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Flexural strength and impact resistance study of fibre reinforced concrete in simulated aggressive environment

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HIGHLIGHTS

- Exploring simulated aggressive environments effects on flexural and impact strengths of FRC.
- Exploring relationship between flexural strength and impact resistance of FRC.
- Microfibre ruptured in bending whereas macrofibre was pulled-out.

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ABSTRACT

In addition to being exposed to chloride and sulphate attacks, marine structures are subject to seismic and impact loads resulting from waves, impact with solid objects, and water transports. Therefore, the flexural behaviour and impact resistance of Fibre-Reinforced Concrete (FRC) in marine environment must be elucidated. However, such information is scarcely reported. Therefore, this study aims to explore the effects of simulated aggressive environments on flexural strength and impact resistance of FRC and to identify the relationship between the two parameters. Three types of fibres, namely, coconut fibre, Barchip fibre (BF), and alkali-resistant glass fibre, were used in this study. The fibre dosage ranged from 0.6% to 2.4% of the binder volume. All mixes have constant water/binder ratio of 0.37 and their compressive strengths were all exceeding 60 MPa. The specimens were prepared and exposed to three different aggressive exposure environments, namely, tropical climate, cyclic air and seawater conditions, and seawater environment for up to 180 days. Results indicate that flexural strength and impact resistance of FRC have a direct relationship with fibre content. Nonetheless, change in fibre type is more significant than increasing fibre dosage in enhancing flexural strength but alteration in both matters would significantly impact the impact resistance. Tensile strength of an individual BF (640 MPa) is much higher than the flexural strength of the BFRC composite. Thus, failure of concrete matrix was observed to occur prior to the rupture of the fibre which in turn resulted in fibre pull out from the concrete matrix. Among the various FRC examined, FRC containing the highest BF content (2.4%) demonstrated the best flexural strength performance. The flexural strength of the Barchip FRC was observed to be increased by 11–13% in all exposure environments after 180 days. The pre-crack energy absorptions, which were determined through impact load test were found to increase by 60–63% as compared to the control concrete, which exhibited no post-crack energy absorption. Meanwhile, the post-crack energy absorptions of the 2.4BF were found to range between 3.67 J and 3.71 J for various environmental exposure conditions. Analysis of variance (ANOVA) results showed that flexural strengths were significantly increased after six months of exposure to the various aggressive environment conditions, especially in seawater. This could be due to formation of salt crystals which contributed towards enhancing the fibre/matrix frictional bond. However, the exposure environments have no significant effect on impact resistance performance. A logarithmic relationship was found between flexural strength and total impact energy absorption.

1. Introduction

Fibre Reinforced Concrete (FRC) is a conventional concrete mix which contains short discrete (or discontinuous) fibres that are randomly distributed within the fresh concrete mix. Subsequently,

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the fibres may be partially aligned by the process of shotcreting, surface finishing or by other means of consolidations. Besides, partial alignment of the discrete fibre could also be achieved due to geometrical constraints in formwork, mould surfaces, or interfaces with existing concrete, rock or subgrade [1]. There are four categories of discontinuous fibre in general, namely; natural, synthetic, glass and steel fibre.

Fibre is useful in bridging cracks, transferring loads, and developing microcracks distribution systems [2]. With that, the use of fibre reinforcement in concrete enhances its compressive, flexural, and tensile strength. In such circumstances, the structural performance, shear strength, energy absorption capacity, damage tolerance in flexural and shear-critical members under reversed cyclic loading as well as the ductility of concrete is also improved by the composite actions that occur between the fibre and the bonding matrix [3,4]. According to Tatnall [1], the presence of a high amount of fibres in the matrix corresponds to a high probability of intercepting the microcracks, which is, the zone of weakness upon being subjected to bending stresses. Nonetheless, excessive fibre content would create air voids in the micro and macrostructures of the cementitious matrix, resulting in poor quality of the fibre/matrix interface zone, hence, weak fibre/matrix bond [5].

Reis [6] performed a study on fracture and flexural characteristic of natural fibre reinforced polymer concrete. The main objective of the study was to determine the feasibility of replacing the synthetic fibre using natural fibre in polymer concrete. Three types of natural fibre were used, namely; coconut fibre, bagasse fibre and banana fibre. Among the various type of fibre examined, coconut fibre exhibited the most excellent reinforcing effect, followed by bagasse fibre and banana fibre. The use of coconut fibre reinforcement in concrete has resulted in the improvement in fracture energy by 100.8% as compared to the control unreinforced concrete specimens. Besides, it also allowed the concrete specimens to achieve greater ultimate failure load and mid span deflection under bending. The mechanical strength performance of the coconut fibre reinforced concrete was comparable to the previous work done using carbon and glass fibres reinforced concrete.

Baruah and Talukdar [7] conducted a comparative study on the engineering properties of concrete reinforced using various fibres from different origin. Among different content of coconut fibres (0.5–2.0% by volume fraction), the coconut fibre reinforced concrete (CFRC) with 2.0% fibre volume fraction exhibited the best engineering performance. The compressive, flexural, splitting tensile and shear strengths of 2% CFRC were 13.7%, 28.0%, 22.9% and 32.7% higher as compared to the plain unreinforced concrete.

Savastano Jr. and Agopyan [8] studied the transition zones of fibre reinforced cement composites. They made comparisons between two different water/cement ratios (0.30 and 0.46) and between vegetable fibres (coir, malva and sisal) and synthetic fibres (chrysotile asbestos and polypropylene). They confirmed that the thickness of fibre-paste interface transition zone (ITZ) increased with higher water/cement ratio, but decreased on prolonged period of curing. The ageing effect has caused the fibre to decay. In addition, they explained that the gap between the fibre/matrix interfaces was caused by the high desiccation shrinkage of the vegetable fibres. The porous transition zone caused the debonding of vegetable fibre from the cement paste matrix under loading. However, the impermeable fibres like asbestos and polypropylene could mitigate this problem. A small gap still exists in the transition zone of asbestos and polypropylene reinforced cementitious composite due to the wall effect (the fibres surface get wetted by a thin water film), but the thickness was not more than 20 μm.

MacVicar et al. [9] studied on the ageing mechanisms in cellulose fibre reinforced cement composites have concluded that the ageing effects under natural weathering and carbon dioxide (CO_2) rich conditions enhanced the durability properties. They explained that the natural fibres are able to preserve their flexibility and strength in carbonated cement matrix, where the pH values had already dropped to 9 or less.

Nonetheless, the properties of the vegetable fibre from one single plant have high degree of variation. Location, age, natural degradation, etc. are the important factors which govern the properties of vegetable fibre. These pose a challenge to replicate the properties of natural vegetable fibre [6].

Polyolefin is a polymer created from a chain of simple olefin (monomer) which is the largest group of thermoplastics. Polyethylene and polypropylene are the most common types of polyolefin. Barchip fibre is a new polyolefin based synthetic fibre. It is very light, with density of 900–920 kg/m^3 and durable. Neeley et al. [10] investigated the production of high strength concrete using high content of polyolefin fibres. The fibre bundles could be dispersing uniformly throughout the matrix even when the fibre is used at high volumetric ratio. The use of polyolefin fibres at 0.98 vol% (percentage of concrete volume) to 1.64 vol% could significantly increase the post cracking behaviour as well as all other engineering properties of FRC. The post crack behaviour of polyolefin FRC is comparable to FRC containing 0.25–0.5 vol% hooked end steel fibres. However, the addition of polyolefin fibres has no significant influence on chloride diffusivity and drying shrinkage of FRC.

Yan et al. [11] concluded that the bond which exist between the fibre/matrix interface is mainly mechanical based on their investigations on polyolefin fibre reinforced concrete composite. The fibre/matrix bond could be strengthening by improving the anchorage of fibre tendrils and their surface roughness. Otherwise, the bond would not be strong and mainly dependent on the static friction induced by normal pressure of the matrix on the fibre surface. The debonding process and slippage at the fibre/matrix interface would occur when shear stress on the interface zone has exceeded the fibre/matrix bond strength. Normally, this debonding would occur at the intersections of a crack and fibre, and end by the frictional shear stress. If the shear stress persistently increased, the total pull-out of fibre from the matrix would occur. In their further study [12], they have further explained the dissipation of vibration energy dissipation through debonding process which occurred at the interfacial zone. When a given FRC beam is subjected to impact load, the concrete matrix would rub on the fibre while the strain of concrete is varying, thus the vibration energy was dissipated through the frictions which existed in the fibre–matrix interface zone. Damping effects occurred due to these frictions and the vibration amplitude lied within this range. The debonding would take place when the vibration amplitude is large enough and subsequently resulting in the increment of cracks length, width and number of cracks. When the fibre with greater diameter for a given length (lower aspect ratio) is used in FRC, greater resistance to crack opening at the same level of matrix strain could be observed.

Similar to other fibres, the glass fibres undergo the same mechanical reinforcing mechanism in enhancing the toughness and tensile strength of the GFRC. Barluenga and Hernández-Olivares [13] studied the crack propagation behaviour of concrete with short alkali-resistant (AR) glass fibres at early ages, i.e. less than 24 h. The use of high fibre content (1000 g/m^3) resulted in lower crack control efficiency due to the formation of cracks which were parallel to the fibres orientation at the GFRC slab. Apart from these, the addition of AR glass fibres does alter the compressive strength, flexural strength, ultrasonic pulse velocity and Young Modulus of the concrete significantly.

The aggressive environments refer to the seawater environments and the tropical climate, with the former being more severe than the latter. In addition to suffering from chloride, sulphate, and