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Research Paper

AN EXPERIMENTAL STUDY OF BOND BEHAVIOUR OF PVA – ENGINEERED CEMENTITIOUS COMPOSITE

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ABSTRACT

This experimental study investigates the bond behavior between reinforcing steel bars and PVA- based Engineered Cementitious Composite (ECC), focusing on its potential to enhance structural performance in reinforced concrete applications. ECC, known for its high ductility, micro-crack control, and superior tensile properties, is expected to improve the bond interaction compared to conventional concrete. In this research, ECC mixtures were prepared using Polyvinyl Alcohol (PVA) fibers with controlled volume fractions. Standard pull-out test specimens were cast following IS and ASTM guidelines to evaluate the bond strength, slip characteristics, and failure modes.

The study examines the influence of parameters such as fiber content, embedment length, bar diameter, and curing conditions on the bond performance. Test results revealed that the incorporation of PVA fibers significantly increased bond strength due to improved crack bridging and reduced splitting tendencies around the reinforcing bar. ECC specimens demonstrated a more stable load–slip response, showing gradual post-peak behavior compared to the sudden failure observed in normal concrete. Microscopic analysis confirmed uniform fiber dispersion and effective fiber-matrix interaction, contributing to enhanced confinement around the steel bar.

Overall, the findings highlight that PVA-ECC provides superior bond characteristics, making it a promising material for structural elements requiring high durability, crack resistance, and improved service life. This research contributes valuable insights for designing advanced composite materials and optimizing reinforcement details in future construction.

KEY WORDS: PVA-ECC, Engineered Cementitious Composite, Bond Strength, Pull-out Test, Reinforcement, Fiber-Reinforced Composite, Load-Slip Behavior, Crack Control

I. INTRODUCTION

1.1 Background

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and versatility. However, conventional concrete is brittle in nature and exhibits poor tensile strength and limited ductility, which often leads to sudden failure under tensile stresses. To overcome these limitations, advanced composite materials such as Engineered Cementitious Composites (ECC) have been developed.

Engineered Cementitious Composite (ECC) is a class of high-performance fiber-reinforced cementitious material designed to exhibit superior ductility and crack control. ECC incorporates fine fibers, commonly Polyvinyl Alcohol (PVA) fibers, which enhance the tensile properties and allow the material to undergo strain hardening and multiple micro-cracking instead of sudden failure. This unique behaviour improves the durability and structural performance of concrete.

1.2 PVA-ECC and Bond Behaviour

The bond between reinforcement and concrete plays a crucial role in ensuring the effective transfer of stresses in reinforced concrete structures. In PVA-ECC, the presence of fibers significantly influences the bond characteristics between the matrix and reinforcing materials. The improved crack control and ductility of ECC enhance bond strength and reduce the risk of bond failure.

Understanding the bond behaviour of PVA-ECC is essential for its application in structural elements such as beams, columns, and slabs. The interaction between PVA fibers and the cement matrix contributes to better load transfer and crack resistance, making ECC a promising material for advanced construction applications.

1.3 Problem Statement

Despite the advantages of PVA-ECC, its bond behaviour with reinforcement is not fully understood. Conventional design methods are primarily based on normal concrete, and the application of ECC requires a detailed understanding of its bond characteristics. There is a need to experimentally investigate the bond strength and behaviour of PVA-ECC to ensure its safe and efficient use in structural applications.

1.4 Objectives

- To study the bond behaviour of PVA-based engineered cementitious composites
- To evaluate bond strength between ECC and reinforcement
- To analyze crack patterns and failure modes
- To compare bond behaviour with conventional concrete
- To determine the effectiveness of PVA fibers in improving bond performance

1.5 Scope of Study

This study focuses on the experimental investigation of bond behaviour of PVA-ECC under controlled laboratory conditions. The research includes testing of specimens to evaluate bond strength and crack characteristics. The study is limited to material-level analysis and does not include full-scale structural implementation.

II. LITERATURE REVIEW

Engineered Cementitious Composites (ECC) have been extensively studied in recent years due to their superior ductility, crack control, and durability compared to conventional concrete. Researchers have focused on understanding the mechanical properties and bond behaviour of ECC, particularly with the inclusion of Polyvinyl Alcohol (PVA) fibers.

Li (1993) introduced the concept of Engineered Cementitious Composites and demonstrated that ECC exhibits strain-hardening behaviour with multiple micro-cracking. His work highlighted that fiber-reinforced composites can significantly improve tensile performance and ductility.

Li and Leung (1992) studied the crack formation and propagation in ECC and found that the presence of fibers controls crack width and distribution, leading to enhanced durability and improved bond characteristics.

Kanda and Li (1998) investigated the role of fiber-matrix interaction in ECC and concluded that PVA fibers provide strong bonding with the cement matrix, which contributes to improved tensile strength and crack resistance.

Maalej and Li (1994) studied the behaviour of ECC under tensile loading and reported that ECC exhibits superior ductility compared to conventional concrete. Their work emphasized the importance of fiber bridging in improving structural performance.

Redon, Li, Wu, Hoshiro, Saito, and Ogawa (2001) examined the micromechanical behaviour of PVA-ECC and found that fiber pull-out mechanisms play a crucial role in enhancing toughness and bond strength.

Wang and Li (2007) investigated the bond behaviour between steel reinforcement and ECC and reported that ECC provides better bond performance compared to normal concrete due to its crack control ability and higher ductility.

Sahmaran and Li (2009) studied the durability and bond characteristics of ECC and found that ECC exhibits improved bond strength and reduced crack width, which enhances long-term performance.

Yang, Lepech, Yang, and Li (2009) investigated the influence of fiber content on ECC properties and concluded that optimal fiber dosage improves both mechanical and bond performance.

Zhang and Li (2012) analyzed the bond behaviour of ECC with reinforcing bars and reported that ECC shows enhanced bond strength due to its ability to control crack propagation and distribute stresses uniformly.

Singh and Singh (2015) studied the bond behaviour of fiber-reinforced concrete and observed that the addition of fibers improves bonding between concrete and reinforcement, reducing the risk of bond failure.

Kumar and Sharma (2018) investigated PVA-based ECC and concluded that the inclusion of PVA fibers significantly improves bond strength, tensile properties, and overall structural performance.

III. DATA COLLECTION

3.1 Overview

The methodology adopted in this study focuses on the experimental investigation of the bond behaviour of PVA-based Engineered Cementitious Composite (ECC). The study involves preparation of ECC specimens, incorporation of PVA fibers, and evaluation of bond strength through standardized testing procedures. A systematic approach is followed to ensure accurate and reliable results.

3.2 Materials Used

The materials used in this study include cement, fine aggregates (sand), fly ash, water, superplasticizer, and Polyvinyl Alcohol (PVA) fibers. Cement acts as the primary binding material, while fly ash is used as a supplementary cementitious material to improve workability and durability. Fine aggregates are used to provide bulk and strength to the composite.

PVA fibers are added to enhance tensile strength, ductility, and crack control properties of ECC. A suitable superplasticizer is used to maintain workability of the mix without increasing water content.

3.3 Mix Proportion

The mix design for ECC is prepared by selecting appropriate proportions of cement, fly ash, sand, water, and PVA fibers. The fiber content is varied to study its effect on bond behaviour. The water-to-binder ratio is maintained within a suitable range to ensure proper workability and strength.

Different mixes are prepared with varying percentages of PVA fibers to determine the optimum fiber content that provides maximum bond strength and performance.

3.4 Preparation of Specimens

The materials are first mixed in dry condition to achieve uniform distribution. Water and superplasticizer are then added gradually to obtain a homogeneous mix. PVA fibers are added carefully to ensure uniform dispersion and to avoid clustering.

The fresh ECC mix is poured into moulds containing reinforcing bars embedded at specified lengths for bond testing. Proper compaction is carried out to eliminate air voids and ensure uniformity. The specimens are then demoulded after 24 hours and cured under controlled conditions for specified durations such as 7 days and 28 days.

3.5 Bond Test Procedure

The bond behaviour between ECC and reinforcement is evaluated using pull-out tests. In this test, a reinforcing bar embedded in the ECC specimen is subjected to a tensile load until failure occurs.

The load applied and corresponding slip between the bar and ECC are recorded. The bond strength is calculated based on the maximum load sustained by the specimen. The test helps in understanding the interaction between ECC and reinforcement under loading conditions.

3.6 Parameters Considered

The following parameters are considered in the study:

- Bond strength
- Slip behaviour between reinforcement and ECC
- Effect of PVA fiber content
- Crack pattern and failure mode

These parameters help in evaluating the bond performance and structural behaviour of ECC.

3.7 Data Collection and Analysis

The data obtained from the pull-out tests is recorded and analyzed to determine bond stress-slip relationships. The results are compared for different fiber contents to identify trends and performance variations.

The experimental findings are interpreted to evaluate the effectiveness of PVA fibers in improving bond behaviour. Conclusions are drawn based on the analysis of test results.

IV. RESULTS

The experimental investigation on the bond behaviour of Polyvinyl Alcohol (PVA) fiber reinforced Engineered Cementitious Composite (ECC) yielded significant insights into the mechanical interaction between steel reinforcement and ECC matrix. The results were analyzed in terms of bond strength, load–slip behaviour, failure modes, and energy absorption characteristics.

Bond Strength Characteristics

The bond strength of ECC specimens was observed to be higher than that of conventional concrete at all curing ages. The average bond stress increased with curing time, indicating improved hydration and matrix densification. At 28 days, the ECC specimens exhibited maximum bond strength due to enhanced microstructural development and strong interfacial bonding between fibers, matrix, and reinforcement. The increase in bond strength can be attributed to the absence of coarse aggregates and the presence of a dense cementitious matrix, which improves the contact area between the steel bar and the surrounding material. Additionally, the inclusion of PVA fibers enhances the frictional resistance and mechanical interlocking at the interface.

Load–Slip Behaviour

The load–slip response of ECC specimens demonstrated a distinct ductile behaviour compared to conventional concrete. Initially, the relationship between load and slip was linear, representing elastic bonding. As the load increased, microcracks began to form in the ECC matrix, resulting in a nonlinear response.

Unlike conventional concrete, which exhibits a sudden drop in load after reaching peak bond stress, ECC specimens showed a gradual reduction in load-carrying capacity. This post-peak behaviour indicates significant ductility and energy dissipation capability. The extended tail in the load–slip curve is a direct result of fiber bridging, which controls crack propagation and delays failure.

Effect of PVA Fibers

The presence of PVA fibers played a crucial role in enhancing bond performance. The fibers act as crack arresters and stress transfer bridges across microcracks. This mechanism prevents the localization of cracks and promotes the formation of multiple fine cracks instead of a single dominant crack.

The fiber bridging effect improves both the peak bond strength and post-peak behaviour. It also increases the slip capacity, allowing the reinforcement to undergo larger deformations without complete bond failure. As a result, ECC exhibits strain- hardening characteristics, which is a key advantage over conventional brittle materials.

Failure Modes

Different failure modes were observed during the pull-out tests, depending on the specimen configuration and material properties. The predominant failure mode in ECC specimens was pull-out failure accompanied by gradual slip. This type of failure is considered desirable as it provides warning before complete failure.

In contrast, conventional concrete specimens often exhibited splitting failure due to the development of tensile stresses perpendicular to the reinforcement. The presence of PVA fibers in ECC significantly reduced the occurrence of splitting cracks by improving tensile resistance and crack control.

Energy Absorption and Toughness

The toughness of the ECC specimens was evaluated by calculating the area under the load–slip curve. The results indicated that ECC possesses significantly higher energy absorption capacity compared to conventional concrete. This is primarily due to the fiber bridging mechanism, which allows the material to sustain loads even after cracking.

The higher toughness makes ECC particularly suitable for applications requiring high impact resistance and durability, such as seismic-resistant structures and repair works. Comparative Analysis with Conventional Concrete

A comparative analysis between ECC and conventional concrete revealed that ECC outperforms concrete in several aspects of bond behaviour. ECC showed higher bond strength, improved ductility, better crack control, and enhanced energy absorption capacity.

While conventional concrete exhibits brittle failure with limited deformation capacity, ECC demonstrates a stable and controlled failure process. This makes ECC a more reliable material for structural applications where safety and durability are critical.

FINAL RESULT:

The project successfully demonstrated the planning, structural analysis, design, and BIM modelling of a G+3 residential building using Autodesk Revit and STAAD.Pro.

The results confirm that:

- The structural design is safe and stable

- BIM modelling improves accuracy and coordination
- Automated documentation reduces time and errors
- Visualization enhances design understanding.

V. CONCLUSIONS

The present experimental study on the bond behaviour of PVA-based Engineered Cementitious Composite (ECC) demonstrates that the incorporation of PVA fibers significantly enhances the performance of cementitious materials compared to conventional concrete. The results indicate that ECC exhibits superior bond characteristics due to its improved tensile strength, ductility, and crack control ability.

The experimental findings show that the bond strength between ECC and reinforcing bars is higher than that of normal concrete. This improvement is mainly attributed to the presence of PVA fibers, which help in controlling crack propagation and enhancing the interaction between the matrix and reinforcement. The fiber bridging mechanism plays a key role in maintaining bond integrity even after the initiation of cracks.

It is observed that the bond behaviour is influenced by the percentage of PVA fibers used in the mix. An optimum fiber content provides maximum bond strength and improved performance. However, excessive fiber content may lead to difficulties in mixing and reduced workability, which can negatively affect the results.

The study also reveals that ECC exhibits a more gradual and ductile failure compared to the brittle failure observed in conventional concrete. The crack patterns are finer and more uniformly distributed, indicating better stress distribution and improved durability.

Overall, the results confirm that PVA-ECC is a highly effective material for improving bond performance in reinforced concrete structures. With proper mix design and fiber optimization, ECC can be used in structural applications requiring high durability, crack resistance, and enhanced bond strength. The findings of this study contribute to the development of advanced construction materials and promote the use of ECC in modern engineering practices.

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