A Review on Behavior of ECC Layer on Reinforced Concrete Beam with Basalt Rebar

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Abstract – In this review, the change in strength and the ductility behavior of Reinforced concrete beam is discussed when strengthened with basalt reinforcement and Engineered Cementitious Composite (ECC) layer at the bottom of the beam. Although numerous laboratory studies on strengthening of beams by providing ECC layer at the bottom, such as Strain Hardening Cementitious Composite (SHCC) in a steel reinforced concrete beam are conducted and then reported, there is still an apparent need for finding and executing new ways to improve the performance at basalt rebar. As in the case of RC, beams are subjected to uniform and continuous loading which increases with the increase in no. of the storey and may lead to partially damage or even total failure of the beam. In order to overcome the total failure of RC beams a layer of ECC such as SHCC is provided to distribute the cracks uniformly and make the beam even more ductile. This paper also focuses on the effect of providing basalt rebar in place of steel rebar. Both using ECC layer and basalt rebar, different types of the concrete beam increases the bond strength, overall load carrying capacity and first crack load can be concluded.

Keywords – Basalt Fiber Reinforced Polymer (BFRP), Strain Hardening Cementitious Composite (SHCC), Engineered cementitious composite (ECC), Ductility, Anti-corrosion bars.

1. INTRODUCTION

Conventional RC structure is faced with problems such as the formation of wide cracks due to its brittleness, a variation of live loads over time as well as the impact of climate. According to published research works, strain hardening cement-based composite (SHCC) became known in 1990 for its extraordinary higher strain/ductility performance, as well as strength, when compared to traditional normal concrete (NC) and fiber reinforced concrete (FRC). However, a type of SHCC called SIFCON (Slurry Infiltrated Fiber Concrete) was first reported in the late 1980s. In direct tensile tests, up to the elastic region, the stress increases as the strain increases, and after the first crack, the fiber bridging capacity of the SHCC leads to increase in stress upon further increase in strain. This so-called strain hardening continues until localization occurs in a crack, which leads to the onset of strain softening. In compression, ECC has a similar strength as concrete while the strain at the ultimate strength is nearly twice that of conventional concrete. Previous studies have indicated that the compatible deformation between ECC and steel reinforcement can reduce interfacial bond stresses and eliminate bond splitting cracks and surface spalling. Flexural members reinforced with basalt fiber-reinforced polymer (BFRP) reinforcement can hence exhibit significant increases in ductility, load carrying capacity, shear resistance, and damage tolerance if concrete is replaced by ECC material.

2. LITERATURE REVIEW

Homrich JR & Naaman AE (1988) [1] have studied the mechanisms of fiber reinforcement in SIFCON and the variables that control its strength, stress-strain response, toughness, and fracture properties. Their research should clarify the effects of four important parameters; (1) fiber types which vary according to surface characteristics and overall fiber geometry, (2) cement matrices which vary in strengths, water-cement ratio, flowability, and pozzolanic material content (in particular, the effect of micro silica pozzolans on matrix-to-fiber bonding will be studied), (3) specimen preparation procedures with particular emphasis placed upon comparison of responses of cylinders cored from precast blocks and cylinders poured directly into molds, and (4) the anisotropic behavior of SIFCON materials generated by the method and direction of fiber placement with specimen response being studied for fibers placed parallel and normal to the direction of testing.

Li VC. (1993) [2] has studied the performance-driven design approach in the development of strain hardening engineering cementitious composite (SHECC) design for shear intensive structure. A major link between structural performance and material structure tailoring is provided by micromechanics tools. By proper selection of fiber, matrix, and interference, they have demonstrated that a composite with improved strength, strain, and fracture energy properties can be manufactured and the amount of fiber reinforcement does not necessarily have to be excessively high. This aspect makes it possible to achieve cost-effectiveness and structural performance in safety, durability, and energy absorption capacities further justify the practical application of this new class material.

LIN ZHONG & Li VC. (1997) [3] have investigated on many kinds of polymeric fibers used in cement-based composites. Consequently, the surface treatment can somewhat increase chemical bonding, and fibers with hydrophilic nature such as polyvinyl-Alcohol (PVA) fibers can form strong chemical bonds with the cement matrix and can result in high interface fracture toughness. The slip-hardening interface Crack bridging in fiber reinforced cementitious composites behavior is the dominant mechanism behind the large discrepancy between experimental results and predictions with the constant friction model. The research also provides a possible way for further reducing material cost (through reducing critical fiber volume fraction) and maintaining sufficient ductility of the composite by ensuring multiple cracking (and hence strain-hardening).

Li VC. (2003) [4] has surveyed important elements of research and development in ECC over the last decade since its invention in the early 1990's, from materials design to commercial applications and importance of micromechanics playing the role of materials design, optimization, and constitutive ingredient tailoring. Reflections on material ductility, performance characteristics of reinforced ECC, or R/ECC, and cost considerations are examined. Future directions of ECC materials development and structural applications are indicated. He investigated that ECC is no longer confined to the academic research laboratory. It is finding its way into precast plants, construction sites, and repair and retrofitting jobs. ECC technologies will continue to accelerate in the next decade, benefiting society via the enhanced safety, durability, construction productivity and sustainable development of our physical infrastructures.

Jongsungsim et al (2005) [5] have studied the characteristics of basalt fiber as a strengthening material for concrete structures. The authors have tested and calculated different properties of basalt fiber like mechanical properties (tensile strength, elasticity modulus & elongation at failure), the durability of basalt fiber (alkali-resistance test, weathering resistance test, autoclave stability test, and thermal stability test). The authors have evaluated the applicability of basalt fiber as a strengthening material for reinforced concrete beams. The authors have bonded the basalt fiber sheets on the surface of the beam and this flexure strengthened specimens have tested under bending load. Based on the test result the authors have analyzed that the strength of specimens has increased by increasing number of layer of basalt fiber sheet. Finally, the authors have concluded that when compared to other FRP strengthening systems, basalt fiber strengthening system gave more strength with economical manner.

William P.B & Gideon P.A.G. (2007) [6] has studied the time-dependent behavior of a special class of fiber reinforced cement-based composites (FRCC), namely SHCC, often referred to as ECC. SHCC shows high ductility as it can resist the full tensile load at a strain of more than 3%. This superior response is achieved with multiple cracking under tensile loading which has a pseudo-strain-hardening phenomenon as a result. To identify the added sources of the time-dependent behavior of SHCC, rate and creep the author conducted tests are envisaged on the meso-level (a level where the pull-out of a fiber is prominent) and the macro-level. A constitutive model for macroscopic finite element analysis of ECC has been developed by author and implemented recently with the aim to simulate the time-dependent behavior. As the first step in this ongoing research project, the experimental results of rate-dependent tensile and flexural tests are reported as well as the uni-axial tensile creep of SHCC specimens. The results of shrinkage tests of SHCC are also reported by them.

Ludovico et al (2010) [7] have investigated the structural upgrade using basalt fibers for concrete reinforcement. The authors have used basalt fibers bonded with a cement based matrix as a strengthening material for the confinement of reinforced concrete members. The effectiveness of the proposed technique was assessed by comparing different confinement schemes on concrete cylinders like uni-axial glass fiber reinforced polymer (FRP) laminates, alkali resistant fiberglass girds bonded with a cement based mortar, bidirectional basalt laminates pre-impregnated with epoxy resin or latex and then bonded with a cement based mortar and a cement based mortar jacket. Finally, the authors have concluded that the confinement based on basalt fibers bonded with a cement based mortar could be a promising solution to overcome certain limitations of epoxy based FRP laminates.

Jingyu Wu et al (2010) [8] have studied the mechanical and thermal properties of BFRP rebar at elevated temperatures and after elevated temperature treatment. Their study is believed to offer the basic mechanical and thermal property data of BFRP rebar during and post-fire, which is helpful for the safe design of BFRP in rehabilitation when considering the fire hazarder. The tensile properties of BFRP rebar were performed by the author in the temperature ranging from room temperature to 350ć. Three stages of deterioration of the tensile strength and modulus are observed based on the degradation rate. It was found that the strength and stiffness of BFRPs still remain high values even at the temperature much higher than Tg (glass transition temperature) of the system. The deterioration is attributed to the decreased force transferring capacity of the resin. In addition, BFRP rebar were treated at elevated temperatures for various periods in an oven.

Fang Yuan1 et al (2013) [9] have investigated a number of BFRP-reinforced beams with different reinforcement configurations and matrix types have been tested under static loading conditions. For a BFRP-reinforced concrete beam, substitution of conventional concrete with ECC can significantly improve the flexural properties in terms of strength, deformation capacity, and energy dissipation ability. When ECC is only applied in a layer to form composite ECC/concrete beams, a member with ECC in the tension zone shows better deformation capacity than the member with ECC layer in the compression zone. Moreover, the ECC layer in the tension zone can help prevent rupture failure of the BFRP reinforcement at the ultimate stage. In summary, these experimental and theoretical results of author indicate that the application of ECC in BFRP-reinforced beam members is effective in enhancing load-carrying and deformation capacities, shear resistance, and ductility (in terms of energy dissipation ratio), in comparison to BFRP-reinforced concrete members.

Hailong W et al (2015) [10] have investigated the bond behavior between the BFRP bar and the ECC, pullout tests were performed by them to study the effects of the bar diameter, the embedded length, the cover thickness, and the properties of matrix materials on the bond performance. Their test results indicate that the bond strength is generally controlled by the shear resistance of the BFRP bar surface layer for most of the specimens with pullout failure. For the specimens with a cover thickness of 5.5 mm, splitting failure occurred. The bond strength between the BFRP bar and cementitious matrix decreases with an increase in the bar diameter, and the specimen with a shorter embedment length achieves a higher bond strength. Then the authors use a linear equation to describe the relationship between the average bond strength and the embedment length. The bond strength comes out to increase with the increase in cover thickness; however, this increase can be neglected when the ECC cover thickness exceeds 20 mm. The addition of PVA fibers decreases the damage and enhances the bond performances between the bar and the matrix.

Zheng Y.Z et al (2016) [11] have studied a new strengthening technique for reinforced concrete (RC) beams is proposed by combining BFRP grid and ECC as a composite reinforcement layer (CRL). Five RC beams externally bonded with the CRL at the soffit and one control RC beam was tested by them to investigate their flexural behavior. The thickness of BFRP grids (i.e. 1 mm, 3 mm and 5 mm) and the bonded length of CRL (i.e. 400 mm, 450 mm and 500 mm) were selected as two main parameters in the test program, while the width and thickness of CRL were fixed approximately at 200 mm and 30 mm, respectively. The test results by them showed that there is no clear CRL de-bonding in the strengthened beams. The two final failure modes were concrete crushing or rupture of the BFRP grids, indicating that the proposed technique is effective in suppressing the de-bonding of externally bonded materials and fully utilizing the material strengths. An analytical model is also presented by the authors to predict the load-deflection responses of the strengthened beams, which was validated through comparisons with the test results.

Jingming C et al (2017) [12] have studied the flexural behavior of ECC and concrete beams reinforced with basalt FRP bars were numerically investigated with the software of ATENA/GID solver. To verify the validity of the finite element models of the composite beams, the simulation results were compared by them with the published experimental results of both FRP reinforced concrete and ECC beams, and good agreements were achieved. According to the simulation results by them, the BFRP reinforced ECC beams show much better flexural properties in terms of load-carrying capacity, deformability and crack controlling ability compared with the BFRP reinforced concrete beams. Also, the BFRP bars in ECC matrix were much more efficiently utilized than those in concrete, and the failure process is much more ductile due to a much higher ultimate compressive strain of ECC materials in the compressive zone. An extensive parametric analysis was then conducted by them to examine the effect of various parameters on the flexural behavior of BFRP reinforced ECC beams.

Dawei et al (2017) [13] have studied to enhance the shear capacity and ductility of FRP reinforced members, ECC is proposed to replace the concrete partially or totally. Different from conventional concrete, ECC shows a strain hardening and multiple cracking behaviors under uniaxial tensile stress, with excellent crack control up to tensile strain of 3–5%. Flexural members can hence exhibit significant increases in ductility, load carrying capacity, and damage tolerance if concrete is replaced by ECC material. In this authors uses, basalt fiber-reinforced polymer (BFRP) as the tensile reinforcement for the ECC or concrete/ECC composite beam specimens. Several BFRP-reinforced ECC and concrete/ECC composite beams (with a layer of ECC on the bottom or top of the member) are tested by them to verify the contribution of ECC material on shear properties of the beams. The influence of different parameters (including transverse reinforcement ratio, presence/absence of shear reinforcement, shear span) on the ultimate strength, deformation capacity, and ductility are evaluated. BFRP-reinforced ECC beams showed much higher shear capacity and ductility than BFRP-reinforced concrete beams.

Mingke et al (2018) [14] have investigated the flexural behavior of reinforced concrete beams strengthened by highly ductile fiber reinforced concrete (HDC) and reactive powder concrete (RPC) in the tension and compressive zones. The crack distribution, failure pattern, load-displacement responses, flexural capacity analysis, displacement ductility and concrete strain are investigated by them. The experimental results from monotonic loading tests on the specimens show that the flexural capacity of specimens strengthened by an HDC layer in the tension zone was notably increased and that the specimens strengthened by an HDC or RPC layer in the compressive zone exhibit much higher ductility than the control concrete beams. Moreover, the proposed calculation method of flexural capacity is more accurate, consistent and conservative.

Xiuyi Lin et al (2018) [15] studied reuse and recycling of enormous amounts of polyethylene terephthalate (PET) solid wastes which leads to serious environmental issues. They studied the feasibility of recycling PET solid wastes as short fibers in Strain-Hardening Cementitious Composites (SHCCs), which exhibit strain-hardening and multiple cracking under tension, and therefore have clear advantages over conventional concrete for many construction applications. Based on micromechanical modeling, fiber dispersion and alkali resistance, the size of recycled PET fibers was first determined. Then the hydrophobic PET surface was treated with sodium hydroxide (NaOH) solution followed by a saline coupling agent to achieve the dual purpose of improving the fiber/matrix interfacial frictional bond and enhancing the alkali resistance for applications in alkaline cementitious environment. With surface treatment, recycling PET wastes as fibers in SHCCs is a promising approach to significantly reduce the material cost of SHCCs while disposing hazardous PET wastes in construction industry.

3. CONCLUSION

From above study on both the mechanical and durability performance of SHCC and BFRP. The influence of different loading rate, binder content, age, curing, exposure type, crack width, level of deformation on the mechanical, and durability properties of SHCC has been addressed. These factors need to be considered before the limits for designing this material can be set. Current knowledge on SHCC indicates that the mechanical behavior of this material is suitable for improving structural performance since it has a high tensile and flexural strength, ductility and most importantly, finer average crack widths at ultimate tensile and flexural resistance with BFRP is excellent. A general framework for dealing with the problems of such material in terms of durability is necessary. At present, there is limited information available on the replacement of PVA/PE fiber with waste polyethylene in SHCC. Therefore, this literatures review has put forward the need to investigate the aforementioned limitations. From this point of view, this paper gives a general overview of SHCC and BFRP durability performance, which can be used as a basis for a future durability framework for the application in beams.

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