Durability Study of Textile Fibre Reinforcement

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Abstract: Conventional steel reinforced concrete is one of the most commonly used building materials, yet it has shortcomings in terms of weight, thick concrete covers, and durability namely corrosion of the reinforcement. Textile Reinforced Concrete (TRC), a combination of fine-grained concrete and non-corrosive fibre grids, has emerged as a promising alternative; corrosion is no longer an issue and much thinner and light-weight elements can be designed. Although TRC has been expansively researched, unknowns pertaining to the long-term durability arise when attempting to implement such innovative building materials. The aim of this article is to study the effect of accelerated aging on the tensile strength of various textile fibre grids according to ISO 10406-1 [1]. Carbon, basalt and alkali-resistant (AR) glass fibre grids were immersed into high alkali environment and elevated temperature for 30 days. Direct tensile tests were conducted before and after aging to observe the degree of stiffness and tensile strength loss. After aging, the carbon fibre grids were marked by an increase in both tensile strength and stiffness, while AR-glass and basalt were degraded to the extent that tensile tests could not be conducted. Specimens were therefore exposed to alternative conditions to identify the governing degradation factor.

Keywords: durability, aging, fibres, experimental tests, alternative reinforcement

1. Introduction

Textile reinforced concrete (TRC) is a combination of fine-grained concrete and non-corrosive fibre grids. Furthermore, it can be characterized as a three-phase material consisting of a cementitious matrix, fibre/yarn structure as well as a fibre/matrix interface. The individual fibres incorporated in the yarns which form the textile fibre grid are most often coated by a sizing material serving as a surface protection and improvement of bond between the fibres. This applied sizing could greatly influence the degradation process and long-term performance of the composite [2, 3]. During the service life, TRC could face harsh boundary conditions such as the highly alkaline environment of the concrete pore solution, varying temperature and humidity loads, carbonation as well as sustained and cyclic loading and fatigue which could all have an effect on its long-term mechanical behaviour and durability. Consequently, the critical zones of degradation are most likely the fibre sizing/coatings and the fibre/matrix interface.

Durability performance is most accurately measured in real-time [4]; however, as time is usually a constraint, accelerated aging tests or experimentally calibrated numerical models [5] have been used to predict the long-term performance of textile reinforcement or fibres in concrete. A common method to accelerate the ageing of the fibres, consists of immersing them, in the form of fibre-reinforced polymer (FRP) rods or textile reinforcement, in a simulated or actual concrete pore solution (i.e. alkaline environment) while simultaneously being exposed to high temperature [6].

In this study, accelerated tests paired with direct tensile tests were performed according to ISO 10406-1 [1] on fibre-reinforced polymer (FRP) bars and grids. Carbon, basalt and AR-glass fibre grids were immersed in a high alkali environment (pH=14) with elevated temperature (60 °C) for 30 days. It was of key interest to forecast the so-called long-term mechanical behaviour and material degradation of various commercially available textile reinforcement products for potential use in new façade solutions within the project H-HOUSE funded by the European Commission.

2. Experimental program

2.1 Materials

The durability related to the alkali-resistance of three commercially available textile fibre grids of carbon, basalt and alkali-resistant glass (AR-glass), listed in Table 1, were investigated in this study. TRC building applications have primarily focused on the use of AR-glass and carbon fibre materials, but natural and polymer fibres have also been researched for this application [4]. For the most part, the use and durability of AR-glass has been deeply investigated for use in TRC as it has been both cost effective and readily available [7]. Basalt fibres are mineral fibres extracted from volcanic rock and are often compared to glass fibres, such as E-glass and AR-glass, due to existing similarities in their chemical composition [2, 8].

Table 1. Overview of tested textile fibre grids.

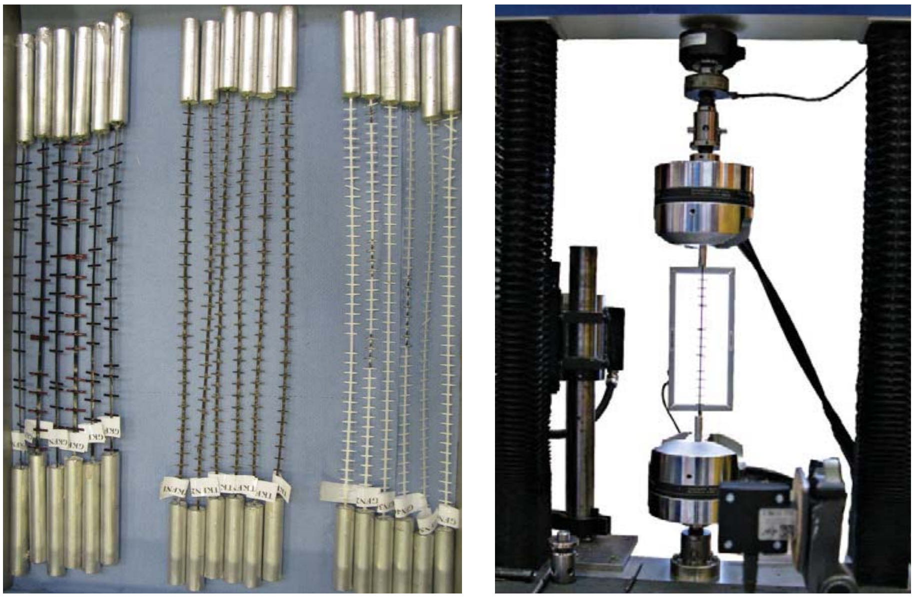
Material	Sizing/coating	Grid spacing 0°/90° (mm)	Weight (g/m^2)
Carbon	Styrene-butadiene resin (SBR), 15%	17/18	250
Basalt	Undisclosed resin, 17%	10/10	165
AR-glass	Styrene-butadiene resin (SBR), 20 %	7/8	210

2.2 Direct tensile tests

Direct tensile tests were conducted on both reference samples and aged samples, denoted as pre-immersion (Case 1) and post-immersion (Cases 2 or 3), respectively. A total of five tests were conducted for each alternative before and after immersion. The tests were carried out using a universal testing machine (Sintech 20D) illustrated in Figure 1b and the force was recorded by a load cell with an accuracy of 1%. The deformation was measured by a Messphysik Videoextensometer ME46 with backlight technique in the background and digital camera in the foreground. A great advantage of using a video extensometer is that it is possible to measure the deformation up to failure of the specimen, i.e. the ultimate strain can be determined directly. A mechanical extensometer most often has to be removed before failure to avoid risk of damage, thereby causing the ultimate strain to be extrapolated by the assumption of linear elasticity.

The fibre reinforcement grid was cut into so-called individual yarns with a remaining 2 mm projection of the cross-points (crossbars) as well as a minimum of three cross-points along the length. An aluminium tube with epoxy resin as infill was found to be the most suitable solution for the end anchorage of the linear samples (Figure 1a). The main purpose of the end anchorage is to transmit only tensile force along the longitudinal axis of the sample. The tubes had a varying length of 75-100 mm, outer diameter of 15 mm and inner diameter of 12 mm. The inside of the tubes were roughened and cleaned with acetone to achieve superior bonding with epoxy.

The main outputs of the direct tensile tests were the tensile capacity, tensile rigidity and ultimate strain of the different alternatives. The tensile rigidity was calculated from the load-strain relation as the secant modulus between the load level at 20% and 50% of the ultimate tensile capacity. In addition, the tensile capacity retention rate was computed to measure the relative mechanical degradation of the post-immersed versus the pre-immersed specimens.



(a) Test specimens with aluminium end caps. (b) Direct tensile test setup.

Figure 1. Direct tensile testing.

2.3 Accelerated testing

The accelerated tests involved the immersion of linear pieces of fibre reinforcement grid in an alkaline solution (pH > 13) while being exposed to a temperature of 60 ±3 °C for 30 days. The alkaline solution prepared according to ISO 10406-1 [1] consisted of 8.0 g of NaOH and 22.4 g of KOH in 1 l of deionized water. The pH of this solution was measured to be pH=14. The linear test pieces were bundled and sealed by epoxy resin end caps to prevent infiltration of the solution. These bundles were immersed in the alkaline solution in plastic cylindrical containers (see Figure 2) which were sealed and placed in a climate chamber. Once removed from the alkaline solution, the test specimens were rinsed in dionized water and visually examined prior to commencing with the aforementioned end anchorage preparation necessary for the direct tensile testing.

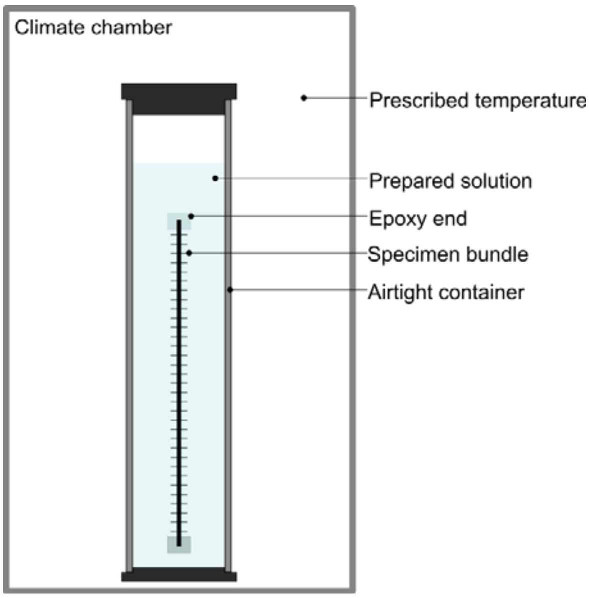


Figure 2. Accelerated aging test setup.

When tensile tests could not be conducted due to the extent of sample degradation based on the standard boundary conditions, which particularly applied to basalt and AR-glass, additional tensile tests related to alternative boundary conditions were executed. In the standard accelerated test (Case 2), the specimens face two upper bound variables simultaneously in terms of temperature (60 °C) and alkalinity (pH=14), which, in turn, makes it problematic to identify the actual cause of material degradation. Accordingly, in this study, test samples were also aged for 30 days at 60 °C and pH=7, denoted as Case 3.

3. Results and Discussion

3.1 Visual observations

The external appearance of the fibre grid specimens was examined pre- and post-immersion, for comparison of colour, surface condition and change in shape. Photos depicting the visual macroscopic changes are shown in Figure 3.

(a) Carbon (b) Basalt (c) AR-glass

Figure 3. Visual observations pre- and post-immersion.

For carbon fibre grids, no significant visible change of colour or surface texture were observed after 30 days of immersion in pH=7 and pH=14 at 60 °C (Cases 2 and 3). The basalt samples aged according to the standard conditions (Case 2) were marked by colour change and what appears to be the lifting of the coating to the surface. These samples lost a great deal of stiffness to the point that they broke prior to removal from the solution. For those exposed to Case 3, the observed degradation was similar to the Case 2 samples, yet these could be further tested in tension. The AR-glass specimens exposed to Cases 2 and 3 lost the majority of cross-threads which revealed an uncoated and transparent surface in these locations. These samples also lost a significant amount of physical stiffness and could be easily broken by hand at the cross-points.

3.2 Experimental results

A compilation of the mean tensile test results along with the associated standard deviations are reported in Table 2. It can be seen that both basalt and AR-glass samples aged according to the standard conditions (Case 2) were unable to undergo direct tensile testing due to the resulting extent of sample degradation. When exposed to alternative boundary conditions of 60 °C and pH=7 for 30 days (Case 3), however, basalt and AR-glass fibre grid samples could undergo direct tensile tests.

Table 2. Mean tensile test results.

Case	Reinforcement	Mean properties (st. dev.)			
		Tensile capacity (kN)	Ultimate strain (%)	Tensile rigidity (kN)	Tensile capacity retention rate (%)
(1) Reference	Carbon	1.88 (0.23)	0.87 (0.06)	221.38 (5.05)	-
	Basalt	0.62 (0.03)	2.85 (0.08)	23.73 (0.49)	-
	AR-glass	0.41 (0.02)	1.91 (0.10)	22.49 (0.49)	-
(2) 60 °C, pH 14, 30 d	Carbon	2.36 (0.03)	1.01 (0.03)	235.68 (18.60)	125 (2)
	Basalt	Not measurable			
	AR-glass	Not measurable			
(3) 60 °C, pH 7, 30 d	Carbon	2.14 (0.21)	0.91 (0.14)	234.33 (6.75)	114 (11)
	Basalt	0.39 (0.01)	1.70 (0.10)	23.13 (0.66)	62 (2)
	AR-glass	0.15 (0.03)	0.73 (0.10)	20.54 (2.62)	35 (7)

The tensile test results for the pre-immersed (Case 1) samples are compared to the post-immersed samples (Cases 2 and 3) in terms of applied load versus strain in Figure 4. The carbon fibre specimens appear to have increasing tensile capacity (14-25%) and rigidity (6%) after immersion which is thought to be due to a stiffening effect of the applied coating. In addition, the basalt and AR-glass samples were observed to have a significant degradation even after aging according to Case 3. The tensile capacity and rigidity of basalt were reduced by 38% and 3%, while those corresponding to the AR-glass decreased by 65% and 9%, respectively. It can be drawn from this outcome that AR-glass appears to have a greater sensitivity to the temperature effect. Furthermore, for all tested specimens, there was no significant difference in failure mode noted before and after immersion and failure primarily occurred at the cross-points.

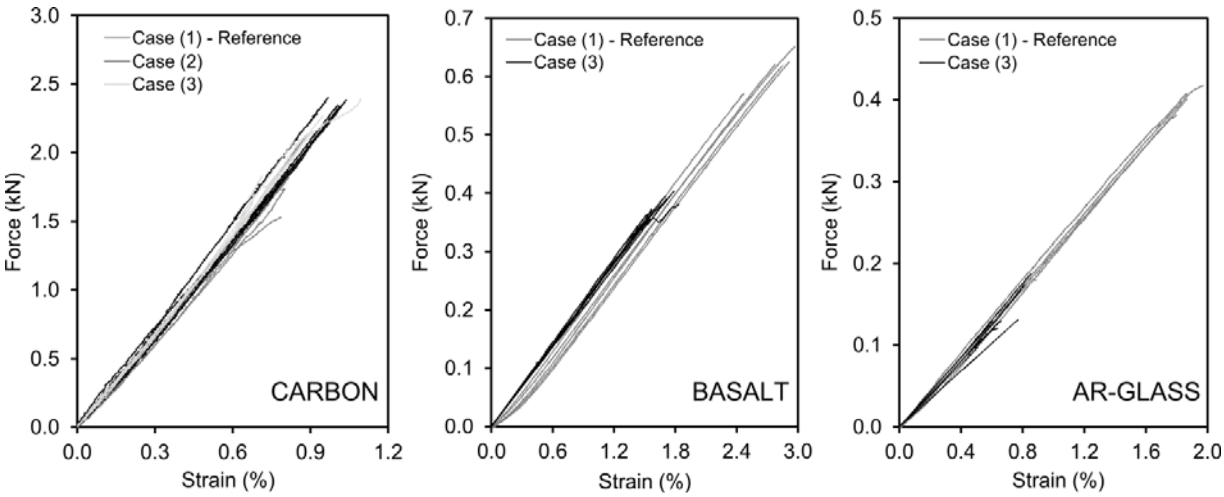


Figure 4. Applied load versus strain curves for all specimens.

4. Conclusions

The tensile capacity and alkali resistance of selected textile fibre grids were investigated using ISO 10406-1 [1]. According to the results, it can be concluded that the tested carbon fibre grid has a superior alkali and temperature resistance in comparison to the other alternatives. It was not possible to quantify the material degradation for basalt and AR-glass according to the standard boundary conditions. A downside of this method is that it simply describes the relative difference in durability between different samples, but does not predict the actual durability of the material neither does it specify requirements to be met.

It is believed that further parametric studies, in terms of varying boundary conditions, are needed to gain a deeper understanding of the degradation processes. Statistical analyses of these presented results could also help highlight the significance of the observed trends. Moreover, the time-dependent degradation of fibre cross-sections could be additionally investigated using an electron-microscope to observe the effectiveness of sizings/coatings.

5. Acknowledgement

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