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Beyond Ordinary Concrete: A Review of Engineered Cementitious Composites' Development and Potential

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ABSTRACT

A crucial component of many building projects is concrete. An innovative construction material known as Engineered Cementitious Composites, or Bendable Concrete, is developed by utilizing polyvinyl alcohol and jute fibers to generate a cementitious matrix that is reinforced with high-performance fibers. The characteristics of ECCs include a relatively average fiber content of 2% or less by volume, a narrow fracture width of about 60 µm, and high flexibility in the strain range of 3-7%. Uniaxial pressures cause these composites to exhibit strain-hardening behaviors. In comparison to ordinary and fiber-reinforced concrete, the strain can reach 3-8% higher. In this paper, the background, development, and potential of ECCs are discussed along with a study of the properties of conventional concrete and ECCs. By using a material design based on fracture principles and micromechanics, ECCs have been created to achieve increased tensile ductility with only a moderate amount of fiber reinforcement. Because of its resilience to cracks and ability for self-healing, engineered cementitious composites (ECC) offer the potential to lower the energy and carbon footprints of the built environment. In today's world, sustainability is essential to almost every industry, but none more so than the building and construction sector. Hence, exploring the potential of ECCs as a sustainable building material is necessary.

KEYWORDS: *Construction, Engineered Cementitious Composites, Reinforced Concrete, Sustainability.*

1. INTRODUCTION

Despite being the most common building material, concrete's lower flexural and tensile strength limitations—which can lead to structural failure under tension and shear without warning because of its brittle nature—have prompted research into improving these features even more. Currently, the construction industry uses a variety of fiber types to improve the aforementioned limitations of concrete and to increase its ductility, toughness, flexural strength, and tensile strength [1]. Engineered cementitious composites (ECC) have gained recognition as a special type of construction material with numerous advantages over conventional concrete, including improved ductility and strain-hardening capabilities. ECC was developed by Prof. Victor C. Li of the University of Michigan in the 1990s. Over the past two decades, ECC has been successfully utilized in various construction projects for the purposes of repairs and retrofitting, demonstrating its transformative potential in the field. In the composition of ECCs, Ordinary Portland Cement (OPC) plays the role of the binder, polyvinyl alcohol (PVA) fibers act as the fiber reinforcement, and silica sand serves as the fine aggregates in ECC. As ECC requires less maintenance because of its endurance, its usage phase has a significant impact on the sustainability of civil infrastructure [2]. ECC's microscopic, tightly controlled cracks minimize water infiltration and corrosion, leading to longer-lasting structures. It offers improved seismic performance, allowing it to absorb energy and deform without catastrophic failure. The high tensile capacity allows for thinner designs, saving material and weight. ECC can be sprayed, pumped, or extruded, enabling complex shapes and repairs inaccessible to traditional concrete. Being a novel material, ECC is progressively being applied in various projects, including repairing earthquake-damaged structures, building precast components with intricate details, and creating durable and lightweight bridge decks.

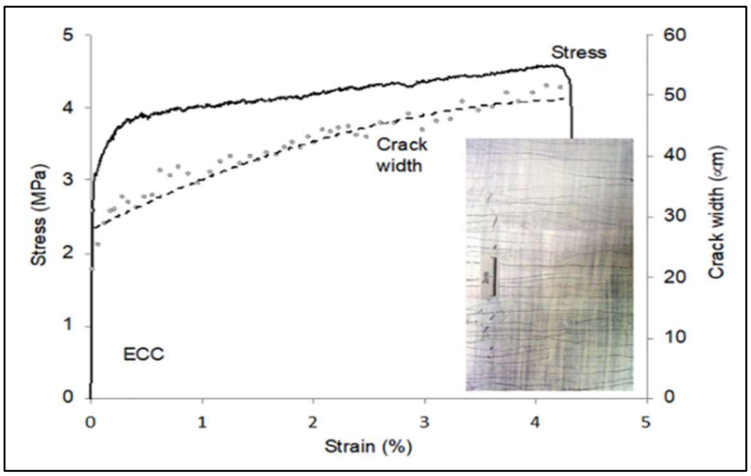

Figure 1: Common ECC strain-hardening behaviour, with a strain capacity of several percent and a crack width of less than 100 μm [3].

2. MATERIALS EMPLOYED

ECC exhibits pseudo-strain-hardening with a comparatively low percentage of fiber volume (2% and less). It shows both fine multiple cracking and excellent tensile ductility. The materials used in ECC manufacturing are mentioned in detail below.

2.1. CONVENTIONAL CEMENT TYPE 1 GRADE 53

After a period of 28 days of curing, grade 53 cement is used to achieve a minimum compressive strength of 53 megapascals (MPa). Cement's compressive strength is a measure of how effectively it can withstand axial loads without breaking down. For constructions requiring the maximum level of compressive strength, grade 53 cement is chosen. It can be used in key structural applications where long-term durability and the capacity to support large loads are essential [4].

2.2. FINE SAND

For ECC to maintain the required stiffness and volume stability, fine silica sand possessing a value of 0.36 for the sand to binder ratio (S/B) is utilized. Glass, iron ore tailings, coarse river sand, sea sand, and recycled concrete have all mostly or entirely replaced fine silica sand in the ECC [5].

2.3. FLY ASH

For a high tensile strain capacity, a significant volume percentage of fly ash is typically used to diminish the polyvinyl alcohol (PVA) fiber/matrix interface bond and matrix toughness. There is a limit to how much ash can replace cement due to the development of compressive strength [6].

2.4. WATER REDUCER

As it can greatly enhance the durability, mechanical properties of concrete, along with its rheological performance, in addition to fulfilling the multi-level and multi-functional requirements of numerous construction projects and service environments, polycarboxylate superplasticizer (PCE), an essential component of cementitious materials, is becoming more and more important to the building sector [7].

2.5. POLYVINYL ALCOHOL FIBERS

Monofilament fibers known as polyvinyl alcohol fibers spread throughout the concrete matrix to form a multidirectional fiber network that controls shrinkage, resists abrasion, and shields the material from thermal expansion and contraction [8, 9].

3. DEVELOPING ECCS USING PVA AND JUTE FIBERS

ECC is a member of the micro-mechanically engineered material family, so called because it was developed with considerable tensible ductility by the use of fracture mechanics [10]. As a result, it provides a forum for research directions, paying particular emphasis to in-depth material analysis and composite scales. All the constituent parts of concrete are present in the ECC, but to improve load distribution, different types of fiber are used in place of the coarse aggregates. They are often considered green building materials because throughout the production process, they reduce greenhouse gas emissions by 35–40%. ECC has good flexibility and a strain capacity of more than 1.5–3% [11], which allows for controlled cracking. Sand to binder ratio (S/B) of 0.36 for fine silica sand is required to maintain the appropriate stiffness and volume stability of the Engineered Cementitious Composite. Water to binder (w/b) ratio for the ECC-M45 is 0.26, and the entire amount of cement and fly ash (Type F) constitutes the binder system.

Table 1: Mix proportions of PVA-ECC M45 [12].

Vol%	Cement (kg/m^3)	Fly Ash (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	PVA Fiber (kg/m^3)	Total (kg/m^3)
2	571	685	456	332	6.8	26	2076.8
0.5	571	685	456	332	6.8	6.5	2057.3
0.1	571	685	456	332	6.8	1.3	2052.1

The flexible reinforcing agents in concrete that deliver both static and dynamic loads to their surroundings are the polymer-modified jute fibers. Employing natural fibers in the experimentation processes has its own benefits over artificial fibers. ECC is being utilized to assess a broad range of fiber types; however, poly-vinyl alcohol (PVA) fiber, measuring 12 mm in length and 39 µm in diameter, is employed in the largest experimental dataset, PVA-ECC-M45. In order to lessen the fiber/matrix interfacial bonding, it is surface coated with a proprietary oiling agent (1.2% by weight) and has nominal tensile strength, stiffness, and density of 1600 MPa, 40 GPa, and 1300 kg/m^3. A fiber percentage of 2% by volume is typically used to allow for diversity in mix formulation. Excellent ECC has been experimentally produced with the mix design mentioned above. Many building projects have made use of this reference mix's adaptations. The United States and Japan both engaged in full-scale production of ECC.

4. EXPERIMENTAL INVESTIGATIONS AND RESEARCH

The main cause of structural element failure over time is concrete's inability to support tensile strain. The ability of the ECC to exhibit strain hardening behaviour following the emergence of cracks sets it apart from normal fiber reinforced concrete. ECC exhibits a very high damage tolerance and a phenomenal fracture toughness that is on par with aluminum alloys. A green ECC with high tensile ductility and robust matrix strength at early stages was developed through an experiment carried out by Zhu et al. [13]. A combination of mineral admixtures derived from granulated blast furnace slag was used to evaluate 65–70% of the attributes of the ECC through a comprehensive experimental study. The specimens treated with admixtures may demonstrate strain hardening behaviour and an ECC tensile capacity of more than 2.5% at 90 days after casting, according to the results, which were obtained using the same standard tests. It was possible to obtain high-quality strength early on with the samples that comprised only fly ash and slag [14]. After 60 years of use in the field of bridge decks, comparative studies conducted by the Centre for Sustainable Systems at the School of Natural Resources and Environment, in collaboration with Li's group, reveal that ECC is nearly 37% less costly than standard concrete. There is a nearly 40% reduction in energy consumption. In comparison to ordinary concrete, the production of carbon dioxide is also decreased by over 39% [15].

5. RESULTS AND DISCUSSION

After reviewing the research that has been carried out on ECC, the results show that the flexural strength of standard concrete is 4.83 MPa, but specimens containing 0.5% hybrid fibers (PVA and Jute fibers) have a flexural strength value of 8.66 MPa. When compared to the conventional beams, the 0.5% fiber beams displayed an approximately 79.3% improvement in flexural strength. In contrast to normal concrete, which had a ductility index less than 23.35%, specimens with 0.5% fiber content had a ductility index of 23.35%. Consequently, compared to regular/plain concrete mix, fiber-filled concrete specimens are more ductile. More flexural and ductile behaviour is observed in the ECC composite material than in traditional concrete products when 0.5% of PVA or jute fibers are added. Bendable concrete, which emerged from laboratories, is being used in new building projects, repairs, and retrofits [14].

6. CONCLUSION

In the construction sector, ECC is considerably better than other building materials. It has the potential of being considered as a building material of the future generation. In addition to proving concrete with shear strength, the fibers function as ligaments. It promotes sustainable growth and is robust [15]. ECC's small crack width and strong tensile ductility allow it to address a wide range of contemporary issues with traditional concrete's brittleness and cracking. Consequently, infrastructure is improved and strengthened significantly. The PVA-microscopic ECC's crack enables it to self-heal under a variety of environmental conditions. The future of ECC is full of potential, with ongoing research and development paving the way for innovative applications and improved performance. A large number of researchers and engineers worldwide are working on further developing the ECC. It is currently being used in several projects involving civil engineering, playing its role in shaping the future of sustainable and resilient construction [16].

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