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Flexural Performance of a Pultruded GFRP Short Beam with Reinforced Concrete Infill

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Abstract **-** This study reports on the results of an experimental investigation into the flexural behaviour of a hybrid pultruded GFRP-reinforced concrete short beam. The external pultruded GFRP composites not only protect the concrete core from chemical attacks in the marine environment but also serve as structural enhancements to the hybrid system. Conversely, the concrete core provides the system with bulk size and structural stability. The experimental results, including the load-displacement curves and failure modes, are compared for the reinforced beams with or without the external GFRP reinforcements. The loading capacity shows in increase of 150 % when compared to the normal reinforced short beams.

Keywords**:** Pultruded composites; Short hybrid beam; Reinforced concrete; Failure modes

1. Introduction

Reinforced concrete structures are integral to coastal engineering, offering robust solutions for a variety of marine structures that are subjected to environmental stresses. From seawalls and breakwaters to bridge supports and offshore platforms, reinforced concrete can provide sufficient strength to withstand the harsh loading environment [1]. However, the durability of reinforced concrete structures is a critical concern due to the corrosive marine environment they are exposed to. The presence of chloride ions as well as the cyclic wetting and drying cycles could notably accelerate the deterioration of the concrete structures [2-5]. To address the durability issue of reinforced concrete in coastal engineering, external fibre-reinforced polymer (FRP) sheets have been increasingly used as a protective measure due to their excellent anti-corrosive performance [6]. The use of FRP sheets could not only provide a barrier against chemical attack from seawater and marine organisms, but also providing structural strengthen and confinement to the internal reinforced concrete members [7, 8].

While external FRP sheets offer several advantages in enhancing the durability of concrete structures, they are not without their own challenges. One primary issue associated with FRP sheets is their adhesion to the concrete substrate [9]. The degradation of the adhesive material between the FRP and concrete substrate can lead to delamination or debonding over time, consequently compromising the effectiveness of the FRP. Another concern with the FRP sheets is the high labour cost of the traditional FRP composites [10]. To address these challenges, proper selection of high-quality/advanced FRP materials is essential. Among FRP composites, pultruded glass fibre reinforced polymer (GFRP) composites offer a promising solution to the challenges associated with traditional FRP materials. Unlike traditional FRPs, pultruded GFRPs are manufactured through a highly automated continuous process, resulting in reduction of labour-cost, higher fibre volume fractions as well as outstanding mechanical properties [11, 12]. This advantage justifies the initial investment and at the same time, the enhanced structural performance could provide sufficient stiffness and strength to the material, making it an ideal independent structural element, hence avoiding the use of adhesive when combined with concrete in one hybrid system. The aim of this study therefore is to investigate the behaviour of a hybrid system made of a rectangular hollow pultruded GFRPs filled with reinforced concrete. To this end, experiments are carried out on reinforced concrete beams with/without the use of pultruded GFRP to compare the structural performance of the hybrid beams.

2. Experimental program

2.1. Manufacture of the beams

Three reinforced concrete short beams and three concrete-infilled pultruded GFRPs hybrid beams were prepared to meet the project requirements and testing equipment specifications. Each reinforced concrete beam had dimensions of 350 mm × 170 mm × 80 mm. Each hybrid beam comprised a 350 mm long hollow pultruded GFRP composite and a reinforced concrete core, as depicted in Fig. 1. The pultruded GFRP composites measured 190 mm × 100 mm × 10 mm and were composed of an isophthalic polyester resin and 60% volume fraction glass fibres. Mechanical properties of the pultruded composites are detailed in [10]. All beams and corresponding concrete cylinders were cast on the same day using the same mix to minimize the variations. To encapsulate moisture within the infilled concrete, all beams were stored under room temperature conditions with steel plates and plastic bags sealed on both ends. Cylinders tests conducted on the same day as the beam tests yielded results of 61.5 MPa for compressive strength, 29.5 GPa for elastic modulus, and 4.2 MPa for indirect tensile strength.

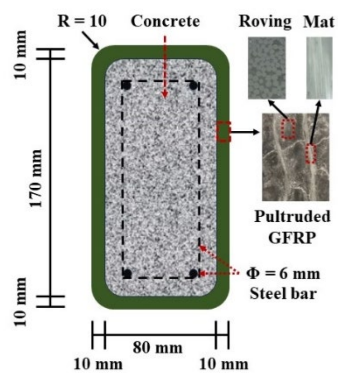

Fig. 1: Cross-sectional design of concrete infilled hybrid beam.

2.2. Test set-up and procedure

All the manufactured beams were positioned on the GEO-CON MCC8 Quasi-static loading machine with a three-point bending setup (see Fig. 2). A camera system was equipped to facilitate crack detection and monitor crack development. A loading rate of 100 N/s was selected in accordance with the quasi-static testing protocol for the beams.

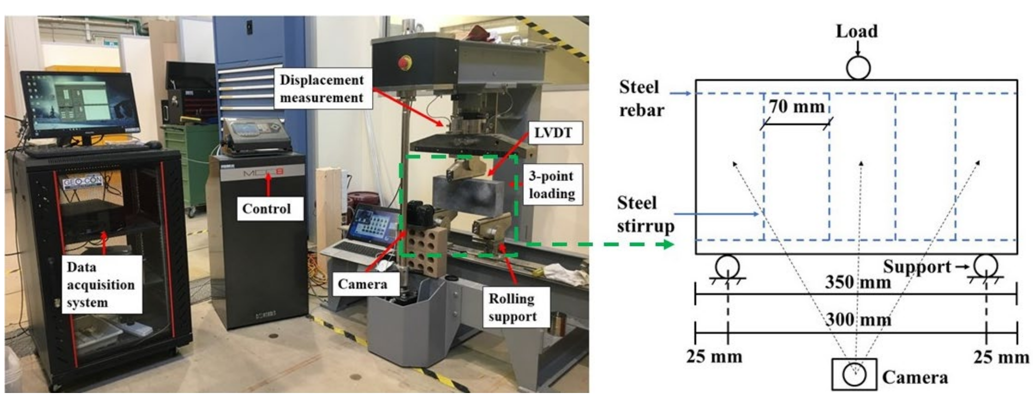

Fig. 2: Experimental setup of the beam tests.

3. Results and discussions

3.1. Failure modes

Fig. 3 illustrates the failure modes observed in both types of beams: reinforced concrete sort beam and hybrid GFRP-reinforced concrete beam. In the case of the reinforced concrete beams, failure ensued due to significant shear cracking (Fig. (Fig. 3(a)). Followed by the emergence of symmetrical shear cracks originating from the bottom and extending towards the the top loading position at a 45-degree angle. On the other hand, the failure modes of hybrid beams are plotted in Fig. 3 (b-d). The major shear crack in the internal concrete core remained concealed by the external GFRPs. The predominant failure mechanisms observed included shear cracks of the pultruded composites, delamination, and slippage between the concrete core and the FRP composites. For all the hybrid beams, ultimate failure occurred due to shear cracks developed at the corners of the pultruded composites.

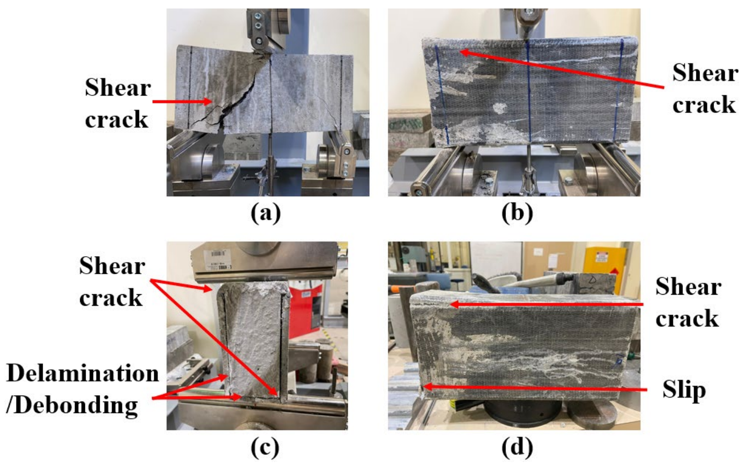

Fig. 3: Failure modes of tested beams (a: Reinforced concrete beam; b: Front view of hybrid beam; c: Side view of hybrid beam; d: Back view of hybrid beam).

3.2. Load-displacement behaviour

The load-midspan displacement histories for all tested beams are presented in Fig. 4. As shown, these curves illustrate distinct stages for both types of beams: an initial loading stage followed by a plastic resistant stage. During the first stage, there is a near-linear increase in load until the maximum value of load is reached. Notably, a slight drop occurs at around 800 microns of mid-span displacement for the reinforced concrete beams and approximately 1600 microns for the hybrid beams, indicating the initiation of the first crack in the concrete section. The average maximum load for the reinforced concrete is 71.6 kN, whereas for the hybrid beams, it is 180.4 kN, representing a remarkable 150 % increase in load-carrying capacity compared to the reinforced concrete beam. The second stage extends from the peak load to the occurrence of ultimate failure. In this stage, a major shear crack is developed at a 45-degree angle for the reinforced concrete beams. Conversely, the hybrid beams exhibit multiple failure mechanisms, including debonding failure (delamination) between the concrete and pultruded composites, as well as shear cracks on the corners of the pultruded GFRPs. The average maximum displacement of the hybrid beams recorded at the end of this stage is 5794 microns, approximately 1000 microns higher than that of the reinforced concrete beams.

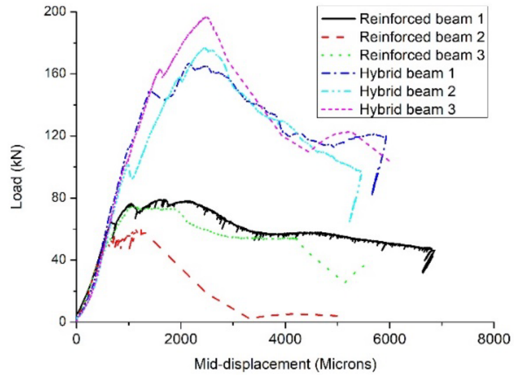

Fig. 4: Load-displacement curves of tested beams.

4. Conclusion

An experimental investigation into the behaviour of a pultruded GFRP short beam with reinforced concrete infill was conducted in this study. Two types of beams were tested using an instrumented three-point loading machine. The reinforced concrete beams exhibit s shear failure mode. Conversely, the hybrid beams displayed multiple failure mechanisms, including delamination and shear cracks on the external pultruded composites, with the latter serving at the precursor to ultimate failure. With the enhancement provided by the pultruded composites, the load capacity increased by 150 % compared to normal reinforced short beams.

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