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Review on Numerical Modelling Of Textile Reinforced Concrete

Ardra V[1]
[1]*Student, Department of Civil Engineering, M A College of Engineering, m21secm019@mace.ac.in*

Abstract
Sustainable construction practices are gaining importance in modern days which leads to the use of alternative building materials. Textile reinforced concrete (TRC) can be used as it includes environment friendly building materials. TRC consist of fine-grained concrete matrix reinforced by multiaxial, non-corrosive textile fabrics. TRC is sustainable in nature. It develops thin structures and hence consumes less material compared to conventional concrete structures. It can also be used for retrofitting and repair of existing buildings. Due to heterogeneous cross section of fibres, TRC has a complex bond behaviour. The non-linear behaviour of TRC can be simplified by establishing numerical models available in commercial finite element software. The review focuses on developing a 3D finite element model of TRC and investigation of the structural behaviour under uniaxial tensile stress and four-point bending test. The numerical modelling of TRC members is going to be done in different software. The results will be validated and compared with the experimental results.

Keywords: *Textile reinforced concrete, Structural behaviour, Tensile test, Four point Bending test*

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I. INTRODUCTION

The construction industry is in need of sustainable development which requires replacement for conventional construction materials. It has led to the emergence of composite structures and non-traditional materials. Motivated by the desire for filigree and lightweight elements with high durability, textile-reinforced concrete (TRC) has been steadily developed in recent decades, thereby opening up a new field of application for concrete. TRC differs from ordinary steel-reinforced concrete by its more complex structure. The complex behaviour of TRC has become the driving force for the development of analytical models. New technological advances making use of non-traditional types or amounts of material and energy could be used to meet the demand for a sustainable industry [26]. An innovative material which is thought to have emerged from this idea is Textile Reinforced Concrete (TRC).

TRC is a combination of fine-grained concrete and multi-axial textile fabrics, which has been fundamentally researched over the past decade [6]. This composite material has been shown to have the potential to be used to design slender, lightweight, modular and freeform structures, while eliminating the risk of corrosion and providing high strength in compression and also in tension [18]. It has also been proven to be a suitable solution for the strengthening of existing structures [19]. TRC is differentiated from ordinary steel reinforced concrete mainly by its complex heterogeneous structure. A textile reinforcement yarn consists of numerous filaments which inhibit the even penetration of the fine-grained concrete matrix between the filaments. The inner filaments, as a result, have less contact with the fine-grained concrete matrix depending on the size of the fill-in zone [6]. This phenomenon causes the damage localization process to be governed by the bond between the textile mesh and the fine-grained concrete matrix. Accordingly, the complex bond behaviour has become the driving force for developing numerical models in various scales: macro, meso, micro and multi. However, there are difficulties to quantify the bond-slip relationship at different scales; and when incorporated, can become computationally demanding [11].

TRC technology is used in the improvement of the rural and urban areas, so there is a need of the more construction method with affordable cast. The TRC panels are made by the Textile Reinforced Concrete Prototyping Technology (TRCPT) which is light in weight, non-corrosive, durable, and cost-effective.

1.1 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 [4].

1.1 TEXTILE 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. In general, textile reinforcements are available in woven, nonwoven or knitted forms. 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.

1.2.1 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.

1.2.2 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.

1.2.3 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. 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.

1.2.4 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].

II. MATRIX COMPOSITION OF TRC

The cement matrix for TRC comprises binders, fine-grained aggregates, and a low water-to-binder ratio. The parameters to be considered for choosing the binding materials are (i) its high strength, based on the application, (ii) a sufficient bond between the reinforcement and cement matrix, (iii) its workability during fabrication and setting, (iv) its geometrical stability, (v) the production process , and (vi) low shrinkage and creep. Generally a binder content of 40-50% is taken for TRC and the water-binder ratio varies from 0.29 to 0.40. The mortar and the reinforcement will have a better bonding with increase in binder content. The size of rain varies from 1 to 2 mm, depending on the mesh size of the reinforcement used. The common mineral admixtures used are fly ash, micro silica, and metakaolin. The bonding and the mechanical beahaviour of these matrix are highly improved due to their high pozzolanic activity and also smaller size. It also has higher durability since the permeability is lower. Based on the literature, the typical compressive strength used in the cement matrix is 50–60 MPa for structural applications. A higher strength of 120 MPa has also been used for filigree construction and bearing applications in architecture [24].

2.1 BONDING IN TRC

Most studies investigated the bond between TRM and concrete substrate. The bond between carbon TRM and concrete has also been studied by a few researchers, but studies on the bond between glass or steel TRM and concrete are quite limited. The major modes of failure observed in bond tests are (1) slippage of fibres through the mortar; (2) debonding of TRM with part of concrete; (3) debonding of TRM in the concrete–mortar interface; and (4) rupture of TRM. The major cause of failure was due to slippage of the fibres through the mortar. Debonding of TRM strips with part of concrete was also observed in some specimens. For glass TRM jackets, failure was due to rupture of TRM strips. A description of the main parameters investigated is given subsequently. It was observed that ultimate load and bond capacity increased nonlinearly with the bonded length [13].

The compatibility between the textile fibre and the matrix is mainly due to the inherent heterogeneous structure of the textile yarn. This interaction is an important input parameter for the numerical modelling of textile reinforced concrete. Pull out tests have been conducted to find the interaction. With the increase in embedment length, the maximum pull out force and the corresponding deformation was observed to be increased. The scatter of the results evidently increased as the embedment length increased, which could be due to an enlarged potential for bond irregularities along the embedment length. The factors which affect the bond slip function are material properties of concrete matrix, reinforcement geometry and surface, configuration and stiffness of the mesh. The local bond stressslip functions for carbon reinforced TRC were initially calibrated to match the experimental results. From the experimental results, a first estimate of a local bond-slip function was made. It was them given as an input in global analysis. The local bond versus slip was corrected in several steps until reasonable agreement was found on the global level in relation to the TRC component behaviour and is shown in figure 1 [17].

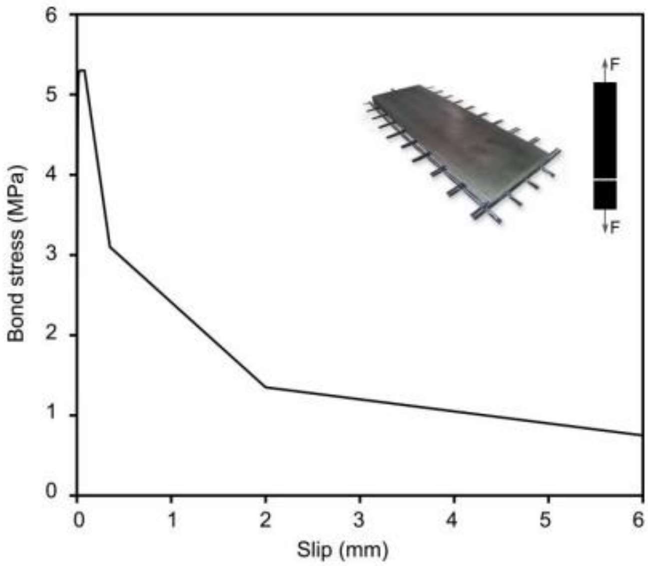

Figure: 1 Calibrated bond-slip curve [17]

2.2 IDEALIZED STRESS-STRAIN RESPONSE

The stress-strain curve will be different for composites containing different textiles and matrix compositions. Thus, an idealized stress-strain curve is proposed. ported in Fig. 1a with a continuous line for comparison. The idealized trilinear stress-strain response should be independent of the test set-up adopted for the tensile test. However, in reality, the specimen morphology, fiber volume fraction in the longitudinal direction, clamping method, and control mode may affect the response.

According to the idealized stress-strain response of Fig. 1a, the material responds in a linear elastic manner while uncracked. This stage, named Stage 1 or uncracked stage, ends with the occurrence of the first crack in the matrix, which is sometimes responsible for a sudden drop in the applied stress. With increasing deformation, further cracks appear along the specimen length and the axial stress does not increase significantly (Stage 2 or crack development stage). When the matrix is unable to form additional cracks (i.e. when matrix crack saturation is achieved) the applied load is sustained solely by the longitudinal (load-aligned) fibers (Stage 3 or post-cracking stage). Therefore, Stage 3 should be characterized by a slope of the stress-strain curve similar to the elastic modulus of the bare (matrix-free) fibers and failure should occur due to fiber rupture.

III. TENSILE BEHAVIOUR OF TRC

3.1 STRAIN HARDENING TENSILE BEHAVIOUR OF TRC

The tensile stress-strain curve of TRCs with sufficient bond between matrix and fibre is a trilinear curve consisting of three stages. The three stages are linear elastic stage, multiple crack stage and failure stage, which is depicted in figure

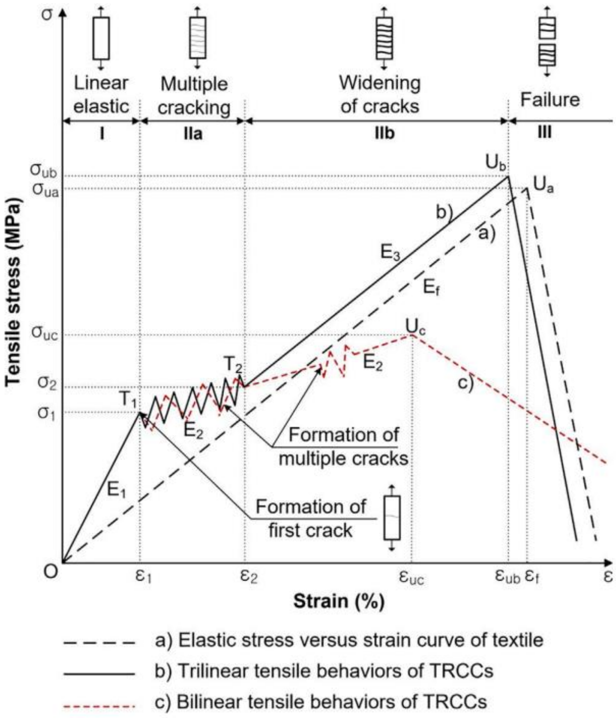

Figure: 2 Schematic representation of a typical tensile behaviour of TRC and Textile

The first stage composes of the uncracked matrix. The stage IIa shows the initial crack due to the transfer of applied load to the textile reinforcement and the generation of multiple cracks. The stage IIb shows the widening of existing crack without further cracks. In this stage, the strength and stiffness is governed by elastic modulus and tensile strength of textile reinforcement. The third stage is the failure stage which is reached when the tensile stress of the textile reinforcement reaches it's ultimate value. For TRCs with insufficient bond between the matrix and the fibre, the stress-strain curve will be bilinear.

3.2 EXPERIMENTAL RESULTS

Uniaxial tensile test was conducted on a textile reinforced concrete made of highly ductile fibre reinforced concrete and carbon textiles. The strength was affected by reinforcing textile ratio, type and volume content of short fibres etc. It exhibited multiple crack pattern. Increase in the short fiber volume content and the reinforcing textile ratio increased the number of cracks and decreased the crack width and spacing in TRHDC (Textile Reinforced Highly Ductile Concrete). The failure pattern can be changed from slippage to textile tensile rupture by increasing the short fiber volume content and matrix strength due to the better bond properties at the textile-to-matrix interface. The TRHDC specimens exhibited higher ultimate stress, toughness, and strength utilization coefficient of the textile compared to the corresponding TRM and HDC specimens. The tensile strength of TRHDC is mainly determined by the mechanical properties of the carbon textile, the reinforcing textile ratio, and the bond behavior at the textile-to-matrix interface and is not the superposition of the bearing capacity of each warp yarn. Increasing the reinforcing textile ratio enhanced the ultimate stress and toughness but led to a decrease in the strength utilization coefficient. Short fibers can improve the brittleness of the matrix and the bond behavior at the textile-to-matrix interface and thereby increase the ultimate stress, toughness, and strength utilization coefficient [14].

TRC can be used for tension. It has smaller crack width due to narrow crack width. Crack spacing depends on the reinforcement amount and distance of transverse rovings. The bond between the matrix and textile fabric is mainly due to adhesion and friction [20]'

TRC can be used as face material in sandwich panel. The nonlinear behaviour of the face material in tension results in a complex behaviour of the sandwich panel with a gradual shift of the neutral axis toward the face in compression upon loading [10].

3.3 TENSILE BEHAVIOUR OF TRC SANDWICH PANELS

A TRC sandwich panel was modelled in ABAQUS software. A displacement-controlled analysis was performed, increasing the displacement at the upper part of the pre-cracked composite while the lower part is locked along a distance corresponding to the fixed clamp. Failure of the panel is due to an entire pull-out of the textile in the clamped length of the specimen due to the insufficient adherence length. In uniaxial tension, the stress-strain behaviour is linear elastic until reaching the initiation cracking stress followed by a softening stress-strain due to the creation of micro-cracks and strain localization in concrete. In uniaxial compression, concrete behaviour is linear elastic until crushing initiation stress. FEM method allows for detection of more realistic crack opening at the initiation of concrete damage. [30]

3.4 TENSILE BEHAVIOUR OF BASALT TEXTILE REINFORCED MORTAR

Basalt has lower elongation ratios and is perfectly elastic until failure. A bitumen coat can be provided to allow for smoother load transmission by enhancing the bond between textile and the matrix. Uniaxial tensile test has been conducted by varying the reinforcing ratios. The failure of specimen with single reinforcement was smooth. Upon increasing the reinforcing ratios, the failure became more brittle. The increase of the reinforcement rate also affected the crack pattern, which strongly influenced the behaviour of the composite. The number of cracks was higher with a greater number of basalt textiles acting as strengthening core. the overall behaviour of the TRM load–strain curves are not significantly affected by the interface between basalt fibres and mortar. [22]

3.4 TENSILE BEHAVIOUR OF FAÇADE PANELS

Beam elements with 2 nodes (T3D2) were used for the reinforcement modelling and solid brick elements with 8 nodes (C3D8R) for the concrete. A static Riks nonlinear analysis (that uses an incremental loading increase until loss of strength or stability) was employed. For the facade panels it is observed that in the case of concrete classes with a lower compressive strength the first plastic deformations appear at lower forces, but the strength reserves are similar to those in the upper concrete classes. In the case of both the panels and the proposed lighting poles, the use of highstrength concrete leads to an increase in the strength value (approximately 40% for TRC panels, approximately 15% for TRC lighting poles) [7].

IV. BENDING BEHAVIOUR OF TRC

A 2D macroscale model of a textile reinforced concrete slab was model for four point bending test which was reinforced with carbon fibres. After the initial crack, multiple cracking occurred which was followed by a deformation hardening behaviour. The load and midspan deflection value were slightly higher than the experimental results which could be due to uncertainty in bond-slip curve or due to overestimation of the deformation. The failure observed from the experiment was anchorage failure [17]. The set up for four point bending is shown in figure 4.

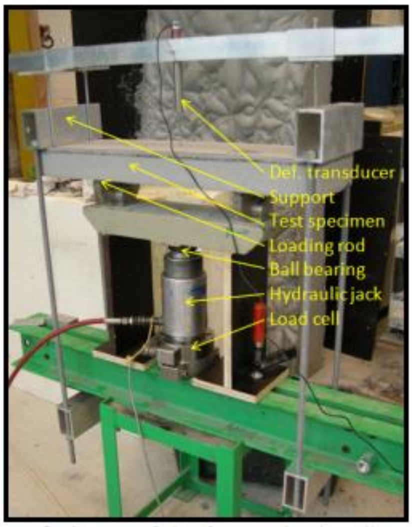

Figure :4 Setup of four point bending test

4.1 BENDING BEHAVIOUR OF TRC SANDWICH BEAM

For Finite Element Analysis, TRC could be modelled as a homogeneous material considering it's non-linearity or as by discretising the fabric as grid reinforcement embedded in the matrix. The numerical study provides a reliable prediction of the results; in case of deep beam the model over estimates the maximum load of about 10% while for slender sandwich beam the solution is conservative. [12]

4.2 FOUR POINT BENDING TEST REINFORCED WITH POLYPROPYLENE FIBRES

Four point bending test have been done on textile reinforced concrete reinforced with polypropylene fibres. The addition of polypropylene fibre was useful for improving the cracking load and ultimate load. The main reason being the effectiveness of polypropylene in improving the early age performance of fine grained concrete [28].

4.2.1 Effect of various cover thickness

After cracking, the specimens with small concrete cover had higher stiffness and hence had higher bearing capacity at the same mid-span deflection. The reason for this effect is that if the cover thickness satisfies the necessary value to ensure an anchorage of the reinforcement, the thinner the concrete cover, the more fully the role of the textile in limiting cracking can be utilized [28].

4.2.2 Effect of different surface treatment

The specimen in which sand has been stuck on textile showed higher stiffness and higher bearing capacity as the sticking of sand with textile decreases the slip between the matrix and the textile. It also exhibited better crack pattern. The specimen with no sand stuck on the textile exhibited larger crack width and a lower load bearing capacity.

4.2.3 Influence of polypropylene fibre

The bridging effect of polypropylene fibre delays expansion of crack and also reduces the crack width. It also improves the stiffness after cracking. But, there is an optimum value for polypropylene content which is around 1kg/m3.

4.3 FOUR POINT BENDING TEST REINFORCED WITH CARBON FIBRES

The effect of carbon fibres was studied by using fine, medium and coarse textile mesh. Delamination of the textile caused the failure of Medium and Fine specimens, while textile failure occurred in the Coarse specimen. The textile bond was found to be increased with an increase in anchorage length. A 2D non-linear macroscale model was developed and analysed by varying the contact perimeter of bond interface. It was observed that with the increase in contact perimeter, a complete interaction was achieved with the textile and the concrete matrix. All analyses reached approximately the same maximum load as in the test, but revealed differences in ductility.

V. CONCLUSION

A number of experiments have been conducted on the tensile and flexural behaviour of textile reinforced concrete. Numerical modelling was also done and compared with the experimental results to validate the models. In most studies, there were good correlation between the experimental and numerical analysis. This paper also comprises of the matrix composition and bonding in textile reinforced concrete. In many studies, the bond slip behaviour was assumed for the textile reinforced concrete which gave reliable results. The numerical modelling of TRC using finite element software is effective in predicting the bond behaviour, load-deflection response, stress-strain relations etc

REFERENCES

[1]. Adam Sciegaj, Fredrik Larsson and Karin Lundgren. (2022), "Experiments and calibration of a bond-slip relation and efficiency factors for textile reinforcement in concrete." Cement and Concrete Composites, Vol. 139

[2]. Ali Shams, Josef Hegger and Michael Horstmann. (2014), "An analytical model for sandwich panels made of textile-reinforced concrete." Construction and Building Materials, Vol. 64, pp. 451-459

[3]. Amir Si Larbi, Amen Agbossou and Patrice Hamelin. (2012), "Experimental and numerical investigations about textile-reinforced concrete and hybrid solutions for repairing and/or strengthening reinforced concrete beams." Composite Structures, Vol. 99, pp. 152-162

[4]. Anjana Elsa Alexander1 and A P Shashikala. (2020), "Sustainability of Construction with Textile Reinforced Concrete- A State of the Art." Materials Science and Engineering, Vol. 936, doi:10.1088/1757-899X/936/1/012006

[5]. Ba Tam Truong , Amir Si Larbi and Ali Limam. (2016), "Numerical modelling of reinforced concrete beams repaired by TRC composites." Composite Structures, Vol. 152, pp. 779-790

[6]. Bruckner, A., Ortlepp, R., and Curbach, M., 2006. Textile reinforced concrete for strengthening in bending and shear. Materials and Structures, 39(8): p. 741-748

[7]. Dan Alexandru Libotean, Alexandru Chira, Ferdinánd-Zsongor Gobesz. "Textile-Reinforced Concrete Structural Elements." Sciendo

[8]. Graf, W., Hoffmann, A., Möller, B., Sickert, J.-U., et al., 2007. Analysis of textile-reinforced concrete structures under consideration of non-traditional uncertainty models. Engineering Structures, 29(12): p. 3420-3431

[9]. Hartig, J., Häußler-Combe, U., and Schicktanz, K., 2008. "Influence of bond properties on the tensile behaviour of Textile Reinforced Concrete." Cement and Concrete Composites, 30(10): p. 898-906

[10]. Heidi Cuypers and Jan Wastiels. (2011), "Analysis and verification of the performance of sandwich panels with textile reinforced concrete faces." Journal of Sandwich Structures and Materials, Vol. 13(5), pp. 589-603

[11]. Isabella G. Colombo, Matteo Colombo & Marco di Prisco. (2018), "Numerical modelling of Textile reinforced sandwich panels." Computational Modelling of Concrete Structures, ISBN 978-1-138-74117-1

[12]. Isabella Giorgia Colombo, Matteo Colombo, Marco di Prisco and Farhang Pouyaei. (2018), "Analytical and numerical prediction of the bending behaviour of textile reinforced concrete sandwich beams." Journal of Building Engineering, Vol. 17, pp. 183-195

[13]. Lampros N. Koutas1, Zoi Tetta, Dionysios A. Bournas, and Thanasis C. Triantafillou, P.E., M.ASCE. (2019), "Strengthening of Concrete Structures with Textile Reinforced Mortars: State-of-the-Art Review." Journal of Composites for Construction, Vol. 23(1)

[14]. Min Zhang, Mingke Deng. (2022), "Tensile behavior of textile-reinforced composites made of highly ductile fiber-reinforced concrete and carbon textiles." Journal of Building Engineering, Vol. 57, https://doi.org/10.1016/j.jobe.2022.104824

[15]. Mohammad Alma'aitah, Bahman Ghiassi and Ali Dalalbashi. (2021), "Durability of Textile Reinforced Concrete: Existing Knowledge and Current Gaps." Applied Sciences, Vol. 11

[16]. N. Williams Portal, K. Lundgren, A.M. Walter, J.O. Frederiksen, L.N. Thrane. "Numerical Modelling Of Textile Reinforced Concrete."

[17]. Natalie Williams Portal, Lars Nyholm Thrane and Karin Lundgren. "Flexural Behaviour of Textile Reinforced Concrete Composites: Experimental and Numerical Evaluation."

[18]. Orlowsky, J. and Raupach, M., 2011. Textile reinforced concrete - from research to application. Cement Wapno Beton, 16(6): p. 323-331

[19]. Ortlepp, R., Weiland, S., and Curbach, M., 2009. Rehabilitation and strengthening of a hypar concrete shell by textile reinforced concrete. in Proceedings of International Conference on Concrete Construction, London, Sept 9-10, pp.357-363 num mod 4

[20]. Patrick Valeri, Miguel Fernandez Ruiz and Aurelio Muttoni. (2020), "Tensile response of textile reinforced concrete." Construction and Building Materials, Vol. 258

[21]. Peiffer, F., 2008. Framework for adaptive simulations applied to textile reinforced concrete. PhD thesis, RWTH Aachen University

[22]. Pello Larrinaga, Carlos Chastre, Hugo C. Biscaia and Jose T. San-Jose. (2014), "Experimental and numerical modeling of basalt textile reinforced mortar behavior under uniaxial tensile stress." Materials and Design, Vol. 55, pp. 66-74

[23]. Sai Liu, Xuan Wang, Prashant Rawat, Zheng Chen, Caijun Shi and Deju Zhu. (2021), "Experimental study and analytical modeling on tensile performance of basalt textile reinforced concrete." Construction and Building Materials, Vol. 267.

[24]. Sanjay Gokul Venigalla, Abu Bakar Nabilah , Noor Azline Mohd Nasir, Nor Azizi Safiee and Farah Nora Aznieta Abd Aziz. (2022), "Textile-Reinforced Concrete as a Structural Member: A Review."

[25]. U. Haubler-Combe and J. Hartig. (2007), "Bond and failure mechanisms of textile reinforced concrete (TRC) under uniaxial tensile loading." Cement and Concrete Composites, Vol. 29(4), pp. 279-289

[26]. Vanegas, J.A., DuBose, J. R. and Pearce, A. R., 1996. Sustainable Technologies for the Building Construction Industry. in Proceedings of the Symposium on Design for the Global Environment, Atlanta, USA, November 2-4

[27]. Xiaoshan Lin and Y. X. Zhang. (2013), "Novel Composite Beam Element with Bond-Slip for Nonlinear Finite-Element Analyses of Steel/FRP-Reinforced Concrete Beams." Journal of Structural Engineering, Vol. 139(12)

[28]. YIN Shiping, XU Shilang and LI Hedong. (2013), "Improved Mechanical Properties of Textile Reinforced Concrete Thin Plate." Journal of Wuhan University of Technology-Mater. Sci. Ed, Vol. 28(1)

[29]. Yunxing Du, Xinying Zhang, Fen Zhou and Deju Zhu. (2018), "Flexural behavior of basalt textile-reinforced concrete." Vol. 183, pp: 7-21

[30]. Zakaria Ilyes Djamaia , Myriam Bahrarb , Ferdinando Salvatorea , Amir Si Larbia and Mohammed El Mankibi. (2017), "Textile reinforced concrete multiscale mechanical modelling: Application to TRC sandwich panels." Finite Elements in Analysis and Design, Vol. 135, pp. 22-35