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Sustainability of Construction with Textile Reinforced Concrete- A State of the Art

Anjana Elsa Alexander^{1*} and A P Shashikala²

¹ Research Scholar, Department of Civil Engineering, National Institute of Technology Calicut, India

² Professor, Department of Civil Engineering, National Institute of Technology Calicut, India

*anjanaelsaalexander@gmail.com

Abstract. Steel reinforcement in reinforced concrete structure is prone to corrosion. It has been found that a sustainable building material that can be used to replace steel from the construction industry is textile reinforcement. Textiles of high strength and fine-grained mortar are used to make a composite material termed as Textile Reinforced Concrete (TRC). This review paper presents an evaluation of different textiles that can be used as reinforcement in TRC, their bonding behaviour, durability characteristics and applications. A comprehensive overview on TRC reveals that TRC has excellent mechanical properties and durability characteristics. TRC is applicable for constructing lightweight, thin structural elements and for strengthening or repair of damaged structural elements.

1. Introduction

Steel has been used in concrete as reinforcement for over 100 years. But steel reinforcement is prone to corrosion reducing the effective cross-sectional area of bar resulting in spalling of the concrete leading to structural failure in extreme cases. Gries T et al., 2015 [1] have shown that “durability and reliability of structures can be increased by replacing steel reinforcement by textile reinforcement”. Textile Reinforced Concrete (TRC) consist of fine-grained mortar and high strength textile fabrics. Textiles are multifilament yarns having high tensile strength usually made of carbon (Figure 1 a), basalt, alkali-resistant (AR) glass or polymer materials. Maximum size of aggregate used in TRC depends on the yarn distance and dimensions of the structural elements. Usually, aggregate used in TRC has less than 2mm size. High tensile strength, pseudo ductile behaviour and corrosion resistance are the major advantages of TRC. Also, TRC has excellent mechanical properties and durability characteristics which make this composite applicable for the construction of lightweight structural elements (Figure 1 b)) and for repair and rehabilitation of old structural elements [2].



Figure 1. (a) Carbon textile (b) Formwork element made of TRC [3].



2. Sustainability aspects of construction with TRC

In the modern era, new technologies to provide sustainability are becoming a major driving force for innovation in the construction industry. The sustainability qualities offered by TRC spans over a wide range:

- a) Potential for making components with considerably smaller amount of material.
- b) Longer service life than conventional concrete.
- c) To extend the life-span of existing structures that are undergoing deterioration or need upgrading of their mechanical performance to withstand higher static and dynamic loads.

3. Fibre reinforcements

Fibres such as carbon, AR glass, basalt or aramid are commonly used in the manufacturing of textile materials. These fibres have very high mechanical properties compared to metals. Properties of those selected fibres are given in table 1 and described below [4]. In general, textile reinforcements are available in woven, nonwoven or knitted forms [5]. Dimensional characteristics of these textile reinforcements can be given in the form of planar (2D) or spacer (3D). Spacer reinforcements withstand loads within a volume.

Table 1. Fibre properties [4].

Fibre	Tensile Strength in MPa	Modulus of elasticity in GPa	Ultimate Strain (%)	Density (g/cm ³)
Glass (AR)	2500	70	3.6	2.78
Carbon	3500-6000	230-600	1.5-2.0	1.60-1.95
Aramid	3000	60-130	2.1-4.0	1.4
Basalt	3000-4840	79.3-93.1	3.1	2.7
Steel	1200	200	3-4	7.85

3.1. Glass

The basic ingredient is silica (SiO₂), and other oxides are added to modify the three-dimensional network structure. Glass fibres are amorphous and isotropic. The most economical and widely used glass fibres are E-glass (high electrical resistivity). However, in an alkaline environment, the sensitivity of E-glass fibres is quite higher. Alkali-resistance to glass fibre can be provided by adding 15 percentage of zirconia (ZrO₂). Presently, AR glass filaments are widely used in TRC applications because of their good adhesion properties in cement matrices and are economical in nature [4].

3.2. Carbon

Carbon fibres are commercially available as continuous tow and chopped (6–50 mm long) fibres. Continuous carbon yarns contain numerous (~10,000) filaments with diameters of 7–15 µm. These filaments exhibit high resistance to acid and alkaline environments and to organic solvents while their adhesion to cement-based material is not as good as that of AR glass [4].

3.3. Aramid

Aramid fibres are highly crystalline aromatic polyamide fibres. In contrast to glass and carbon, aramid filaments fracture in a ductile manner with considerable necking and fibrillation. This property is considered beneficial for impact or dynamic loading applications [6]. Aramid fibres are unaffected by temperature up to 160°C, but the filament is likely to lose most of its strength above 300°C. Aramid fibres absorb moisture and exhibit internal cracking and longitudinal splitting at increased moisture content, but the effect of moisture on fibre tensile properties are minimum. Also, aramid fibres are sensitive to ultraviolet light. Thousands of filaments bundled together comprise an aramid yarn, each 10–15 µm in diameter.

3.4. Basalt

Basalt fibres exhibit increased modulus of elasticity and strength, high temperature (1,100°C–1,200°C) and corrosion resistance [7][8]. Basalt fibres have strength higher than that of glass fibre and cost almost similar to glass fibre. It has good resistance to the alkaline environment (pH 13 or 14) but relatively less stable in strong acid.

4. Matrix composition

Considering the necessities of workability, durability and adequate bonding, a cement-based matrix for the TRC production have been developed. High binder content (40–50% by volume) of the matrix helps to achieve sufficient bonding with the filaments of the textile reinforcement. The maximum aggregate size is determined based on yarn distance, the spacing between textile layers and the dimensions of the structural elements. Typically, the aggregate size used ranges between 1 and 2 mm [9]. The advantage of using cement-based matrix in TRC is that it prevents a catastrophic failure because the cement matrix cracks much before the full potential of fabric is utilised [5].

Protecting RC structures against corrosion are achieved to an extent by the alkaline matrix of concrete, but in case of fibres, it will result in a very aggressive environment [10][11][12][13]. Hence, to develop a new matrix with improved energy, lower CO₂ emission, high durability and optimal bonding to reinforcement are essential for sustainability. This can be achieved either by using

- Mineral Additives - lower energy consumption and CO₂ emission.
- Alternative Cements- evaluating the use of alternative cements like High-alumina cements, Calcium aluminate cement, Inorganic phosphate cements or Geopolymers.
- Polymer-modified cement-based systems- adding polymers help in modifying the properties of the fine-grained concrete [14].

5. Bonding in TRC

Strength, ductility and toughness of the composite are largely influenced by the textile-matrix bond [15]. Strong bonding results in a composite with high strength and low ductility, which may lead to brittle failure; whereas weak bonding shows a more ductile behaviour causing fibre pull-out. The bond between the cement matrix and fibre is strongly influenced by the elastic nature of fibre [5][16]. By increasing modulus of elasticity of fibre the clamping stresses that develop around the fibre increases, which in turn increases the bond strength of fibre [17] as shown in figure 2. Fabric geometries and anchoring of fabrics play an important role in increasing bonding with the cement matrix in TRC composites [18].

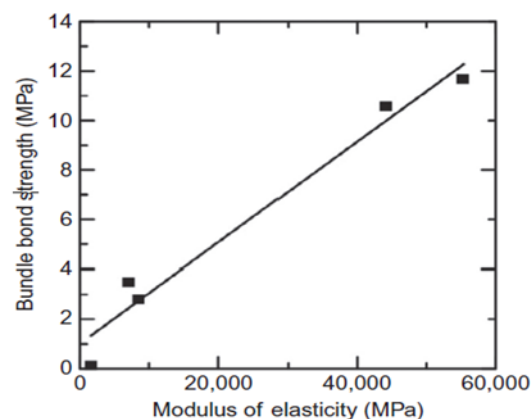


Figure 2. Graph showing variation of modulus of elasticity on the bond strength of yarn.

5.1. Bonding mechanism: Telescopic pull-out

In TRC, hundreds or thousands of multifilament yarns (rovings) bundle together to form a fabric. But using this fabric in the cementitious matrix is challenging, as large cement particles of about 5-70 μm cannot completely penetrate the gaps between the internal filaments of fabric ($<5 \mu\text{m}$). As a result, external filaments of yarns have direct contact with the cementitious matrix whereas the inner filaments

(core) have no contact with the hydration product resulting in a unique microstructure as shown in figure 3 (a & b). Thus, external filaments have better bonding with matrix [15][19][20][21][22].

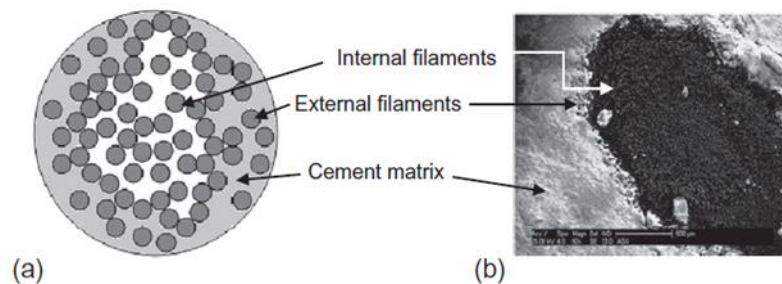


Figure 3. (a) Cross-section of cementitious matrix comprising of yarn (b) its actual view [15][22].

During loading, these external filaments become fractured. After they fail, the internal filaments slip against the external filaments resulting in a telescopic pull-out form as in figure 4 [21]. So, these core filaments are considered as wasted. When the tensile behaviour of carbon fabric in the cement matrix and fabric itself is compared, effective use of the internal filament is not achieved due to low cement penetration as depicted in figure 5 [22].

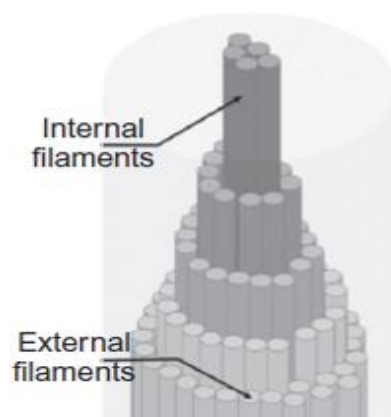


Figure 4. Pull-out behaviour of a fabric yarn [21].

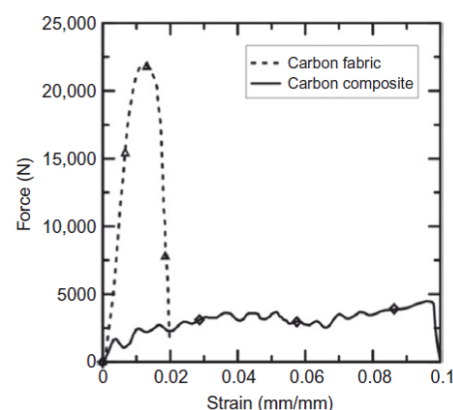


Figure 5. Tensile behaviour of carbon fabric in cement matrix and fabric itself [22].

5.2. Bond improvement

Filling the spaces between bundles inner filament can improve the stress transfer between them. Several researchers have examined the effect of polymer coating and bundle gaps filling. Xu et al. (2004) [23] observed that fabrics coated with epoxy exhibit enhanced bond strength and stiffness when compared to uncoated bundle filaments. This was observed for AR glass, carbon and aramid textiles and also for epoxy impregnated prestressed yarns. Good mechanical performance and penetrability were seen for polymer fillers in carbon fabrics. But they are affected at high temperature. To overcome these limitations, the use of nanoparticles to fill these gaps have been studied by few researchers. Bentur et al., 2010 [4] and Cohen and Peled, 2010 [21] compared mineral nanoparticles and polymer-based coating to evaluate the performance of AR glass and carbon fabric. Improved tensile strength, strong bonding and good filling were shown by mineral filler composites.

6. Durability

6.1. Durability of matrix

Durability of the TRC matrix may get affected by frost action, chemical attack or by abrasion. Deterioration of the composite can be hindered to some extent by adding short fibres in TRC [24].

6.2. Durability of textile fibre

In the manufacture of TRC, carbon, AR glass and basalt textiles are commonly used. Carbon fibre has high resistance to chemical attack. Compared to conventional glass fibre, AR glass fibre shows increased resistance to alkaline environments. But with increasing temperature and pH value of matrix, corrosion damage of AR-glass fibre occurs (Yilmaz and Glasser, 1991). But to a large extent such damages can be delayed by applying organic polymer size to the glass filament surfaces during its production. Butler et al. (2009) [12] concluded that if the organic polymer size is removed largely at some areas of filament then due to stress concentration, this nanoscopic defect becomes an important cause for damage. However, this failure of individual filament will be compensated in case of multifilament yarns in TRC due to redistribution of the load to the neighbouring filaments. Basalt fibres have low cost, temperature resistance and are available locally but it has reduced load-bearing capacity due to corrosive nature of fibre in an alkaline environment [25][10]. Generally, basalt fibre has low resistance to the alkaline environment compared to AR-glass fibre, however much better compared to E-glass fibre. Moreover, by adding zirconia to basalt fibre, its alkali resistance can be improved [26].

7. Fire resistance

Tanano et al., 1999 [27] stated that “Material used for building construction should have resistance to initial fire (flammability) and smoke and gas-generating properties”.

7.1. Fibre response

At high temperature, the thermomechanical properties of commonly used fibres differ. Above 400–500°C temperature, carbon fibres start to oxidise while aramid fibres tend to oxidise above 150°C, limiting their use. In the case of glass fibres, oxidation will not happen but when reaching 600–800°C they start softening [4]. Carbon-fibre textiles, compared to AR-glass textiles shows superior performance at high temperature [28][29][30].

7.2. Fire resistance of TRC

Antons et al. (2012) [31] conducted flexural tests on heated prisms loaded with 30, 50 and 80 percent of its ultimate flexural capacity. They concluded that below 300°C, the temperature has no clear impact on the load levels considered; between 300°C and 600°C, as load is increased there is a negative influence of temperature; and beyond 620°C for any load level, melting of AR glass fibre was observed causing sudden failure.

8. Applications of TRC

Highly-finished surface, minimised product thickness, possibilities of freeform architecture, increased mechanical and durability characteristics are the advantages of TRC technology. TRC finds applications in making precast structural elements and in repair and rehabilitation of reinforced structures.

8.1. TRC in precast industry

Prefabricated TRC products are used for both architectural and structural elements due to less concrete consumption; minimised production, transportation and erection costs; and less wastage. Hegger et al., 2015 [32] reported the use of textiles like AR glass or carbon for facade construction. Engberts, 2006 [33] also reported the usage of a combination of continuous AR-glass yarns and fibre meshes embedded in a self-compacting fibre-reinforced micro concrete for the construction of larger ventilated facade elements (4–7 m²). TRC was used in precast pedestrian bridges. The bridge built in Oschatz, Germany was the first TRC Bridge having a span of 8.6 m. AR glass yarns woven into mats was used as reinforcement inserted in four layers in fine concrete. The textile reinforcement helped to reduce the crack width as it served as minimum reinforcement. Then, a 17-m long TRC bridge in Kempten, Germany, was built. Vehicles weighing 3.5 t were allowed on it. To account for this load to the superstructure, additional crossbeams have been added. In 2010, the longest TRC Bridge in the world was constructed in Albstadt, Germany with 97 m length. Alkali resistant glass textile was used as reinforcement [34]. Prefabricated garages composed of a ceiling of TRC was widely used as transportation costs for the lighter TRC parts are very low. AR glass fibres impregnated with epoxy resin have been used as textile reinforcement. Freeform structural members are becoming the most

remarkable trends in modern architecture. Pavilion building is an example for freeform construction, RWTH Aachen University [35]. Hybrid pipes consisting of an outer TRC ring enveloping an inner polymer tube have been developed to meet the water supply and sewage disposal needs [36]. Another application of TRC is in noise barrier parapets production. Further TRC can be used in the manufacture of handmade furniture, sculptures, ornaments and small boats.

8.2. TRC in repair and rehabilitation of reinforced concrete structures

Textile reinforced mortar (TRM) was used for flexural strengthening and shear strengthening of damaged RC beams and slabs[37][38]. TRM jackets also help in bridging shear cracks. When TRM jackets are provided by fully wrapping the cross-section of RC members, they give maximum shear enhancement (Figure 6 a). Open TRM systems are also effective but proper anchorage should be provided (Figure 6 b).

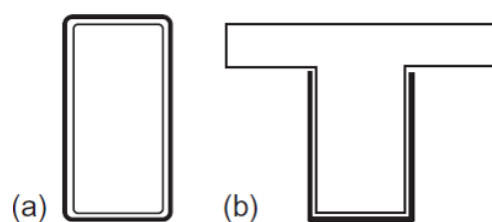


Figure 6. Shear strengthening of RC elements (a) Fully wrapped, (b) three-side wrapped [4].

9. Further scope of the research

Future research directions could be related to the following

- Bonding of various types of textile fibres at high temperature to the cementitious matrix are not studied.
- Application of TRC in thin structural elements is mentioned in most of the literature. But its behaviour in large structural elements is not presented.
- The behaviour of TRC in various types of high strength inorganic matrix such as ultra-high performance concrete, self-compacting concrete are not studied.

10. Conclusions

In this review paper, fibres such as glass, carbon, aramid, and basalt are examined for their applicability in TRC. Carbon fibres are inert and compared to other fibres has superior characteristics in terms of tensile strength and modulus of elasticity. But carbon has high cost. Alkali Resistant glass is found to be the most cost-effective and gives satisfactory results in terms of tensile strength. Improved tensile properties, good filling in between bundles and strong bonding are observed for matrix with mineral filler composite.

As TRC has advantages like thin size, good load-bearing capacity, resistance to corrosion, excellent ductility, no magnetic disturbances and lightweight of components, it is now widely used for various applications including precast constructions, repair, rehabilitation and structural strengthening of existing structures. With TRC it possible to produce lightweight members which save up to 80 % of concrete thereby reducing 80% of transportation costs and hence a sustainable material for the construction industry.

11. References

- [1] Stolyarov O, Quadflieg T and Gries T 2015 Effects of fabric structures on the tensile properties of warp-knitted fabrics used as concrete reinforcements *Textile research journal* **85** 1934–45
- [2] Lieboldt M, Butler M and Mechtcherine V 2008 Application of textile reinforced concrete (TRC) in prefabrication In: Gettu, R. (Ed.) *7th Int. RILEM Symp. on Fibre Reinforced Concrete: Design and Applications*. RILEM Publications S.A.R.L pp 253–62

- [3] Hegger J, Aldea C, Brameshuber W and Curbach M 2006 Applications of textile reinforced concrete *Brameshuber, W.(edited) State-of-the-Art Report of Rilem Technical Committee* pp 237–66
- [4] Peled A, Bentur A and Mobasher B 2017 *Textile reinforced concrete* (CRC Press)
- [5] Peled A and Bentur A 2003 Fabric structure and its reinforcing efficiency in textile reinforced cement composites *Composites Part A: Applied Science and Manufacturing* **34**(2) 107–18
- [6] Mallick P K 2007 *Fiber-reinforced composites: materials, manufacturing, and design* (CRC press)
- [7] Artemenko S E 2003 Polymer composite materials made from carbon, basalt and glass fibers - structure and properties *Fiber Chemistry* **35**(3) 226–9
- [8] Militky J K and Kovacic V 1996 Ultimate mechanical properties of basalt filaments *Textile Research Journal* **66**(4) 225–9
- [9] Triantafillou T 2016 *Textile fibre composites in civil engineering* (Woodhead Publishing)
- [10] Scheffler C, Forster T, Mader E, Heinrich G, Hempel S and Mechtcherine V 2009 Aging of alkali-resistant glass and basalt fibers in alkaline solutions: Evaluation of the failure stress by Weibull distribution function *Journal of Non-Crystalline Solids* **355** 2588–95
- [11] Scheffler C, Gao SL, Plonka R, Mader E, Hempel S, Butler M and Mechtcherine V 2009 Interphase modification of alkali-resistant glass fibres and carbon fibres for textile reinforced concrete I: Fibre properties and durability *Composites Science and Technology* **69** 531–8
- [12] Butler M, Mechtcherine V and Hempel S 2009 Experimental investigations on the durability of fibre–matrix interfaces in textile-reinforced concrete. *Cement and Concrete Composites* **31**(4) 221–31
- [13] Hempel S, Butler M and Mechtcherine V 2015 Bond behaviour and durability of basalt fibres in cementitious matrices *In 3rd ICTR Int. Conf. on Textile Reinforced Concrete, ed Brameshuber W* (Aachen, Germany) pp 225–33
- [14] Mechtcherine V and Lieboldt M 2011 Permeation of water and gases through cracked textile reinforced concrete *Cement and Concrete Composites* **33**(7) 725–34.
- [15] Brameshuber W 2006 *Textile Reinforced Concrete: State of the Art Report (RILEM TC-201-TRC, Report 36)* (Aachen/ RILEM Publications)
- [16] Peled A and Bentur A 2000 Geometrical characteristics and efficiency of textile fabrics for reinforcing cement composites *Cement and concrete research* **30**(5) 781–90
- [17] Stang H 1996 Significance of shrinkage-induced clamping pressure in fiber-matrix bonding in cementitious composite materials *Advanced Cement Based Materials* **4** 106–15
- [18] Peled A and Bentur A 1998 Reinforcement of cementitious matrices by warp knitted fabrics *Materials and structures* **31**(8) 543–50
- [19] Bartos P 1980 Analysis of pull-out tests on fibres embedded in brittle matrices *Journal of Materials Science* **15**(12) 3122–8
- [20] Zhu D, Mobasher B and Peled A 2013 Experimental study of dynamic behaviour of cement-based composites *Journal of Sustainable Cement-Based Materials* **2**(1) 1–2
- [21] Cohen Z and Peled A 2010 Controlled telescopic reinforcement system of fabric cement composites durability concerns *Cement and Concrete Research* **40**(10) 1495–506.
- [22] Zhu D, Peled A and Mobasher B 2011 Dynamic tensile testing of fabric cement composites *Construction and Building Materials* **25**(1) 385–95
- [23] Xu S, Krüger M, Reinhardt H W and Ozbolt J 2004 Bond characteristics of carbon, alkali resistant glass, and aramid textiles in mortar *Journal of materials in civil engineering* **16**(4) 356–64
- [24] Barhum R and Mechtcherine V 2013 Influence of short dispersed and short integral glass fibres on the mechanical behaviour of textile-reinforced concrete *Materials and structures* **46**(4) 557–72
- [25] Sim J and Park C 2005 Characteristics of basalt fiber as a strengthening material for concrete structures *Composites Part B: Engineering* **36** 504–12
- [26] Rybin V A, Utkin A V and Baklanova N I 2013 Alkali resistance, microstructural and mechanical performance of zirconia-coated basalt fibers *Cement and Concrete Research* **53** 1–8

- [27] Tanano H, Masuda Y and Tomosawa F 1999 Characteristics and performance evaluation methods of continuous fiber bars-State of the art studies on fire properties and durability of continuous fiber reinforced concrete in Japan *American Concrete Institute* **188** 523–34
- [28] Kruger M and Reinhardt H W 2006 Composite materials-6.4, Fire resistance *Textile reinforced concrete—State-of-the-art report of RILEM TC 201-TRC* (RILEM Publications S.A.R.L. France) pp 211–9
- [29] Buttner T, Orlowsky J and Raupach M 2007 Fire resistance tests of textile reinforced concrete under static loading-results and future developments *In Fifth Int. Workshop on High Performance Fiber Reinforced Cement Composites (HPFRCC 5)* (Mainz, Germany) pp 10-13
- [30] Reinhardt HW, Kruger M, Raupach M and Orlowsky J 2008 Behavior of textile-reinforced concrete in fire *American Concrete Institute* **250** 99–110
- [31] Antons U, Hegger J, Kulas C and Raupach M 2012 High-temperature tests on concrete specimens reinforced with alkali-resistant glass rovings under bending loads *In Proc. of the 6th Int. Conf. on FRP Composites in Civil Engineering* (Rome, Italy) pp 13–5
- [32] Hegger J, Will N, Chudoba R and Scholzen A 2015 Classification of approaches to dimensioning and assessment of lightweight TRC structures *In FERRO 11–11th Int. Symp. on Ferrocement and 3rd ICTRC-Int. Conf. on Textile Reinforced Concrete* pp 45–50
- [33] Engberts E 2006 Large-size facade Elements of textile reinforced concrete *In ICTRC'2006-1st Int. RILEM Conf. on Textile Reinforced Concrete 2006* (RILEM Publications/SARL) pp 309–318
- [34] Raupach M, Orlowsky J, Büttner T, Diltthey U, Schleser M and Hegger J 2006 Epoxy-impregnated textiles in concrete-load bearing capacity and durability *In ICTRC'2006 1st Int. RILEM Conf. on Textile Reinforced Concrete (RILEM Publications/SARL)* pp 77–88
- [35] Scholzen A, Chudoba R and Hegger J 2015 Thin-walled shell structures made of textile-reinforced concrete: part I: structural design and construction *Structural Concrete* **16(1)** 106–14
- [36] Lieboldt M, Helbig U and Engler T 2006 Textile reinforced concrete multilayer composite pipes *Proceedings of the ICTRC* pp 369–78
- [37] Amir SL, Raphael C, Emmanuel F and Patrice H 2011 Flexural strengthening of reinforced concrete beams with textile reinforced concrete (TRC) *In Advances in FRP Composites in Civil Engineering* (Springer, Berlin, Heidelberg) pp 665–7
- [38] Bruckner A, Ortlepp R and Curbach M 2008 Anchoring of shear strengthening for T-beams made of textile reinforced concrete (TRC) *Materials and Structures* **41(2)** 407–18