TEXTILE COMPOSITE CONCRETE PROVIDES SPECIAL ARCHITECTURAL AND PERMANENT SHUTTERING OPPORTUNITIES

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ABSTRACT

In the field of fibre reinforced cement, polypropylene (PP) fibres, in the form of textile fabric additions have proved most successful in recent years, leading to the development of a "new material": ***textile concrete*****. Although the strength and modulus of polypropylene is not very high, careful design, through the appropriate placement and high fibre volume fraction of a textile format, has the ability to lead to appropriate strengths and stiffness, while at the same time achieving high toughness. In particular the development of a fibrillated core fibre to which is attached an outer layer of ultrasonically welded, or bonded, "fluffy" fibres of PP, has been most successful, and is a unique feature. These outer fluffy layers provide excellent physical bonding characteristics to the cement matrix, thus overcoming the intrinsic hydrophobic nature and otherwise weak bonding of PP fibres. Recent testing of single "fibre pull-out" as well as structural bend and tensile testing of fibre textile concrete multi-layer laminates, has shown that the composite exhibits an effective "elastic–ductile" stress strain behaviour, with minimal load softening, and remarkable toughness.**

Since the textile concrete exhibits such high toughness, together with minimal corrosion susceptibility, is a user friendly and tolerant material, and can be ultrasonically welded to waterproof membranes, it has found some diverse and significant applications, even though its development is still in the early stages. Such applications include architectural cladding, artificial rock features for gardens, permanent shuttering (for both beams and columns, and which ensures there is no blistering or honeycombing).

The next step in the further development of this NEW material, is its long-term durability and environmental performance, and to this end an extensive testing programme has been initiated to investigate these aspects of textile concrete, including wet/dry and hot/cold cycling and environmental effects. In particular the fibre, in both its un-welded and ultrasonically welded format is mechanically characterised in tension and flexure, together with single fibre pull out tests to monitor interface bond behaviour.

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1. INTRODUCTION AND BACKGROUND

In view of the low general tensile strength of cement and concrete, the conventional approach has been to provide appropriate reinforcing in regions subject to tensile stresses. Concrete can readily sustain high compressive stresses however, as it is strong in compression. On the macro scale, steel bar reinforcing is used, whereas on the micro scale short fibre composite additions have been employed. The most successful of these latter fibre additions has been asbestos fibres, but it has now been recognised that these pose a serious health hazard [1]. Alternatives have therefore been sought, including glass, steel and polymeric fibre materials, but have themselves associated constraints: of alkali degradation; mixing, workability and placement difficulties; and poor fibre-cement interfacial bonding, respectively [2].

There has also been resistance to change the conventional production process, which in some cases has inhibited alternative fibre development [2,3]. The alternative fibres, however, possess entirely different chemical and mechanical properties from those of asbestos fibres, and their bonding characteristics are of a different nature [3]. Furthermore, it was almost impossible to achieve high fibre volume fractions (in excess of 3%) in efforts to attain the load transfer and required mechanical strength and toughness property performance.

It has been recognised that there is a need for a cement composite with sufficient tensile strength, but high toughness [4]. That is, a composite that exhibits strain hardening after first cracking rather than tension softening, as is most commonly experienced in most low fibre volume strong fibre cement composites [2]. Wang and Li [4] address this issue using locally oiled PVA fibres to reduce fibre cement interfacial bond and make it controllable and refer to it as ‘engineered cement composites, ECC’. With such an approach they have been able to achieve strain hardening characteristics and adequate strengths (~4MPa) and ‘ductile’ strain (~4%), for single fibre pull-out tests.

Similar high toughness results have been achieved by Tait and Guddye, for single fibres [5], as well as Taylor et al [6] and Akers et al [3] for laminated composites, using polypropylene (PP) fibres. Although PP fibres do not normally bond very well in cement composites, the approach taken here has been to use a fibrillated form of the PP fibre as a core. To this core an outer “fluffy” or “hairy” layer has been spun, which is furthermore intermittently ultrasonically welded to the fibrillated core to provide a substantial *mechanical* bond with the cement matrix. This modified ‘fibre provides the basis for achieving sufficient strength but very good and controlled bonding and fibre pull–out [5]. This fibre can then be woven into a matrix cloth or bonded to other materials to provide the desired properties. It can also be placed in the cement composite in the appropriate location and orientation, for optimum performance and with very high fibre volume fractions (in excess of 10%).

The performance of composite materials depends largely on the efficiency of the fibre matrix bonding and its ability to transfer load, therefore a key concern is its long term durability and ageing performance, and how this changes with ageing and environmental factors. In this project an attempt is made to address the preliminary stages of this by undertaking firstly, a mechanical characterisation of the properties of the composite, and secondly an evaluation of how these characteristics change with accelerated ageing, as well as from the effects of fatigue and creep.

2. EXPERIMENTAL DETAILS AND INITIAL RESULTS

To study the properties of textile concrete as a function of accelerated ageing, it was first in order to develop an appropriate characterisation of the constituents as well as a representative mix design. The mix needed to be such that self compaction was achievable, together with good mechanical properties, while at the same time striving to be not too exotic or far from ‘normal’ practice. Mechanical properties of the mix and fibres were first characterised and then tests undertaken to evaluate single fibre pull out. This was followed by mechanical strength tests of textile concrete laminates, initially in bending, but also in tension, as this type of testing was regarded as providing more information about the fibre interface mechanical bonding. This would then set the base line and benchmark for subsequent similar tests when specimens had been subject to various regimes of accelerated ageing and environmental degradation, involving hot and cold temperature, as well as wet dry excursions, which may adversely affect interfacial bond.

To achieve an appropriate mix, coarse aggregate was avoided, and a fine aggregate up to 600 μm, fineness modulus of 1.8 and controlled moisture content was employed. Nine mixes were considered, which had the requirements to be self-compacting, with a minimum setting time of two hours, and with a minimum of segregation and bleeding. Sand/binder ratios between 0.8 and 1.2 were considered, with a nominal water/binder ration of 0.5, and varying amounts of ‘superpozz’ plasticizer to assist in achieving flow. A Hobart A 120 mechanical mixer was employed and mixing undertaken for two minutes, and the flow characteristics determined using an ASTM jolting table (ASTM C-124-39/SABS 1245:1994). This entailed the mix being placed via a cone onto the jolting table at certain specified times after mixing, and its flow characteristics (diameter as a function of jolt impacts) being determined. Curing typically entailed wet curing for 1-2 days then stripping, followed by 28-day cure at 55-60% humidity and 23°C in an environmentally controlled room. From this, and allied 50mm cube tests, two mix types were selected for subsequent study. The 28 day mortar cube strength of such mixes was typically 28 to 35 MPa.

The mechanical testing comprised three principal test types, (a) single fibre tensile pull-out, and laminates testing in (b) bending and (c) tension. The single fibre pull out tests were based on the ASTM tensile test method for cement paste [7], together with developments by Currie and Gardiner [8] and Tait et al [5], in which a figure of eight type specimen was used, Fig 1. This configuration is unique in that it does not apply any significant loading to the fibre (by compression) which can be a difficulty in other (compression) pull out tests. This system is acknowledged (for example by Li [9]) to simulate the fibre bridging pull out behaviour of cement composites and is aptly used in the study of fibre matrix bond behaviour, whose characteristics strongly influence the mechanical properties of the composite.

Nominal single fibre specimens were cast into such figure of eight specimens by first filling the mould to mid depth and then locating the fibre longitudinally in the mould. Location was facilitated through two pieces of acetate sheet, to hold the fibre in place, and then additional mortar inserted up to full mould depth, followed by conventional vibration and curing. Prior to tensile testing these acetate sheets facilitated tensile strength evaluation of the fibre pull out itself, without being masked by any tensile bond strength of the paste. The tests were conducted on a Zwick tensile testing machine and the load deflection traces exhibited post peak load ‘ductility’, Figs 2, 3.

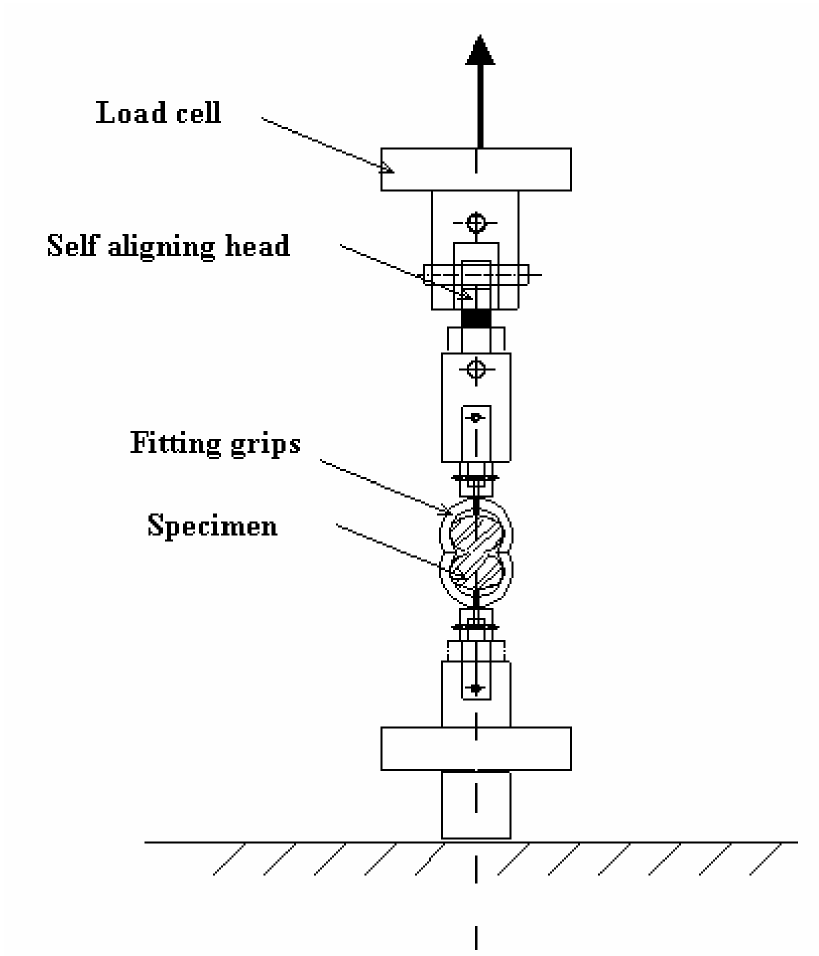

Figure 1. Schematic of the “figure of eight” single fibre pull out test system.

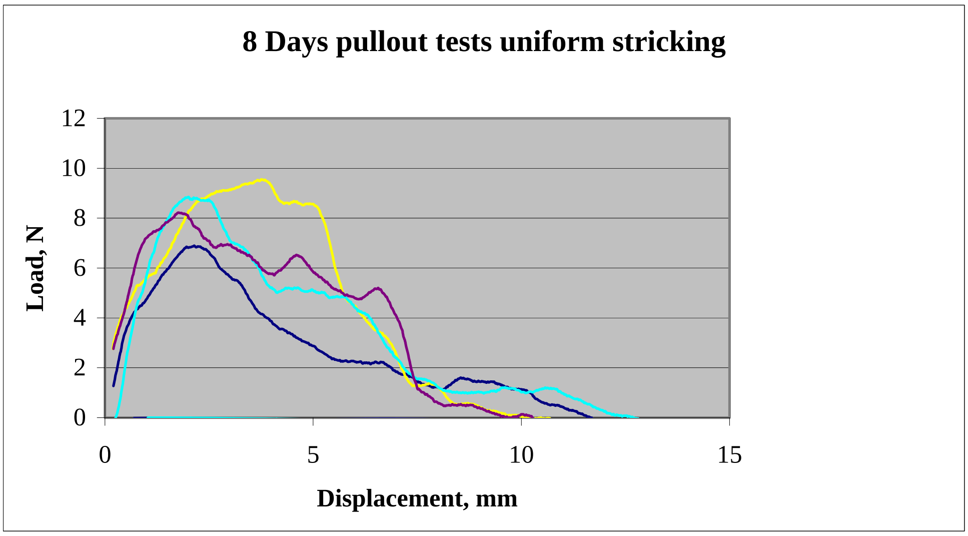

Figure 2. Single fibre pull out test results showing some post peak load ductility.

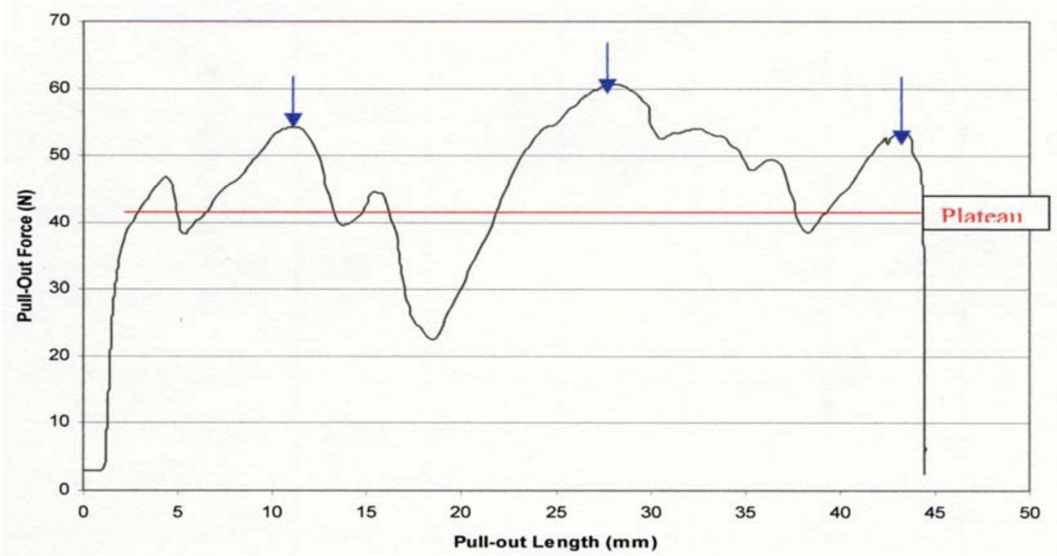

Figure 3. Fibre pull out tests at 28 days showing substantial post peak 'ductility'.

The laminated textile concrete was laid up by hand, for both flexural (bend) specimens as well as tensile 'dog bone' type specimens, with between two and six layers of textile fabric and then pressure compacted and cured conventionally, (some specimens were also steam cured for comparison). The test method was based on ASTM standards, in both tension and bending, and preliminary tensile testing utilised cross-head displacement as a measure of deflection, whereas future testing will use a conventional extensometer mounted on the gauge section of the tensile specimen. The tensile specimens were of two types, either 200 or 300mm long and 6-8mm thick, with the flexural tests 280 x 80 x 10 (or12) mm thick. The results of, not only the flexural tests, Fig 4, but also the tensile tests, Fig 5, exhibited extensive non-linear behaviour. Concrete in tension normally manifests 'elastic-brittle' behaviour, and with the addition of this textile fabric in relatively high volume fractions, effectively ductile behaviour is obtained, as can be seen from the load deflection traces. The flexural behaviour of the materials tested in this preliminary phase indicated a load deflection characteristic, which was typified by strain hardening, and a kind of plateau portion of the load deflection curve. After an initial linear elastic load characteristic to first cracking (at typically 2 to 3 MPa), the subsequent load deflection behaviour exhibited a steady increase.

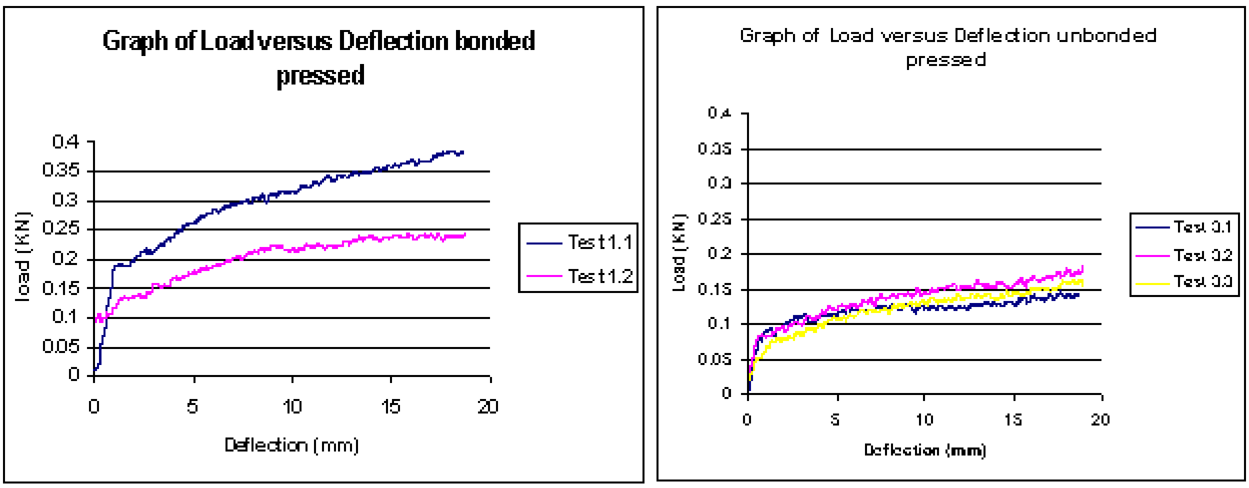

Figure 4. Load deflection tests for flexural tests on laminate textile concrete, that had been pressed for (a) ultrasonically bonded, and (b) non bonded fibre material.

This steady increase is contrast to load softening behaviour, which is so frequently encountered in cement composites. . Allied to this was multiple cracking behaviour of the flexural specimens, at a crack spacing of typically 10 –14mm (rather than a single major crack, as occurs with load softening). Fig 4(b) shows the load deflection behaviour of three specimens for which the fibres were not ultrasonically welded, but which had also been pressed to consolidate the composite. The traces are all very similar which indicate consistency and repeatability, and a plateau load region of approximately 0.09 to 0.16kN (corresponding to stresses of approximately 3 to 5 MPa). For similar composite material samples for which the fibre was ultrasonically welded, Figure 4(a), there is a similar consistency and strain hardening behaviour. The loads achieved are now higher (0.15–0.35kN, however, corresponding to plateau stresses of approximately 3 – 7 MPa), consistent with the fluffy outer region having been welded to the inner fibril core, providing greater strength and toughness.

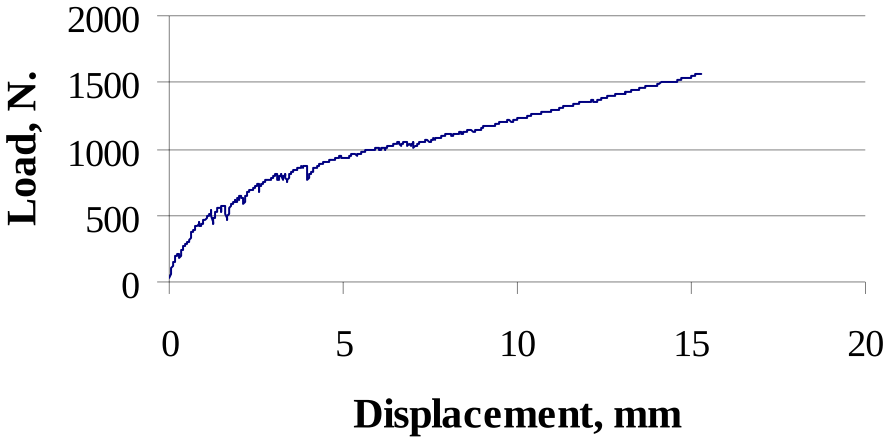

Figure 5. Load deflection plot from a tensile test of laminate plate, again exhibiting non-linear behaviour and significant ductility.

This strain hardening load deflection characteristic, (Figures 4 and 5) are exactly of the form suggested as an essential requirement by Wang and Li for Engineered Composite Concrete, (ECC) [4], but as achieved for a whole laminate form. Thus it is apparent that this textile concrete has substantial effective toughness, which facilitates its use in practical, readily handled structures, such as form-work and permanent shuttering.

3. FUTURE DEVELOPMENTS

The next step in the further development of textile concrete is to assess its long term durability and environmental performance, and to this end an extensive environmental and ageing testing programme has been initiated to investigate these aspects of textile concrete. The aim is to evaluate the ageing effect of environment on the mechanical properties as manifested by the fibre pullout, tensile and flexural strength behaviour. It is not feasible to wait several years for this to occur naturally, so an accelerated ageing/weathering programme is under development which will expose specimens to cyclic wetting and drying, as well as hot and cold temperature exposure regimes. Parallel examination of fibre interfaces through microscopy is also envisaged to try to contribute to the understanding of the microstructural behaviour. A dedicated automated accelerated ageing facility has been developed, as shown in Fig. 6, which combines heating and drying (using a halogen globe heating system, together with water cooling (but not wetting)). An adjacent chamber facilitates wetting and drying ageing (nominally at constant temperature, using a vacuum pump system to accelerate drying). The whole system is controlled on PLC and relay systems and runs automatically with a cycle time, which is still being refined (depending on the drying) of about four hours. In this way accelerated ageing is used in an attempt to understand the mechanisms of degradation and ageing on the interfacial bonding of textile concrete, and its effect on structural performance.

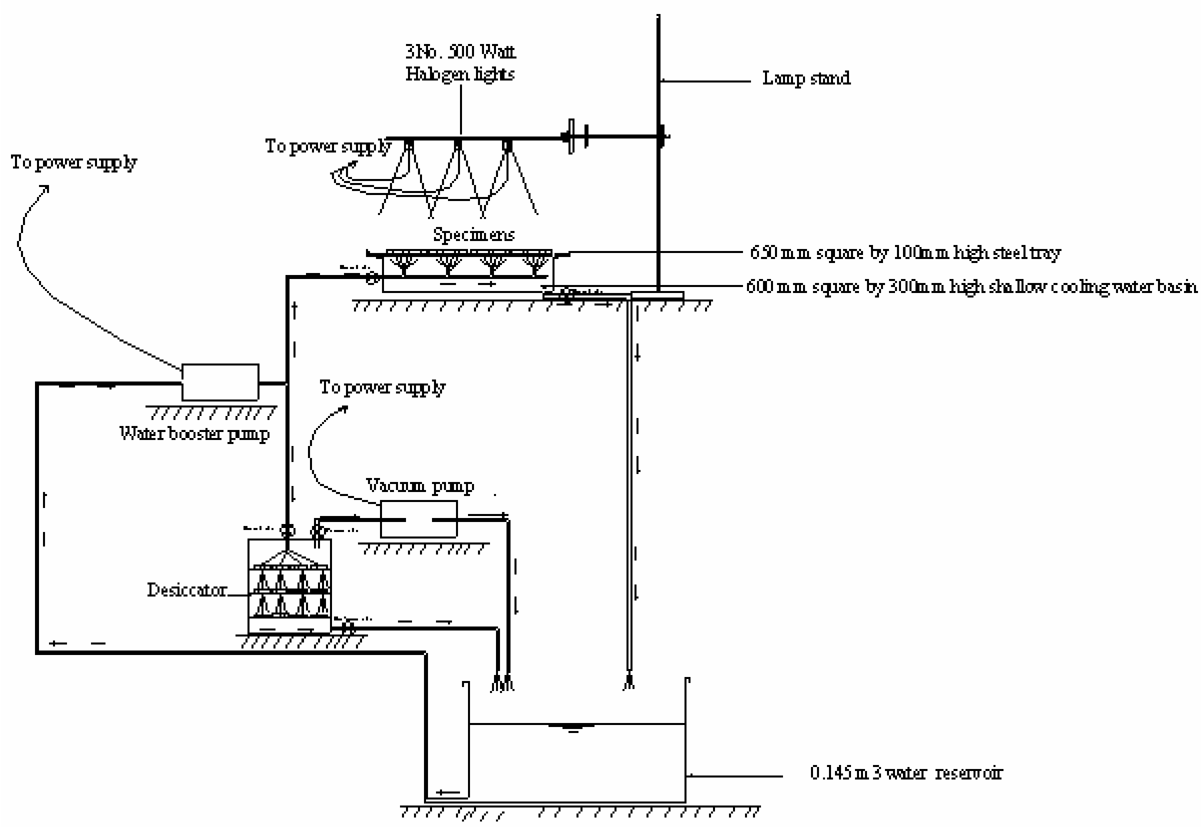

Figure 6. Automated environmental test facility combing wetting and drying with hot cold exposure for textile concrete samples.

Although these environmental ageing tests are still in the preliminary stage, this textile concrete has already found a number of industrial applications in the following forms: structural members for concrete placement, permanent shuttering (including columns, beams and large but lightweight waffle construction), artificial rocks and garden furniture, architectural features including cladding of buildings, ecological habitats for fish, protective road linings, waterproof members for reservoirs and ditches, and many more. In this regard, although the study is still somewhat preliminary, it is believed that textile concrete has a promising future and will develop, in the theme of the conference, to serve a myriad of practical needs.

4. REFERENCES

[1] Takahashi, K, Case, BW, Dufresne, A, Fraser, R, Higashi, T, and Siemiatycki, J. Relation between lung asbestos fibre burden and exposure indices based on job History. **Occupational and Environmental Medicine**, Vol.51, 1994, pp.461-469.

[2] Hannant, DJ. **Fibre Cements and Fibre Concrete**. John Wiley, 1978, pp. 56-139.

[3] Akers, SAS, Tait, RB, and Hourahane, D. Non-woven textile reinforced composite concrete. **Fibre society conference, "Engineering with Fibres**," Ed. Acar, M, Loughborough, 2003, pp.75-76.

[4] Wang, S and Li, VC. Tailoring of PVA fibre/matrix interface for engineered cementitious composites *(ECC).* **Fibre society conference, "Engineering with Fibres,"** Ed. Acar, M, Loughborough, July, 2003, pp.91-92.

[5] Tait, RB, and Guddye, C. Textile concrete – mechanical characterisation of a unique fibre system for cement composites*.* **Concrete for 21st Century conference**, Johannesburg, March 13-14, 2002.

[6] Taylor, PC, Mostert, HF, Hourahane, D. The evolution of cellular cement mortar fibre and fabric for reinforced precasts in South Africa*.* **ACI Spring Conference**, Seattle, April 1997.

[7] ASTM C190-85, Standard test method for **Tensile Strength of Hydraulic Cement Paste**, 1985.

[8] Currie B and Gardiner T, "Bond between polypropylene fibres and cement matrix", **Int. J of Cement Composites and Lightweight Aggregate**, Vol. 11, No.1 1981.

[9] Li V C, "Engineered Cementitious Composites", in **Fibre Reinforced Concrete- Present and Future**, edited by N Banthia, A Bentur and A Mufti, Canadian Society of Civil Engineers, Montreal 1998, pp 64-97.

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Biography

Prof Robert B Tait

Bob Tait is a Professor in the Mechanical Engineering Department of the University of Cape Town. He obtained his education at Oxford University (as a Rhodes scholar), and UCT, with a first class Honours BSc Engineering degree, and Ph.D. in the field of Fatigue and Fracture Mechanics. Prof. Tait is a specialist in the field of fracture mechanics and fatigue, covering both metals and alloys, as well as brittle non-metallic materials and composites, and fatigue in cementitious systems. His other research interests include NDT and residual stress, and he works closely with industry, in the application of fracture mechanics and failure analysis to industrial problems. He is co-author of a book on *Fracture Mechanics*, and is on the editorial board of the International Journal *Engineering Failure Analysis,* as well as the author of numerous papers. He is a registered Professional Engineer, and currently immediate past national president of SAIMechE.