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Tensile behaviour of textile reinforcement under accelerated ageing conditions

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ABSTRACT

Textile reinforced concrete (TRC) has emerged as a promising alternative wherein corrosion is no longer an issue and much thinner and light-weight elements can be designed. Although TRC has been expansively researched, the formalization of experimental methods concerning durability arises when attempting to implement and design such innovative building materials. In this study, accelerated ageing tests paired with tensile tests were performed. The change in physico-mechanical properties of various commercially available textile reinforcements was documented and evaluated. The ability for the reinforcements to retain their tensile capacity was also quantified in the form of empirical degradation curves. It was observed that accelerated test parameters typically applied to fibre-reinforced polymer (FRP) bars and grids are generally too aggressive for the textile reinforcement products and alternative boundary conditions are necessary. The developed degradation curves were found to have an overall good correlation with the experimental findings.

1. Introduction

Textile reinforced concrete (TRC) not only presents sustainable advantages [1] but has also been found to be a suitable material for structures such as thin cladding and sandwich elements [2,3]. These alternative reinforcement materials are typically made of alkali-resistant (AR) glass, basalt or carbon fibres and offer a much lower density (1800–3000 kg/m^3) in comparison to steel reinforcement bars (7850 kg/m^3) which further contributes to a reduction in dead weight. Nonetheless, questions regarding the long-term durability arise when attempting to design and implement new building materials such as TRC, as there is minimal long-term performance or durability data available [4,5].

TRC can be generally characterised as a three-phase material consisting of a cementitious matrix, fibre-yarn structure as well as a fibre-matrix interface. This heterogeneous material can be exposed to various degradation processes over its service life, such as fibre degradation due to chemical attack, fibre-matrix interfacial physical and chemical interactions, and volume instability and cracking [6]. These degradation processes can occur individually or simultaneously which in turn makes the characterisation of the long-term performance of fibre-based composites complex. Another aspect which is critical to understand is that fibre-based reinforcement materials are marked by small surface defects or weak zones resulting from production and handling processes [7]. These defects have been found to be one of the factors contributing to strength loss of the final reinforcement product. Particularly concerning glass fibres, these weak zones have been observed to consequently grow when exposed to sustained loading conditions as a result of a mechanism called static fatigue or delayed failure [7,8]. The static fatigue strength of the composite is related to the critical flaw size, stress level and exposure conditions which govern the crack growth rate of surface defects [9].

Individual fibres incorporated in the yarns which form the textile reinforcement grid are typically composed of a sizing material applied during production which serves primarily as a surface protection [10]. This applied sizing could greatly influence the degradation process and long-term performance of the composite [11–13], particularly concerning AR-glass and basalt fibres. During the service life, TRC and the reinforcement could face such

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Table 1
General properties of the studied reinforcement materials.

Material (Product/Supplier)	Coating	Grid Spacing 0°/90° [mm]	Weight [g/m^2]	Tensile strength of yarn [N]
AR-glass (Glasfiberväv Grov), Sto Scandinavia AB	Styrene-butadiene resin (SBR), 20%	7/8	210	> 400
Basalt (Mesh-10–100), Sudaglass Fiber Technology Inc.	Undisclosed resin, 17%	10/10	165	1152
Carbon (SIGRATEX Grid 250-24), SGL Group	Styrene-butadiene resin (SBR), 15%	17/18	250	4243

boundary conditions like the high alkalinity of the concrete pore water (peak during hydration), 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. As such, the critical zones of degradation will most likely be the fibre sizing-coating and the fibre-matrix interface.

Durability performance is most accurately measured in real-time [5]; however, typically having time as a constraint, accelerated ageing tests [6] or experimentally calibrated models [10] have been used to predict the long-term performance of textile reinforcement, fibres or fibre-reinforced polymers (FRP) in a cementitious matrix. A common method to accelerate the ageing of fibres in the form of FRP rods or textile reinforcement consists of immersing them in a simulated or actual concrete pore solution, i.e. alkaline environment, while simultaneous being exposed to high temperature [10,14]. For instance, this method has been used to measure the loss of tensile strength exclusively due to the so-called chemical corrosion process related to AR-glass textile reinforcement [15]. Alternatively, basalt or glass fibre yarns have been immersed in sodium hydroxide (NaOH) and hydrochloric acid (HCl) solutions for varying time periods [16] or 3-ionic solutions to target localised attack [17,18]. Electron-microscopes have commonly been applied to investigate the degradation phases of the fibre-yarn surface [18] or the fibre-yarn-matrix interface [13]. Accelerated ageing of textile reinforcement cast in concrete has also been conducted in climate chambers at varying temperatures or moisture conditions followed by the quantification of loss of tensile strength and bond through various mechanical tests [4,13,19,20]. A time-dependent model was even developed and calibrated to determine the strength loss of AR-glass textile reinforcement in TRC [21–23], which was thereafter applied to design a pedestrian bridge [24]. Although a number of accelerated tests have been reported in this field of study, researchers have applied varying experimental methods and have investigated differing materials making them subjective and to some degree non-comparable.

2. Research significance

In this study, accelerated tests paired with direct tensile tests were performed according to ISO 10406-1 [25] pertaining to fibre-reinforced polymer (FRP) bars and grids. 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. Alternative boundary conditions were also included in the scope of work to investigate the discrete influence of two key variables on material ageing, i.e. temperature and pH of a simulated pore solution. The change in physico-mechanical properties of the various textile reinforcements was documented and evaluated in this work. The ability for the reinforcement materials to retain their tensile capacity was also quantified in the form of empirical degradation curves. The study also included development of methods for preparation of end anchorage, gripping system to the testing machine and measurement of strain up to failure.

3. Experimental programme

3.1. Textile reinforcement

AR-glass, basalt and carbon textile reinforcement grids primarily selected based on the current availability of commercial products were investigated. 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 [5]. 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 [21]. Alternatively, basalt fibres, mineral fibres extracted from volcanic rock, are often compared to glass fibres, such as E-glass and AR-glass, due to existing similarities in their chemical composition [11,16,26]. Regarding carbon fibre materials, the price per square metre of product is still significantly higher than the other alternatives, which is primarily because it is still most commonly demanded in other industries such as automotive and aerospace. General material and mechanical properties are commonly provided by the textile reinforcement producers, such as those data presented in Table 1, and at times also including the modulus of elasticity and elongation. The methods used to obtain the mechanical properties vary based on the source, which could decrease the soundness of the available data. Even so, tensile testing of these reinforcement materials was conducted according to the standard method stated in ISO 10406-1 [25] to base further evaluations in this study on these obtained data.

3.2. Test specimen preparation

The mechanical properties and durability of the selected textile reinforcement materials were investigated. Specimen preparation and test methods provisioned in ISO 10406-1 [25] were applied to determine the tensile capacity, tensile rigidity and ultimate strain of the textile reinforcement alternatives pre- and post-immersion into an alkaline solution. The textile reinforcement, initially in the form of a grid, was cut into so-called individual yarns with a remaining 2 mm projection of the cross-points (crossbars) as well as more than three cross-points along the length.

The method applied for gripping the specimens in tensile tests is known to be crucial for the test results, and various methods have previously been evaluated for tensile tests of FRP-bars [27]. The method must be suitable for the given specimen geometry while transmitting only the tensile force along the longitudinal axis of the specimens. It should also be ensured that premature failure of the specimen does not take place in the grip zone which is an undesirable failure mode. Accordingly, various types of end anchorage were evaluated in this study which led to the conclusion that an aluminium tube with epoxy resin was the most suitable method as it allows for the tensile force to be transmitted to the specimen by shear stress within the epoxy. Other gripping methods, such as clamp-to-yarn, emery cloth, rubber sheets and aluminium tabs were found to underestimate the tensile strength of the material which resulted in the specimens to either slide out of the test grip or fail within the grip.

The aluminium tubes used as end anchorage had a length ranging from 75–100 mm, outer diameter of 15 mm and inner