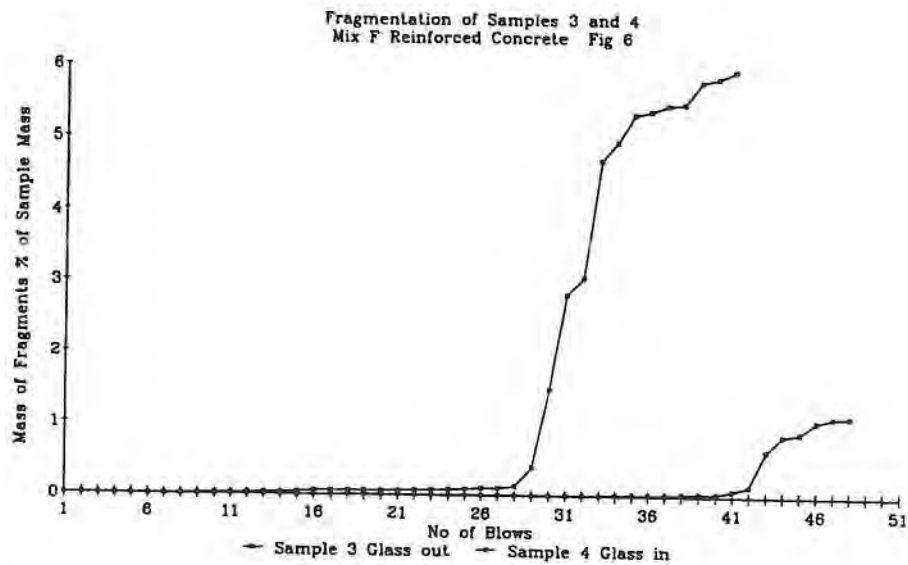
Table 5. Samples for fragmentation test.

Sample Number	Size mm	Concrete mix	Reinforced with	Area of steel %
1	600 × 300 × 80	E	Steel	0.7
2	600 × 300 × 80	E	Steel + Glass mat	0.7
3	600 × 300 × 80	F	Steel	0.7
4	600 × 300 × 80	F	Steel + Glass mat	0.7

The steel reinforcement was 8mm diameter bars with three bars parallel to the longer edges and six bars parallel to the shorter edges.

The samples were tested by supporting them at each end and dropping a 3.3kg steel ball onto them from a height of 3m. The ball was dropped down a length of 100mm diameter pvc pipe to guide it. After each blow the fragments from the sample were collected and weighed. For the samples without steel reinforcement it was necessary to clamp their edges to the supports in order to prevent them failing in bending, this ensured that all samples failed in punching shear. The results are in Figs 5 and 6.





ANALYSIS

The results of the durability related measurements were tested for significance using Analysis of Variance (ANOVA) to see whether the addition of the glass achieved a significant improvement for each property. The F statistic (9) was calculated for the interactions (all first order) and is given in Table 5 together with the Critical value of F for significance at the 5% level.

Table 5. Analysis of Variance

Test	Air cured samples		Water cured samples		All samples	
	F	Fcritical	F	Fcritical	F	Fcritical
ISAT (10 minute)					35.33	18.51
ISAT (30 minute)					10.25	18.51
ISAT (60 minute)					5.75	18.51
Absorption	24.27	18.51	.02	18.51	2.49	6.61
Figg	7.14	18.51	5.17	18.51	12.06	6.61

When considering this table it is important to note that the glass improved the samples in all cases (except the water cured samples for absorption), the cases where F is less than Fcritical are those where the sample was too small for significance at the 5% level.

For the air cured samples the improvement in the Absorption results was significant. For the water cured samples none were significant, however the 10 minute ISAT and the Figg results were significant for the total populations.

DISCUSSION

The four durability related tests (ISAT, Absorption, Figg and Carbonation) all show improvements from the glass and some of these have been shown to be statistically significant. This work has shown that the glass mat has the potential to improve durability but the mechanism has not been investigated. A possible explanation for the improvement is a mechanism that derives from control of the movement of water in the surface layer of the concrete during the setting and hydration of the concrete. Evidence for this may be seen in the more significant improvements that occurred for the dry cured samples. Several different processes could be possible. The glass may prevent water loss during curing either by acting as a barrier or by adsorbing water onto the fibres.

It is not surprising that the presence of such a thin layer of material of comparatively low elastic modulus has no significant influence on the ultimate flexural strength. Its effect in enhancement of low-stress stiffness and delay of first crack formation is, however, of great potential significance. The results have been obtained from a relatively small sample of tests, and will require confirmation by a more extensive testing programme. The influence on initial cracking stress may be due to the glass mat's inhibiting effect on surface crack-inducing irregularities. The mechanism of its apparent effect on the elastic modulus is less clear, and will require further testing to be confirmed and explained.

The fragmentation results are readily explained by the physical effect of the fibres. The results suggest that this material would be suitable for applications such as crash barriers or military installations where fragmentation is likely to occur.

Site trials would be required to find the types of project for which this material would be suitable and whole-life costing would be required to justify the expenditure.

Comparison with Controlled Permeability Formwork shutter liners.

Controlled permeability formwork (CPF) has been used in construction for some time (10). It works by permitting the water near the surface of the wet concrete to escape and thus locally reduce the water/cement ratio and improve the durability. In some systems (shutter liners) the water is retained in the liner and is then available to be re-absorbed during curing. There is an obvious similarity between the proposed use of the glass mat and the present use of the CPF because they are both used as shutter liners to enhance durability.

The essential practical difference between glass mat and CPF liners is that the glass mat remains in the concrete but the CPF liner is removed and, after cleaning, may be re-used. This will tend to give the CPF an economic advantage over the glass mat but it is understood (10) that cost of the glass mat is less than 20% of that of the CPF and it would be less expensive to fix because it can form to the shape of surfaces and could therefore just be laid in the shutters with minimal fixing and would not require stretching across the shutters to prevent folding which is necessary for the CPF.

CONCLUSIONS

1. Placement of glass fibre mat in the surface of concrete would be practicable on construction sites and would not be detrimental to the appearance of the finished concrete.
2. Glass mat in the concrete surface substantially inhibits the transport processes which permit the ingress of aggressive species from the environment and would therefore inhibit the corrosion of embedded steel.
3. The weights of mat which are envisaged in this project are insufficient to have a significant effect on the strength of a structure with steel reinforcement but there are indications that it may delay first crack formation and raise low-stress stiffness.
4. Glass mat in the surface of concrete substantially inhibits fragmentation on impact.
5. Glass mat is likely to cost less in use than CPF shutter liners despite the potential for re-use of the CPF.
6. Glass mat in the surface of concrete will be less prone to deterioration caused by alkaline pore solutions than glass fibres in the interior of a concrete element.

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