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Materials, Analysis, Structural Design and Applications of Textile Reinforced Concrete/Fabric Reinforced Cementitious Matrix

SP-345

Editors:
Barzin Mobasher and Flávio de Andrade Silva

American Concrete Institute
Always advancing

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PREFACE

Materials, Analysis, Structural Design and Applications of Textile Reinforced Concrete/Fabric Reinforced Cementitious Matrix

Several state-of-the-art sessions on textile-reinforced concrete/fabric-reinforced cementitious matrix (TRC/FRCM) were organized by ACI Committee 549 in collaboration with RILEM TC MCC during the ACI Fall 2019 Convention in Cincinnati, OH, and the ACI Virtual Technical Presentations in June 2020. The forum provided a unique opportunity to collect information and present knowledge in the field of TRC and FRCM as sustainable construction materials. The term TRC is typically used for new construction applications whereas the term FRCM refers to the repair applications of existing concrete and masonry. Both methods use a textile mesh as reinforcement and a cementitious-based matrix component and, due to high tensile and flexural strength and ductility, can be used to support structural loads. The technical sessions aimed to promote the technology, and document and develop recommendations for testing, design, and analysis, as well as to showcase the key features of these ductile and strong cement composite systems. New methods for characterization of key parameters were presented, and the results were collected towards the development of technical and state-of-the-art papers. Textile types included polymer-based (low and high stiffness), glass, natural, basalt, carbon, steel, and hybrid, whereas the matrix can include cementitious, geopolymers, and lightweight matrix (aggregates). Additives such as short fibers, fillers, and nanomaterials were also considered.

The sessions were attended by researchers, designers, students, and participants from the construction and fiber industries. The presence of people with different expertise and from different regions of the world provided a unique opportunity to share knowledge and promote collaborative efforts. The experience of an online technical forum was a success and may be used for future opportunities.

The workshop technical sessions chairs sincerely thank the ACI staff for doing a wonderful job in organizing the virtual sessions and ACI TC 549 and Rilem TC MCC for the collaboration.

August 2020
Barzin Mobasher
Flávio de Andrade Silva

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CARBON REINFORCED CONCRETE UNDER CYCLIC TENSILE LOADING

Arne Spelter, Juliane Wagner, Manfred Curbach and Josef Hegger

Synopsis: Carbon reinforced concrete (CRC) is a material composed of a high-performance concrete and a carbon reinforcement (textile grids, lamellas, rods). Composite materials with reinforcements of other fiber materials are called textile reinforced concrete (TRC). The investigations of CRC started more than 20 years ago and the continuous development as well as research findings have opened many fields of application. Today, the use of CRC includes the strengthening of reinforced concrete elements as well as the realization of new elements such as facades, shells and even bridges.

Some of these structures require knowledge of the fatigue behavior due to cyclic loading (e. g. bridges). In a collaborative project of the Institute of Structural Concrete of the RWTH Aachen University and the Institute of Concrete Structures of the TU Dresden, the uniaxial tensile fatigue behavior of two carbon textile reinforcement types was systematically investigated. The specimens were subjected up to 107 loading cycles and stress ranges up to 261 ksi (1,800 MPa). The influence of the maximum load and amplitude were investigated as well as fatigue curves for these two reinforcement types derived.

Keywords: Carbon reinforced concrete (CRC), cyclic loading, fatigue curve, S-N curve, tensile fatigue, textile reinforced concrete (TRC)

Shear Capacity of TRC slabs: Modelling and Examples from Practice

Jan Bielak, Norbert Will, Josef Hegger and Sven Bosbach

Synopsis: Textile-reinforced concrete (TRC) combines high-performance fabrics made of impregnated carbon yarns with state-of-the-art high strength concrete. Due to the corrosion resistance of non-metallic reinforcement, the application of TRC for external components especially with freeze-thaw and de-icing salt exposure is promising. This allows for reduction of concrete cover, to create slender structural elements and to execute thin slabs without additional waterproofing or protective decking. Different existing theoretical models and experience from various research projects were used in design of several pedestrian- and road bridges in Germany. The pedestrian bridges in Rems Valley and Ottenhöfen use TRC slabs without shear reinforcement as transversal road-bearing component. For the road bridges in Gaggenau, skew slabs made of TRC with shear reinforcement were chosen as principal structural system. Prior and during construction, experimental investigations on shear capacity were performed at the Institute of Structural Concrete (IMB) of RWTH Aachen. A comprehensive characterization of the material properties of the non-metallic reinforcement is a prerequisite for transfer and adaption of existing design rules, e.g. the determination of tensile strength of the bent portion of pre-formed shear reinforcement. This paper highlights the application potential and further challenges for the use of textile-reinforced concrete in new engineering constructions.

Keywords: bridges, carbon concrete composite, design provisions, shear, shear span, size effect, textile-reinforced concrete (TRC)

REFERENCES

[1] Pancar, E.B. & Akpınar, M.V. Int J Concr Struct Mater (2016) 10: 39. https://doi.org/10.1007/s40069-016-0130-2.

[2] Oxfall, M. (2016). Climatic conditions inside nuclear reactor containments: Evaluation of moisture condition in the concrete within reactor containments and interaction with the ambient compartments. Lund.

[3] Naus, D.J., 2006. The effect of elevated temperature on concrete materials and structures-a literature review (No. ORNL/TM--2005/553). Oak Ridge National Laboratory (United States). Funding organisation: ORNL work for others (United States).

[4] FIB Bulletin 38, 2007. Fire design of concrete structures-materials, structures and modeling. The International Federation for Structural Concrete.

[5] Ehlig, D., Jesse, F. and Curbach, M., 2010, September. High temperature tests on textile reinforced concrete (TRC) strain specimens. In International RILEM Conference on Material Science (pp. 141-151). RILEM Publications SARL.

[6] Colombo, I., Colombo, M., Magri, A., Zani, G. and di Prisco, M., 2011. Textile reinforced mortar at high temperatures. In Applied mechanics and materials (Vol. 82, pp. 202-207). Trans Tech Publications.

[7] de Andrade Silva, F., Butler, M., Hempel, S., Toledo Filho, R.D. and Mechtcherine, V., 2014. Effects of elevated temperatures on the interface properties of carbon textile-reinforced concrete. Cement and Concrete Composites, 48, pp.26-34.

[8] Rambo, D.A.S., de Andrade Silva, F., Toledo Filho, R.D. and Gomes, O.D.F.M., 2015. Effect of elevated temperatures on the mechanical behavior of basalt textile reinforced refractory concrete. Materials & Design (1980-2015), 65, pp.24-33.

[9] Nguyen, T.H., Vu, X.H., Larbi, A.S. and Ferrier, E., 2016. Experimental study of the effect of simultaneous mechanical and high-temperature loadings on the behaviour of textile-reinforced concrete (TRC). Construction and Building Materials, 125, pp.253.

[10] Rambo, D.A.S., de Andrade Silva, F., Toledo Filho, R.D., Ukrainczyk, N. and Koenders, E., 2016. Tensile strength of a calcium-aluminate cementitious composite reinforced with basalt textile in a high-temperature environment. Cement and Concrete Composites, 70, pp.183-193.

[11] Rambo, D.A.S., Yao, Y., de Andrade Silva, F., Toledo Filho, R.D. and Mobasher, B., 2017. Experimental investigation and modelling of the temperature effects on the tensile behavior of textile reinforced refractory concretes. Cement and Concrete Composites, 75, pp.51-61.

[12] Homoro, O., Vu, X.H. and Ferrier, E., 2018. Experimental and analytical study of the thermo-mechanical behaviour of textile-reinforced concrete (TRC) at elevated temperatures: Role of discontinuous short glass fibres. Construction and Building Materials, 190, pp.645-663.

[13] Tlaiji, T., Vu, X.H., Ferrier, E. and Larbi, A.S., 2018. Thermomechanical behaviour and residual properties of textile reinforced concrete (TRC) subjected to elevated and high temperature loading: Experimental and comparative study. Composites Part B: Engineering, 144, pp.99-110.

[14] Messori, M., Nobili, A., Signorini, C. and Sola, A., 2019. Effect of high temperature exposure on epoxy-coated glass textile reinforced mortar (GTRM) composites. Construction and Building Materials, 212, pp.765-774.

[15] Truong, G.T., Park, S.H. and Choi, K.K., 2019. Tensile Behaviors of Lap-Spliced Carbon Fiber-Textile Reinforced Mortar Composites Exposed to High Temperature. Materials, 12(9), p.1512.

Case study of a staircase system made of carbon reinforced concrete (CRC)

Egbert Müller, Manfred Curbach

Synopsis: Textile reinforced concrete (TRC) is a great composite material which offers many fields of application. It can be used as a material for the strengthening of existing concrete structures or to build new structures. Possible reinforcement materials are AR-glass, basalt or carbon. The last material named can be referred to as carbon reinforced concrete (CRC). The goal of the project autartec® was to create a floating house which is able to be self-sufficient for at least two weeks. For this purpose, structural elements made of CRC were developed. In this article a case study of a specific staircase system will be presented. Besides the production of the elements, the paper will also discuss the experimental investigation of the system. On the one hand, the tests were carried out with the boundary conditions of regular use, on the other hand, unfavourable situations were considered. At the end, the complete staircase system will be demonstrated.

Keywords: Textile Reinforced Concrete (TRC), Carbon Reinforced Concrete (CRC), Fabric Reinforced Cementitious Matrix (FRCM), stair case system, autarkic housing

Experimental Approach to Determine Lap Splice Length of Textile Reinforced Concrete Members Subjected to Tensile Force

Bui Si Muoi, Minoru Kunieda

Synopsis: Textile Reinforced Concrete (TRC) has emerged in recent years as a new construction material, which is seriously considered as substitutes for traditional composite materials. However, the practical utility and design of innovative materials like TRC is hindered by the lack of standardized specifications, including required lap splice length of textile fabrics. This study aims to investigate the structural behavior of TRC members subjected to uniaxial tensile force, therefore providing knowledge for further research on determining overlap length.

Keywords: textile reinforced concrete, TRC, lap splice length, lap splice

Numerical modeling of FRCM composites for the seismic retrofitting of existing concrete structures

Marco Carlo Rampini, Giulio Zani, Matteo Colombo and Marco di Prisco

Synopsis: Fabric-reinforced cementitious matrix (FRCM) composites are promising structural materials representing the extension of textile reinforced concrete (TRC) technology to repairing applications. Recent experiences have proven the ability of FRCMs to increase the mechanical performances of existing elements, ensuring economic and environmental sustainability. Since FRCM composites are generally employed in the form of thin externally bonded layers, one of the main advantages is the ability to improve the overall energy absorption capacity, weakly impacting the structural dead weights and the structural stiffness and, as a direct consequence, the inertial force distributions activated by seismic events. In the framework of new regulatory initiatives, the paper aims at proposing simplified numerical approaches for the structural design of retrofitting interventions on existing reinforced concrete structures. To this purpose, the research is addressed at two main levels: i) the material level is investigated on the uniaxial tensile response of FRCM composites, modeled by means of well-established numerical approaches; and ii) the macro-scale level is evaluated and modeled on a double edge wedge splitting (DEWS) specimen, consisting of an under-reinforced concrete substrate retrofitted with two outer FRCM composites. This novel experimental technique, originally introduced to investigate the fracture behavior of fiber-reinforced concrete, allows transferring substrate tensile stresses to the retrofitting layers by means of the sole chemo-mechanical adhesion, allowing to investigate the FRCM delamination and cracking phenomena occurring in the notched ligament zone. It is believed that the analysis of the experimental results, assisted by simplified and advanced non-linear numerical approaches, may represent an effective starting point for the derivation of robust design-oriented models.

Keywords: FRCM, retrofitting of concrete structures, tensile behavior, numerical modeling, DEWS test.

Effect of Bonded Length on Material Characterization of FRCM Composites

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Synopsis: Fabric Reinforced Cementitious Matrix (FRCM) is an established technology for strengthening and rehabilitation of existing concrete and masonry structures. In the United States, material characterization of the FRCM composites is in accordance with ICC-ES acceptance criteria AC434. The acceptance criteria recommend tensile testing the FRCM coupons with clevis-grips to obtain the mechanical properties for design purposes. The current test method, however, neglects some of the critical factors affecting the test outcome such as the effect of bonded length or number of fabric layers. The effect of bonded length on the FRCM properties tested per AC434 Annex-A is discussed in this paper. Carbon-FRCM coupons of 2, 3, 6, 9, and 12 inches (50.8, 76.2, 152.4, 228.6, and 304.8 mm) bonded length were prepared and tested in direct tension. The other test variable was the number of fabric layers. The tests were conducted with one- and two-layer fabrics for different bonded length. The results discussed in terms of ultimate stress, ultimate strain, and modulus show that the material characterization of the FRCM composites depended on the bonded length and number of fabric layers of the tested specimens. Moreover, the effect of number of fabric layers on the material characteristics was more pronounced in specimens with shorter bonded length. The experimental results are used to make suggestions for improving the FRCM characterization test methods as currently stated in AC434.

Keywords: Bond, Composite Materials, Fabric Reinforced Cementitious Matrix (FRCM), Material Characterization, Strengthening, Tensile testing

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FRCM confined reinforced concrete columns: experimental behavior, analytical and numerical modeling

Luciano Ombres and Salvatore Verre

Synopsis: In the paper, the behavior of FRCM (Fabric Reinforced Cementitious Mortar) confined concrete columns is analyzed both experimentally and theoretically. An experimental investigation was conducted on FRCM confined reinforced concrete columns with square cross section (9 columns, 1000 mm height with 150x150 mm cross section) subjected to eccentric axial load. Parameters investigated were the confining configuration (continuous and discontinuous) and the eccentricity values. The obtained results in terms of failure modes, axial capacity, longitudinal and transversal strain, were presented and discussed. The behavior of FRCM confined columns were analyzed analytically through a model found based on the non-linear constitutive law of the confined concrete, developed for short columns, and numerically by a model found on a Finite Element procedure developed through Abaqus. The accuracy of both models was assessed by the comparison between numerical predictions and experimental results. The main results of the analysis allow evidencing the effectiveness of the FRCM confinement and the influence of geometrical and mechanical parameters on the structural response of reinforced concrete columns.

Keywords: FRCM, reinforced concrete column, confinement, modeling

On the tensile behavior of high-strength strain-hardening cement-based composites (SHCC) reinforced with carbon textile – influence of yarn-SHCC bond

Iurie Curosu, Ameer H. Ahmed, Ting Gong and Viktor Mechtcherine

Synopsis: The combination of short micro-fibers and continuous textile reinforcement in cementitious composites can yield desirable mechanical properties with respect to structural strengthening against severe loading, such as impact or blast. Besides the high tensile strength, high stiffness and considerable inelastic deformation capacity of such composites, their constitutive nature and fresh-state properties enable their application as thin layers by lamination or spraying without contributing substantially to the dead weight of the strengthened structure and without imposing the usage of molds and adhesives. The paper at hand presents an exemplary hybrid-fiber reinforced composite, consisting of high-strength strain-hardening cement-based composites (HS-SHCC) and carbon textile reinforcement. The textile was investigated in two configurations: with and without additional coating for bond-strength enhancement. In this way, the influence of yarn-SHCC bond properties on the cracking and fracture behavior of the composites was emphasized.

Keywords: SHCC, carbon textile reinforcement, UHMWPE, short fiber, tension, bond

Development and design of smart textile reinforcement for concrete pipes

Goezdem Dittel, Kira Heins, Thomas Gries

Synopsis: There is a great demand in the world for low-cost and functional pipeline systems due to the renovation requirements of pipes in use and the continuous development of new settlements. Previously used pipeline systems made of steel reinforced concrete are economical and sufficiently resistant. However, due to the corrodibility of steel reinforcement and to enable sufficient crack reduction, large wall thicknesses and thus heavy constructions are required. Textile reinforced concrete (TRC) eliminates these disadvantages by enabling the production of light and thin-walled structures.
The aim of this research is the development of a concept for the realization of smart pipes made of sensory TRC by using the advantages of lightweight, thin-walled structures, focusing on the production process. Based on different warp knitted textile variations with different coating concentrations, preliminary tests were carried out using the four-point bending test. As a result of the preliminary tests, the textile variation of counterlaid tricot with a maximum coating concentration was selected as a suitable reinforcing material for the concept development. Concepts for the production of smart TRC pipes are developed accordingly. As a result, a casting mold and process were created which allowed a production with reduced diameter and depth of pores and concentric positioning of the reinforcement structure.

Keywords: leakage sensor, sensory carbon fiber, strain sensor, structural health monitoring, TRC water pipe

Design Formulas for FRCM Strengthened Masonry Elements Under Compression or Shear Load

Maria Antonietta Aiello and Alessio Cascardi

Synopsis: The increasing interest in the field of conservation of existing masonry structures pushed to the development of new retrofitting technologies in the recent past. One of the most promising is the use of *Fabric Reinforced Cementitious Mortar* (FRCM), which consists of an open-grid within an inorganic matrix. The effectiveness of the FRCM-application is well-demonstrated in literature by several experimental investigations regarding different structural members, including columns and shear wall. The success of FRCMs is manly related to durability aspects, since the grid is generally non-metallic, the compatibility of the inorganic matrix with the substrates, the easy application, the low weight and spatial impact, the possible installation in damp areas and at high temperatures. The interaction between the substrate, the mortar-based matrix and the open-grid make challenging the theoretical prediction of the mechanical behavior of the FRCM-retrofitted structures. For this reason, the analytical formulations for the proper design of FRCM-strengthening are still an open research problem, referring to both short and long term conditions. The present paper reports and discusses design-oriented relationships for FRCM-confinement and in-plane FRCM-strengthening of masonry elements; the proposals are intended to satisfy the requirements of simplicity and accuracy needed for code-finality.

Keywords: FRCM, confinement, shear, masonry, durability.

Investigation on End-Anchorage of SRG Composites Bonded to a Concrete Substrate

Xingxing Zou, Chris Moore, and Lesley H. Sneed

Abstract: Externally bonded (EB) steel reinforced grout (SRG) composites have the potential to improve the flexural and shear performance of existing concrete and masonry structural members. However, one of the most commonly observed failure modes of SRG-strengthened structures is due to composite debonding, which reduces composite action and limits the SRG contribution to the member load-carrying capacity. This study investigated an end-anchorage system for SRG strips bonded to a concrete substrate. The end anchorage was achieved by embedding the ends of the steel cords into the substrate. Nineteen single-lap direct shear specimens with varying composite bonded lengths and anchor binder materials were tested to study the effectiveness of the end-anchorage on the bond performance. For specimens with relatively long bonded length, the end-anchorage slightly improved the performance in terms of peak load achieved before detachment of the bonded region. Anchored specimens with long bonded length showed notable post-detachment behavior. Anchored specimens with epoxy resin achieved load levels significantly higher than the peak load before composite detachment occurred. For specimens with relatively short bonded length, the end-anchorage provided a notable increase in peak load and global slip at composite detachment. A generic load response was proposed for SRG-concrete joints with end anchors.

KEYWORDS: anchorage, bond, concrete, SRG composite

SHEAR STRENGTHENING OF REINFORCED CONCRETE T BEAMS USING CARBON REINFORCED CONCRETE

Sarah Bergmann, Sebastian May, Josef Hegger, and Manfred Curbach

Synopsis: A fundamental challenge for today and the future is the preservation of existing constructions. In addition to repair and maintenance measures, the effective strengthening of existing structures is of central importance to this issue. According to current regulations, a large number of existing reinforced concrete (RC) structures show deficits in their shear capacity, which is often limited by their existing shear reinforcement. The application of thin carbon reinforced concrete (CRC) layers can be a suitable and effective alternative to previously used strengthening methods. In this study, two RC T beam types, which differed in cross-section, were strengthened with CRC. The essential parameters of the strengthening layers were varied, and the influence of these changes on the load-bearing behavior and shear capacity of the T-beams was analyzed. Compared to non-strengthened test specimens, load increases of about 40% were achieved in the CRC-strengthened T beams.

Keywords: carbon reinforced concrete (CRC); textile reinforced concrete (TRC); fabric reinforced cementitious matrix (FRCM); shear strengthening; shear capacity; experimental test.

Influence of the test set-up on the bond behavior of FRCM composites

Angelo Savio Calabrese, Tommaso D'Antino, Pierluigi Colombi, Carlo Poggi, Christian Carloni

Synopsis: Externally bonded fiber-reinforced cementitious matrix (FRCM) composites are applied to the tension side of reinforced concrete (RC) beams to increase their flexural strength. Composite action is often prematurely lost because of the debonding of the composite, which for most of the available FRCMs occurs at the matrix-fiber interface. The bond behavior is studied at the small-scale by means of single- and double-lap direct shear tests. An alternative small-scale test configuration is the beam test. Beam tests can be performed using a single notched prism with a composite strip attached to the face where the notch is located (notched beam test) or by two prisms connected by a cylindrical hinge on one side and by a composite strip on the opposite side (modified beam test). As the scientific community is discussing the best test configuration, the goal of this paper is to shed light on the differences between the two test methods. In this paper, an FRCM composite comprising polyparaphenylene benzo-bisoxazole (PBO) fibers, which exhibits debonding at the matrix-fiber interface, is subjected to single-lap shear and modified beam tests. Load responses and failure modes are compared in an attempt to provide guidance on the selection of the test method.

Keywords: bond, direct shear test, FRCM, modified beam test

Flexural Behavior of Carbon Fiber Textile-Reinforced Concrete I-Section Beams

Kissila Botelho Goliath, Daniel C. T. Cardoso, and Flavio de A. Silva

Synopsis: Textile-reinforced concrete (TRC) is a composite material resulting from the combination of fine-grained concrete and textile reinforcement, widely used to strengthen existing structures. In addition, TRC is an alternative to obtain lighter and thinner structures. However, the behavior of these structures depends on the properties of the matrix and fiber used, as well as on the interface between these two phases. In this work, the interface properties of SBR-based carbon textile-reinforced concrete as supplied and after sand-coating treatment are evaluated through pullout tests. Then, to assess the bending behavior of structural members, four-point bending tests were performed on I-section beams using textiles with and without surface treatment. To analyse the evolution of cracking, digital image correlation (DIC) technique was used. The effectiveness of epoxy-sand treatment surface in textile reinforcement improve the bond between textile as well matrix as the failure mode of TRC beams and was confirmed by improved interface properties, i.e. a stiffer and stronger interface was obtained. In addition to the improved crack pattern, it was observed smaller and less spaced cracks.

Keywords: Textile Reinforced Concrete (TRC), I-section beam, Carbon textile, flexural behavior

An Overview of The Tensile and Bond Behavior of Fabric Reinforced Cementitious Matrix (FRCM) Composites

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Synopsis: In 2017, the Rilem Technical Committee 250-CSM coordinated a Round Robin initiative, in which 19 research institutions tested 28 Fabric Reinforced Cementitious Matrix (FRCM) composites, with the support of 11 industrial partners. Two years after the publication of the first papers on the results of this wide investigation, it is still worth further analysing its outcomes to highlight the fundamental properties of mortar-based reinforcements and give an overview of the various available fabrics and matrices, which are currently used in structural rehabilitation activities. Equally, a better understanding still needs to be gained on the causes of the variability observed in test results. These include the quasi-brittle behaviour of the inorganic matrix and its sensitivity to manufacturing, curing and handling. Test implementation, such as gripping method and measuring techniques, also plays a crucial role in the reliability and repeatability of experimental outcomes.

Keywords: Round Robin Test (RRT), Steel Reinforced Grout (SRG), Shear bond tests, Tensile tests, Test methods, Textile Reinforced Mortar (TRM).

Utility of Textiles in Ultra High Performance Cementitious Matrices

B.Y. Pekmezci

Synopsis: Fabric reinforced cementitious matrices (FRCM) or textile reinforced concrete (TRM) are being developed for various practical application areas by number of research groups. The properties of the composite depend on the properties of fabric and matrix and the matrix-fabric interface. Fabric-reinforced cementitious matrices provide high strength and toughness composite for applications in construction industry. In this experimental study, mechanical properties of glass and carbon fabric reinforced Ultra High-Performance Concrete (UHPC) as well as the performance of FRCM with lower strength mortar were investigated. Glass fabrics, sand coated SBR and only SBR coated carbon fabrics were used as reinforcements. In this context, compressive strength tests on matrices and, tensile tests on composites were performed. Fiber-matrix interfaces were examined and effects of the interface on the composite mechanical properties were also evaluated by scanning electron microscopy. Main result obtained from the study indicates that: the characteristic values of composites produced with ultra-high strength cementitious matrix under tension were higher than the characteristic values of composites produced with lower strength matrix. The difference is higher in the composite with carbon fabric. This difference is attributed to the higher strength and higher adherence of the fiber-matrix interface in the high strength matrix composite.

Keywords: Cementitious composite, FRCM, tensile strength, TRC, TRM, UHPC

Correlation of Tensile and Flexural Response of Continuous Polypropylene Fiber Reinforced Cement Composites

V. Dey, J. Bauchmoyer, C. Pleesudjai, S. Schaef, and B. Mobasher

Synopsis: The influence of engineered hydrophilic polypropylene fibers in the formation of distributed cracking and the associated strengthening and toughening of cement-based composites under mechanical loading was studied by conducting, correlating, and modeling tensile and flexural tests. An automated filament winding system was used to manufacture continuous fiber composites. Composites with continuous fibers consisting of low modulus surface-modified hydrophilic macro-synthetic polypropylene fibers were compared for their reinforcing ability with fibrillated micro-synthetic fibers. The digital image correlation technique was used for damage characterization using quantitative analysis of crack width, spacing, and correlated with the tensile response and stiffness degradation. It was observed that the mechanical properties as well as crack-spacing and composite stiffness were significantly affected by the microstructure and dosage of continuous fibers. Procedures for correlating tension and flexural test results were introduced using closed-form solution approaches for strain hardening materials.

Keywords: Textile Reinforced Concrete (TRC), Fiber Reinforced Concrete (FRC), Polypropylene Fibers, Filament Winding, Tensile response, Flexural response, Digital Image Correlation, Constitutive Relationship

Flexural strengthening of RC slabs with CRC and the influence of the positional accuracy

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Synopsis: Carbon Reinforced Concrete (CRC) can be used for new structures and to strengthen existing components. Carbon fibre rods and fabrics are used as reinforcement for new components. Besides CFRP-lamellas, grid-like carbon reinforcements and shotcrete are very suitable for strengthening. Due to the low concrete cover, thin strengthening layers can be realised, which minimise the additional dead load. Depending on the chosen fibre material and impregnation, different failure mechanisms can be observed. The fibre strand should preferably be able to reach the maximum stress under load, but at this stage, the bond behaviour has to be thoroughly considered to prevent failure due to pull-out or delamination. Two carbon reinforcement fabrics are currently being investigated in the research programme C³ - Carbon Concrete Composite.This paper presents the results of large-scale tests on reinforced concrete slabs strengthened with CRC. In addition to the strengthening procedure and the large-scale component tests that have been carried out, this paper deals mainly with the recalculation of the test results and the positional accuracy of the carbon reinforcement and its influence on the flexural strength.

Keywords: Textile Reinforced Concrete (TRC), Carbon Reinforced Concrete (CRC), Fabric Reinforced Cementitious Matrix (FRCM), flexural strengthening of RC slabs, experimental tests, calculation model, positional accuracy