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Experimental and numerical investigation of Textile Reinforced Concrete: A Review

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Abstract - Textile reinforced concrete is gaining popularity in construction industry due to it's higher strength, stiffness, and flexibility . TRC consist of fine-grained concrete matrix reinforced by multiaxial, non corrosive textile fabrics. The use of textile fibers for repair and retrofit are gaining popularity for its direct role in reducing construction time ,cost and enhancing the durability of structure by crack control. This review paper is going to investigate the previous experimental and numerical studies conducted on TRC to evaluate it's flexural and tensile properties

Keywords- Textile Reinforced Concrete, Multiaxial, Flexural and tensile properties

I. INTRODUCTION

Sustainable development necessitates a shift in traditional construction practices. Innovative material like textile reinforced concrete (TRC) can be used to meet the demand for sustainable industry. Textile-reinforced concrete (TRC) combines the high compressive strength of concrete structures with the tensile resistance and non-corroding behaviour of the textile fibres. It is made of fine-grained concrete that has been reinforced by a high-strength textile made of alkali-resistant glass, carbon, etc. It has been demonstrated that this composite material has the potential to be used to design freeform, modular structures that are thin and light. Numerous experimental studies have been conducted to characterize the mechanical behaviour of TRC, the identification of interaction mechanisms and the stress transfer between the weave fabric (textile) and the matrix. TRC different from steel reinforced concrete has complex heterogeneous structure due to which it is difficult to quantify bond slip behaviour. This is is the major reason behind the development of numerical models of TRC to investigate crack pattern, bond slip, failure mode etc.

The present paper is going to investigate different papers on experimental study and finite element (FE) modeling approach of TRC to predict the flexural and tensile behaviour of elements. Different finite element softwares like TNO DIANA, Abaqus are being used for analysis of TRC in different papers. The results obtained from model predictions were compared with the experimental data for validation of the model.

II. TEXTILE REINFORCED CONCRETE

Textile-reinforced concrete (TRC) has emerged in recent years as a new and valuable construction material. It is made with a continuous textile fabric that is incorporated into a fine grained cementitious matrix consisting of a Portland cement binder and small-size aggregates. In TRC, a fine-grained concrete having a maximum aggregate size of less than 2 mm is commonly applied to achieve a superior bond with the textile fabric **(N. Williams Portal et.al.,2014)**. This material can be categorized as a strain-hardening or deflection-hardening cement composite, made with short yarns have the advantage that their production is simple and site friendly. Yet, a major advantage of TRC is the continuity of the yarns providing inherently high efficiency and reliability, which is so essential for structural and semi structural applications.

The use of composites such as geotextiles, geomembranes, and textile for repair and retrofit is gaining popularity for its direct role in reducing construction time and labour costs. Many structural elements can be reinforced with TRC as a substitute for conventional reinforcement **(Soranakom et al.,2008).** Moreover , it will lead to crack control and distributed cracking with a much smaller crack width ultimately leading to durability enhancements. TRC materials will have a direct impact in the sectional area of the member, since additional strength and ductility reduce the section sizes, while strain-hardening behaviour reduces the potential for early-age cracking and drying shrinkage. TRC is a cost-effective material used in shotcrete and groundwork for mining, tunnelling, and excavation support applications. It is also used in architectural cladding panels, sandwich membranes sensitive to flexure, permanent formwork, and 3D-shaped architectural elements.

III PROPERTIES OF REINFORCING MATERIAL

A fibre is essentially a long, fine filament with a diameter that is typically in the range of 10 m and a length-to-diameter aspect ratio that is typically at least 1,000, but almost infinite in the case of continuous fibres (**Bunsell et.al., 1988).** In addition to its flexibility, the fiber's strength is extraordinary, often possessing a Young's modulus far greater than the same material in its bulk form. The textile is made up of yarns that could consist of individual fibers or bundled filaments. For cement-based matrices, a wide range of fibre types, including carbon, glass, aramid, PVA, PP, PE of high and low modulus, basalt, and sisal, were assessed for reinforcement. The two most popular and extensively researched fibre materials for TRC are carbon and AR glass

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fibres (**Brameshuber et.al, 2006),** both of which have an elasticity modulus greater than the matrix and provide the TRC a strain-hardening tendency. AR glass, while appealing due to its affordable price, is delicate to the alkaline matrix environment. In the zone of multiple cracks, the impact of fibre type becomes substantial. High-tensile and mechanically strong fabric composites . demonstrate enhanced strain-hardening behaviour compared to the soft hardening or quasi plastic behavior of fabric composites with low mechanical and tensile properties

IV. EXPERIMENTAL INVESTIGATIONS IN LITERATURES

1.TENSION TEST

Specimens both unreinforced and reinforced with 1 to 4 layers of yarns in order to analyse the effect of reinforcing rate where subjected to uniaxial tension test. TRM tensile specimens were placed in a Schenk 100 Kn press which was programmed to exert a deformation rate of 0.5 mm/min.(**Pello Larrinaga.et.al, 2014)**. In another paper tension tests were carried out as per AC 434 guidelines but a different gripping mechanism was assumed . The test was executed under displacement control at 0.3 mm/min. This was increased to 0.5 mm/min after the end of the second phase. An extensometer with a gauge length of 100 mm was used to measure the strains in the central area of the specimens **(Elisa Bertolesi et al,2014)**

2 BENDING TEST

Steel plates are attached to the sandwich specimen to prevent local crushing on the supports and under the loading knives during the four point bending test that was conducted on the sandwich beams using an electromechanical press called INSTRON.Two LVDT transducers (LVDT 1, LVDT 2) are used in the test to measure the specimen deflection, as well as an LVDT6 with a gauge length of 300 mm **(Zakaria Ilyes Djamaia et.al,2017).** The experimental findings, used as a guide in this study, relate to tests carried out using a four-point loading technique on sandwich beams that are 550150mm2 ("deep") and 1200300mm2 ("slender"). sandwich beams. Beams are characterised by two 10mm thick external layers made of textile reinforced concrete (TRC) connected by a 100mm thick insulation layer of expanded polystyrene foam (EPS250) (**Colombo.et.al)**

V EXPEIMENTAL RESULTS

From the tension test it was observed that only one crack was formed in the unreinforced specimens. Three distinct stages of cracking is visible in reinforced specimens. First crack is formed when the mortar tensile strength is exceeded, thereafter tensile force is carried by the reinforcement. New cracks appear when tensile force is further increased. This is due to the load transfer from rovings to the matrix by which tensile strength of matrix exceeds and cracks forms. This is called multiple cracking stage. Next stage is post cracking stage where the cracks get stabilised. When all cracks are formed material behaves in a linear way with a slope lower than pre cracking stage. **(Pello Larrinaga.et.al,2014)**. Failure mode of specimens also differed. Specimen with single layer of reinforcement broke smoothely whereas that of multiple reinforcing layers showed brittle rupture. Crack pattern was influenced by the increase of reinforcement rate. More the reinforcing rate more number of cracks formed with lower distance between the cracks. **(Pello Larrinaga.et.al, 2014) All** the stress strain or force displacement curves obtained was trilinear with distinct cracking pattern.

In the flexural strength test results emerged that a large ductility was experienced by both deep and slender specimens; this ductility was achieved thanks to the multi-cracking of both TRC layers and the large compressive plastic strain experienced by the EPS core. The multi-cracking pattern was influenced by the cloth position in the TRC layer thickness, but not the overall reaction.. The failure was due to the tensile failure of TRC. .(**Isabella Giorgia Colombo et.al,2018)**

VI FINITE ELEMENT ANALYSIS

1.INTRODUCTION

The finite elements analysis (FEA) is a 3D powerful tool for material modeling and analysis of structural responses. In the present study, the FEA method was used in order to model the TRC **(Pello Larrinaga et.al , 2014).** A prediction of the beahaviour of TRC under flexure and tension can be provided by FEM.. The model was developed using TNO DIANA (N. Williams Portal et.al) and ABAQUS. **(Zakaria Ilyes Djamaia et.al,2017**). Numerical non linear analysis is performed for the accurate simulation of nonlinear behaviour of TRC due to cracking of the matrix and textile-matrix debonding **(Zakaria Ilyes Djamaia et.al,2017).**

2.MODEL DESCRIPTION

3D Finite Element mechanical models of the TRC sandwich panel have been built to reproduce either global or local behaviours observed during the experimental campaign. Two approaches have been used to achieve an accurate modelling of the mechanical behaviour of the sandwich panel. the macro perspective (TRC considered as one entity). In terms of force vs. imposed stroke, an ABAQUS/Implicit macroscopic model of the sandwich panel is created and compared with the experimental results.Modeled as 3D solid sections with 8-node linear brick parts are the steel plates, TRC layers, and polystyrene layers (C3D8R).Since there was no detachment during the experimental campaign, a tie constraint (perfect bond) is considered to exist at the TRC-Foam interface. Between the TRC layers and the glued steel plates, a tie limitation is also taken into account. **(Zakaria Ilyes Djamaia et.al,2017).**

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Isoparametric elements (solid65) with a smeared cracking technique were employed in this paper's created finite element (FE) models for the concrete. The 3D-solid element was described by eight nodes and three degrees of freedom at each node (translations in the nodal x, y, and z directions). (Larbi et.al). The model developed in DIANA included 2-D plane stress elements for concrete 1-D truss-bar elements for textile reinforcement along with 2-D line interface elements with bond-slip. In **Isabella Giorgia Colombo et.al,2018** the tensile behaviour of TRC layers is assumed homogeneous over the thickness and, in particular, the uniaxial tensile constitutive law derived from uniaxial tensile tests is applied to the whole concrete layer . The specimen is discretized using 8-node linear brick elements and is treated as a solid homogenous section (C3D8R).

3.MODELING OF MATERIALS

TRC could be modelled by treating the material as homogeneous when material non-linearity is taken into account. According to a fabric tensile test that was conducted, the textile is believed to follow the elastoplastic law with a yield stress of 820 MPa and a Young's modulus of 20 GPa. (according to fabric tensile test realized , whereas an arbitrary softening plastic modulus is assumed to capture the textile tension failure.(**Isabella Giorgia Colombo et.al,2018) .**A total strain based crack model with rotating crack was defined for the fine grained concrete, wherein the crack direction continuously rotates according to the principal directions of the strain vector. **(N. Williams Portal et.al.,2014)**

4.BOND SLIP INTERFACE

The interaction between textile and matrix was modeled using a bond-slip law obtained based on the experimental pull-out tests. By utilising its pull out mode of failure, the established textile-concrete bond model has been applied to calibrate the bond slip law of an existent TRC tested in tension. (Djamai et al.)The load transfer mechanisms in the case of TRC differ significantly from those of CFRP at the micro and meso-scales, among others. In fact, the mortar's relatively limited penetration of the bundle results in the generation of both the inner filaments, which make up the majority, and the outside filaments, which are in direct contact with the mortar and interact discontinuously, heterogeneously, and predominantly through friction. **(Amir Si Larbi et.al,2013)** It should be noted that the inter-filament bond was not examined during the development of the TRC improved multiscale model, despite the fact that the coating (which is extensively employed in TRC) significantly improves the inter filament bond. For uncoated textile, however, it is more computationally expensive to assume decreasing bond slip strength laws from the outermost filaments, which are in direct contact with the fine-grained matrix, to the internal filaments, where there is less contact. **(Zakaria Ilyes Djamaia et.al,2017).**

VII RESULTS AND DISCUSSION

1.FLEXURAL TEST

1.1 Load–deflection behaviour

As shown in the figure there was good agreement between the numerical and experimental load deflection response of TRC. Stress redistribution behaviour has high lightened the influence of axial stifness on it.

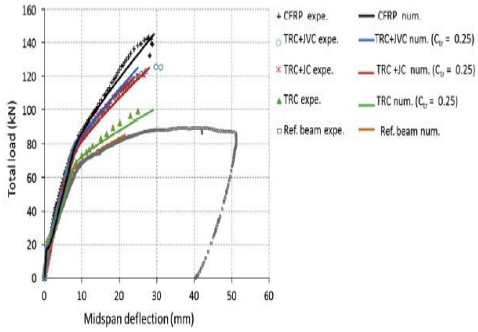

Fig. 1. Experimental and numerical comparison of load versus bending displacement of the analysed beams. . **(Amir Si Larbi et.al,2013)**

In Djamai.et.al. The numerical model and experimental result of flexure members are compared in terms of force vs imposed stroke. Between the mechanical model and the experimental research, a good match has been made. Additionally, the shear failure of the EPS foam, the experimental mode of failure, is accurately recorded. The bottom TRC layer beneath the load application zone is where the shear stress at the interface zone (textile-mortar) reaches its highest and the concrete displays a dense cracking behaviour.

1.2 Crack density

Contact perimeter of the textile affected both the stiffness and the crack pattern. The smaller the contact perimeter, the larger crack distance and thus fewer cracks were observed. The shear stress at the interface zone (textile–mortar) reaches its maximum at the lower TRC layer under the load application zone where concrete exhibits a dense cracking behaviour However, shear bond stress does not reach the bond strength and a pull-out failure has not been noticed. . **(Zakaria Ilyes Djamaia et.al,2017).**

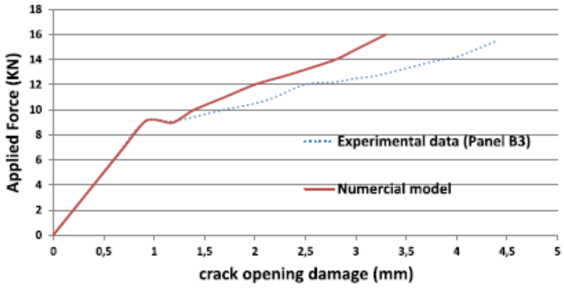

Fig 2. Numerical and experimental comparison of Crack opening damage **(Djamai.et.al)**

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The experimental and numerical results of the force vs COD, with the numerical estimation of the force vs angular strain of EPS 250 during the test, are available in (Figs. 26) respectively. A good qualitative agreement between the experimental and numerical results for the COD has been noticed. However after the crack initiation of 9 kN, disparity exists between the experimental and numerical evaluation. This can be explained by the inability of the numerical model's continuum crack damage method (concrete damaged plasticity) to take into account the actual crack opening at the time of damage. . **(Zakaria Ilyes Djamaia et.al,2017).** The load-displacement curve resulting from the simulation is superimposed to the experimental results in Fig. 2. Looking at the figure it is possible to observe that the numerical response is in good agreement with the experimental behaviour of TRC in bending. This result shows that considering TRC as a homogeneous material over a thickness of 10mm allows to adequately predict the bending behaviour of TRC.(**Isabella Giorgia Colombo et.al,2018)**

2. TENSION TEST

In terms of tension test results numerical model demonstrates both qualitative and quantitative agreement with experimental data specifically in terms of maximum stress transmitted and ultimate strain. The 3 phases of the TRC tensile behaviour are clearly visible. Moreover the numerical model is able to capture the mode of failure (pull-out) and the post peak step where a brutal softening occurred due to the bond damage. The 3 steps of the TRC tensile test behaviour (Fig. 16) are clearly visible in , where relevant numerical variables illustrates the states of stress and damage in the concrete and the textile-concrete bond.

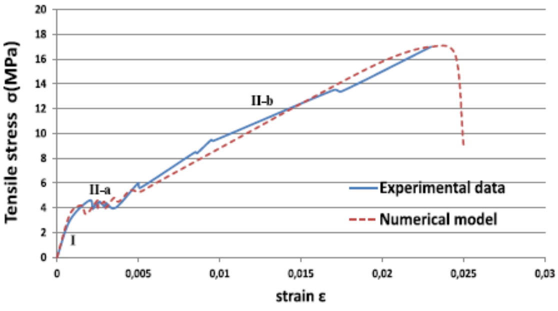

Fig 3 : Stress strain TRC relation (Numerical and experimental comparison) **(Zakaria Ilyes Djamaia et.al,2017).**

VIII CONCLUSIONS

The developed numerical models of TRC was capable of predicting the flexural and tensile response of TRC with reasonable accuracy. The approach presented could be used as an effective tool for adequately Predicting experimental results both in terms of global response and deformation modes. Moreover, the numerical model helped to recognize challenges and ambiguities pertaining to the prediction of the mechanical behavior of TRC. The continuum crack damage approach used can be used to explain differences between the multiscale TRC sandwich panel model and the experimental inquiry concerning the evolution of the crack opening damage after damage initiation .One of the tracks of possible improvement of the proposed enhanced TRC model is the introduction of the XFEM method(extended finite element method) in the formulation of the proposed multiscale TRC approach.

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