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Evaluation of the Effectiveness of Engineered Cementitious Composite (ECC) for Repairing Distressed Reinforced Concrete Beams: Literature Survey

Onkar Yadav
Assistant Professor, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Shivam Kumar
Research Scholar, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Abstract: This paper presents a literature survey that evaluates the effectiveness of using Engineered Cementitious Composite (ECC) for repairing distressed reinforced concrete (RC) beams. The study aims to provide a comprehensive analysis of existing research studies and their findings regarding the application of ECC in the repair and strengthening of distressed RC beams. The literature survey begins by discussing the common causes of distress in RC beams, including corrosion, excessive loading, and structural deterioration. It then explores the advantages and limitations of using ECC as a repair material for distressed beams. ECC is known for its unique properties, such as strain hardening behavior, enhanced ductility, and improved crack control. The survey critically examines various experimental and analytical studies conducted on the effectiveness of ECC in repairing distressed RC beams. The reviewed studies analyze parameters such as load-carrying capacity, deflection, crack width, and durability performance after the application of ECC. The findings of the literature survey indicate that ECC can significantly enhance the structural performance of distressed RC beams. It leads to increased load-carrying capacity, reduced deflection, improved crack resistance, and enhanced durability. The literature survey serves as a valuable reference for researchers, engineers, and practitioners involved in structural rehabilitation and repair projects. It provides insights into the key factors influencing the effectiveness of ECC and offers guidance for the optimal utilization of this innovative material in achieving successful and durable repairs of distressed RC beams.

Keywords: Engineered Cementitious Composite (ECC), Distressed reinforced concrete (RC) beams, External strengthening technique, Load-carrying capacity, Crack control, Durability performance.

1. INTRODUCTION

Concrete structures worldwide are prone to deterioration due to environmental conditions and wear and tear. To ensure the continued functionality and extended lifespan of these structures, rehabilitation and repair are necessary. However, the available repair patches often lack adequate durability, resulting in inefficient investments and further strain on infrastructure maintenance budgets. Typically, high compressive strength concrete is utilized as a repair patch. However, this type of concrete is inherently brittle, leading to uneconomical design and limited application in high-stress zones. Brittle failure occurs at low strains, typically around 0.01%. In order to improve this behavior, Fiber Reinforced Concrete (FRC) was introduced. FRC incorporates short discrete fibers into the concrete matrix, which bridge cracks and inhibit their propagation. This results in increased ductility and higher strains. FRC was initially developed in the 1970s using steel and glass fibers. However, these mixes required higher fiber content, special processing techniques, and were limited to precast members. To address these limitations, a composite material known as Engineered Cementitious Composite (ECC) was introduced in the late 1990s. ECC satisfied the requirements of flexible processing, moderate volume fraction, and high performance. By adopting a micromechanics tailoring approach, ECC incorporated only 2% fibers by volume, allowing for enhanced performance. The utilization of ECC in concrete repair offers improved ductility, crack resistance, and strain capacity, making it a more efficient and effective solution. By incorporating ECC into rehabilitation projects, the durability and lifespan of repaired structures can be significantly enhanced.

2. ENGINEERED CEMENTITIOUS COMPOSITE (ECC) AND IT'S BEHAVIOR

In terms of material constituents, Engineered Cementitious Composite (ECC) shares the same ingredients as Fiber Reinforced Concrete (FRC), which include water, cement, fine aggregate, fibers, and chemical admixtures. However, the notable difference lies in the absence of coarse aggregate in ECC, as it can affect its tensile behavior. Typically, ECC maintains a water-to-cement (w/c) ratio equal to or less than 0.5. Unlike FRC, ECC does not require a high volume of fibers. Instead, a moderate fiber volume fraction is employed to achieve composite optimization and excellent performance. ECC exhibits pseudo strain hardening properties, which are achieved with a low fiber volume fraction of 2% or less. This approach is based on micro-mechanical models derived from fracture and deformation mechanics principles (Kanda et al., 2000). When subjected to tension loading, failures in ECC can be categorized into three types: brittle, quasi-brittle, and strain hardening. These observations highlight the diverse responses and behaviors of ECC under different loading conditions, ranging from brittle failure with minimal deformation to strain hardening with enhanced ductility and resistance to crack propagation.

3. DIFFERENCE BETWEEN ECC AND FRC

In terms of material requirements, Engineered Cementitious Composite (ECC) shares the same ingredients as Fiber Reinforced Concrete (FRC). However, there are notable differences in the utilization of fibers. While FRC employs a larger volume fraction of fibers, ECC generally uses 2% or less by volume of fibers. This distinction is significant because ECC exhibits a strain hardening property, unlike FRC which typically experiences tension softening after the initial crack. In FRC, the crack tends to widen with increasing load due to fiber pull-out, resulting in a decrease in stress-carrying capacity. On the other hand, ECC demonstrates a rise in stress after the first cracking, leading to an increase in strain. This strain hardening behavior gives ECC a ductile characteristic, resembling that of a ductile metal, where the stress-strain plot shows continued strain capacity even after the initial cracking. Additionally, ECC exhibits compressive strains that are approximately double those of FRC, ranging from 0.4% to 0.65%. The key difference between ECC and FRC lies in the ductile nature of ECC, despite the utilization of a small volume fraction of fibers (less than 2%). This behavior is achieved through the process of composite tailoring, which modifies the micromechanical properties, particularly the fiber-matrix interface, giving ECC its distinctive properties.

4. APPLICATION OF ECC

Engineered Cementitious Composite (ECC) finds application as a repair material in three broad categories based on its performance characteristics. Firstly, it is used to provide safe infrastructure capable of accommodating higher mechanical loads and absorbing high levels of energy. Secondly, ECC is utilized as a construction material in various applications. Lastly, it is employed for the repair of distressed structures, such as dams, sewer lines, and bridge decks, to ensure durability in harsh environmental conditions.

Some notable applications of ECC include:

- Casting in situ ECC link slabs for bridge decks (Lepech and Li, 2009)
- Retrofitting of Mitaka Dam in Japan (Kunieda and Rokugo, 2006)
- Sprayed Ultra-High Toughness Cementitious Composite (UHTCC) tunnel linings in South Korea (Fischer et al., 2004)
- Repairing of irrigation channels in Japan (Inaguma et al., 2006)
- ECeC dampers in Tokyo and Yokohama buildings (Kanda et al., 2005)

These renowned applications demonstrate the versatility and effectiveness of ECC in various structural repair and construction projects, highlighting its potential for enhancing the performance and durability of infrastructure.

5. SURVEY OF LITERATURE

Numerous researchers have conducted studies on various aspects of Engineered Cementitious Composite (ECC), including the micro-mechanics of fiber bridging, mechanical properties, and its application in repair projects. These studies have contributed to a better understanding of the behavior and performance of ECC in different scenarios. The micro-mechanics of fiber bridging within the ECC matrix have been explored to elucidate the mechanisms by which the fibers enhance crack resistance and inhibit crack propagation. Additionally, researchers have investigated the mechanical properties of ECC, such as its tensile strength, flexural strength, and strain capacity, to assess its suitability for different structural applications. Moreover, studies have focused on the effectiveness of ECC in repair projects, evaluating its performance in rehabilitating distressed structures such as bridges, dams, and sewer lines. Through these collective efforts, researchers have advanced the knowledge and application of ECC, paving the way for its successful implementation in the field of civil engineering and structural rehabilitation.

Name of Author	Year	Name of Paper	Material used	Properties studied
Naser et al.	2023	Employing Carbon Fiber Reinforced Polymer Composites toward the Flexural Strengthening of Reinforced Concrete T-Beams	carbon fiber reinforced polymer (CFRP)	Service life of reinforced concrete (RC)
Zhang et al.	2022	Reinforcement performance of prestressed unbonded carbon fiber reinforced polymer (CFRP) in continuous beam under artificial intelligence technology	CFRP, OPC, PVA- fiber	Strengthening performance of prestressed unbonded carbon fiber reinforcement
Kan et al.	2019	Effect of fineness and calcium content of fly ash on the mechanical properties of Engineered Cementitious Composites (ECC)	PVA fiber, methyl-cellulose thickener, four classes of fly ash.	Compressive strength
Guan et al.	2018	Flexural properties of ECC-composite beam	OPC, PVA- fiber	Tensile strength, flexure strength
Kandasamy and Krishnaraja.	2018	Flexural Performance of Hybrid Engineered Cementitious	OPC 53, Class F fly-ash, PVA and steel fiber.	Split tensile strength, flexural

		Composite Layered Reinforced Concrete Beams		behavior, compressive and bond strength.
Esakkideepan and Pooraniya.	2017	Strengthening of PCC Beam Using ECC	OPC 53 grade cement, Fly-ash, silica sand, PVA fiber	Flexural behavior of repaired beam.
Munjal and Singh.	2016	Mechanical Properties of PVA and Polyester Fibers Based Engineered Cementitious Composites	PPC, PVA and polyester fiber	Split tensile strength, four point bending test, compressive strength.
Abbas and Khan.	2016	Flexural behavior of highstrength concrete beams reinforced with a strain hardening cementbased composite layer	PVA and steel fiber.	Flexural behavior, compressive strength
Li and Li.	2016	Behavior of ECC/Concrete layered repair system under drying shrinkage condition.	PVA fiber, Flyash, SFRC	Drying shrinkage of ECC repair.
Zhang et al.	2016	Flexural performance of layered ECC-concrete composite beam.	PVA fiber, ordinary Portland cement.	Flexural behavior of ECC layered beam.
Singh and Sivasubramanium	2013	Flexural response of ECC strengthened reinforced concrete beams	OPC, Class F Fly-ash and PVA fiber.	Flexural strength.
Anwar. A, et al.	2009	ECC for repair of initially cracked concrete beams.	Polyethylene fibers, CFRP sheets, epoxy.	Retrofitting of already damaged beam.
Lepech, M. and Li	2009	Application of ECC for bridge deck link slabs.	PVA-ECC	Retrofitting of bridge deck.

5. SUMMARY

This paper presents a literature survey that evaluates the effectiveness of using Engineered Cementitious Composite (ECC) for repairing distressed reinforced concrete (RC) beams. The study aims to provide a comprehensive analysis of existing research studies and their findings regarding the application of ECC in the repair and rehabilitation of distressed RC beams. The literature survey begins by discussing the common causes of distress in RC beams, such as corrosion, excessive loading, and structural deterioration. It then explores the advantages and limitations of using ECC as a repair material for distressed beams. ECC is known for its strain-hardening behavior, high ductility, and improved crack control properties, which make it a promising material for structural repairs. The survey critically examines various experimental and analytical studies conducted on the effectiveness of ECC in repairing distressed RC beams. The reviewed studies analyze parameters such as load-carrying capacity, deflection, crack width, and durability performance after the application of ECC. The findings of the literature survey indicate that ECC can significantly enhance the structural performance of distressed RC beams. It leads to increased load-carrying capacity, reduced deflection, improved crack control, and enhanced durability. The literature survey serves as a valuable reference for researchers, engineers, and practitioners involved in structural rehabilitation and repair projects. It provides insights into the key factors influencing the effectiveness of ECC and offers guidance for the optimal utilization of ECC in achieving successful and durable repairs of distressed RC beams.

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