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A Review of The Flexural Mechanical Properties Of ECC-Fiber Reinforced Composite Composite Reinforced Beams

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Abstract: Engineering fiber-reinforced cementitious composite (ECC) has good ductility and crack control ability, and fiber-reinforced polymer (FRP) has high bearing capacity. Combining the two can effectively enhance the flexural mechanical properties of reinforced concrete beams. This paper introduces ECC and fiber-reinforced composite materials, and the effects of this reinforcement method on cracks, deflection, and bearing capacity of reinforced concrete beams are reviewed.

Keywords: ECC,CFRP, Composite strengthening, Flexural capacity.

1. Introduction

The reinforced concrete structure combines the advantages of steel and concrete structure and has been widely used in the field of civil engineering. However, the tensile strength of concrete is low and shows brittle characteristics. In the use stage, the outer protective layer of concrete is easy to crack, and the cracks will accelerate the invasion of harmful substances, resulting in accelerated structure aging and obvious durability problems. However, there are many shortcomings in the typical building reinforcement materials, and the reinforcement effect of the widely used FRP reinforcement materials depends mainly on the bonding performance with concrete [1-2]. As a binder for FRP reinforcement, epoxy resin adhesive reduces the reinforcement utilization rate of FRP materials because of its intolerance to high temperatures and easy aging.

The high ductility and multi-crack development characteristics of ECC materials [3] can effectively control the cracks in reinforced concrete structures. In addition, ECC material has good durability and fire resistance[4-5] and good bonding performance with concrete. Using this as a binder can solve the problem of easy aging and heat resistance of traditional epoxy resin binder, effectively improving the utilization rate of carbon fiber cloth and preventing bonding damage.

2. ECC Material

Engineering fiber reinforced cementitious composites [6] (ECC) is a kind of short fiber reinforced cementitious composites with super toughness and random distribution, which was proposed by Li V C of the University of Michigan in 1992 based on the principle of micromechanics design. It does not contain coarse aggregate and is prepared with fiber as reinforcing material, cement, and quartz sand as a matrix.

Victor. C. Li [7] carried out uniaxial tensile tests on this material. The results show that the maximum strain of ECC material under uniaxial tensile load is greater than 3 %, showing high ductility.

Bai et al.[8]designed five PVA-SHCC beams and two reinforced concrete beams and conducted concentrated load bending tests to study their cracking performance. The test results show the fiber cement-based composite material has excellent multi-crack development performance. The test beams significantly improve crack width, height, spacing, etc.

Wang et al.[9] used epoxy resin adhesive and ECC as the binder of carbon fiber sheets to reinforce reinforced concrete beams, respectively. The three-point bending test was carried out to study the heat resistance of the two bonding materials. The experimental results show that at the same temperature, the peak load of the reinforced beam with ECC material as the binder is more than 50 % higher.

3. Fiber Reinforced Polymer

Fiber Reinforced Polymer (FRP) is a composite material made of fiber as reinforcement and resin matrix material through winding, molding, or pultrusion[10]. The different reinforcing materials can be divided into basalt fiber-reinforced composites (BFRP), carbon fiber-reinforced composites (CFRP), and so on.

Fiber composite materials have the characteristics of lightweight, high strength, durability, and good corrosion resistance[11], which are often used in the repair of concrete structures [12-13], making them play a huge role in the construction industry.

4. Influencing Factors of Flexural Mechanical Properties of FRP-ECC Composite Reinforced Beams

4.1. Effect on Bonding Roperties

ECC material has good bonding performance with concrete and good fire resistance and durability. As a binder, it can cope with various use scenarios and prevent early debonding of FRP materials.

Victor.C.Li [14] tested the material properties of ECC at 500°Cand the interfacial bonding properties between ECC and CFRP through material tests and pull-out tests. The results show that ECC still has strain hardening and multi-crack development at a specific high temperature, so ECC and CFRP still have good interfacial bonding properties.

Sui et al.[15] carried out a series of shear tests to study the effects of ECC thickness, concrete surface treatment methods, and construction methods on the interfacial bonding properties between FRP-ECC and FRP-ECC-concrete to solve the problem of early debonding failure of FRP materials caused by concrete crack expansion. The results show that adding ECC can effectively delay FRP's debonding and significantly increase FRP's maximum strain. The ultimate load and effective utilization rate of FRP increase significantly with the increase of ECC thickness.

4.2. Crack Performance Impact

The fiber in the ECC material has a strong ultimate elongation and good bonding with the cement matrix. After the crack occurs, the fiber bridges the matrix on both sides of the crack to control the cracks' generation to a certain extent, showing excellent strain hardening and multi-crack cracking performance.

Li et al.[16] studied the strain-hardening ability of ECC materials through uniaxial tensile tests. Studies have shown that ECC materials can still withstand tension after cracks due to the bridging effect of fibers after cracking, showing strain-hardening characteristics.

Ding et al.[17] used a four-point bending loading test to explore the structural behavior of reinforced ultra-high performance cement-based composite (UHPECC) beams under bending. The test results show that compared with ordinary reinforced concrete beams, the number of cracks in the test beams gradually increases after the first crack appears, while the crack width remains almost unchanged, reflecting the excellent crack control ability of ECC materials.

Zhou et al.[18] carried out a four-point bending test on CFRP-ECC composite reinforced concrete beams to study their bending resistance. The experimental results show that the number of cracks in the concrete layer increases due to the multi-crack development characteristics of the ECC layer, and the width of the cracks decreases with the increase of the thickness of the ECC layer.

4.3. Effect on Deflection

The addition of the ECC-FRP composite reinforcement layer makes the comprehensive effective reinforcement ratio of the reinforced beam higher, the bending stiffness of the reinforced beam is larger and the deflection is smaller under the same load.

Deng et al.[19] studied the influence of FRP grid thickness, ECC layer thickness, mix ratio, and interface treatment method on the deflection of reinforced beams by testing the flexural performance of FRP grid-ECC composite reinforced beams. The test results show that the flexural rigidity of reinforced concrete beams has been significantly improved after reinforcement, and the thickness of the FRP grid has the greatest influence on flexural performance.

Yan et al.[20] carried out a four-point bending test on eight pre-damaged CFRP grid-ECC composite reinforced beams to study the bending performance of each reinforced beam under different parameters. The test results show that the reinforcement method can make the pre-damaged reinforced concrete beam still achieve higher stiffness.

Emara M et al.[21] used CFRP reinforcement and CFRP-ECC composite reinforcement to reinforce reinforced concrete beams, respectively, and tested the flexural performance of the test beams. The test results show that the stiffness of the reinforced beams increases significantly with the increase of the width of CFRP, and the addition of an ECC layer can additionally enhance the overall stiffness of the reinforced beams.

4.4. Effect on Characteristic Loads

In the initial loading stage, the existence of ECC material in the composite reinforcement layer effectively delays and inhibits concrete cracking and improves the initial cracking load of the reinforced beam. After the concrete cracks, the FRP material exerts its high specific strength, which can provide additional bearing capacity and share the tension of the longitudinal reinforcement in the reinforced concrete beam so that the yield load and ultimate load of the reinforced beam are improved.

Qin et al.[22] replaced the concrete in the tensile zone of the reinforced concrete beam with ECC material to form a composite beam and studied the influence of ECC material on the flexural performance of the composite beam. The test results show that the composite beam shows better ductility and energy absorption capacity, and the load value of each stage is higher than that of the ordinary reinforced concrete beam.

Yang et al. [23] conducted a flexural performance test on 15 carbon fiber mesh-reinforced engineering cementitious composite reinforced concrete beams. The test results show that the greater the stiffness of CFRP mesh is, the more pronounced the improvement of flexural capacity is. However, when the stiffness of CFRP mesh is too large, debonding will occur, which is not conducive to the reinforcement effect of reinforced concrete.

Esmaeeli E [24] studied the flexural strengthening effect of hybrid composite plate (HCP) on reinforced concrete beams and carried out a four-point bending test on the test beams. The test results show that because SHCC material can exert the high tensile capacity of CFRP composite plate, the bending resistance of the test beams at yield and failure is obviously improved and shows good ductility.

5. Conclusion

This paper analyzes and discusses the research results of ECC materials, fiber-reinforced composites, and composite reinforcement by many scholars at home and abroad in recent years. From the current experimental research, the ECC material-fiber reinforced composite reinforcement method can give full play to the advantages of both, and the crack development, deflection, and bearing capacity of the reinforced beam are better improved. Much experimental research and analysis are still needed to explore the reinforcement effect better. For example, the bonding properties between ECC materials and different strength concrete and different types of fiber-reinforced composite materials, the cooperative working mechanism between the materials is unclear, and the research on the cooperative working effect of each material should be refined.

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