Experimental investigation on reinforced concrete beams by honeycomb sandwich panel structures: mechanical properties study

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Abstract. In this work, the results of an experimental investigation on reinforced concrete by fiberglass honeycomb sandwich panel structures are presented. The experimental program included three beam specimens. Two of the beams were reinforced with different thicknesses of honeycomb structures. Flexural and uniaxial compression tests were performed. The tensile strength remains to be increased by a factor of 2.40 for compression and by 1.60 for flexion. The results obtained in terms of reinforcement are discussed. The changes are likely attributed to a modification of the adhesion forces at the honeycomb structures/concrete interface.

1. Introduction
The shear reinforcement of concrete elements with composite materials is in fact a subject of research far from being completely solved. This composite was used as an innovative strengthening and rehabilitating material and seems to be an attractive topic for practitioners and researchers [1,3]. Thus, the application of reinforcement has received much attention in the construction engineering industry. The use of reinforced structures in civil engineering increase rapidly and various type of reinforcement is used such as glass, carbon, asbestos and steel [4]. The honeycomb sandwich structures is one of the most valued structural engineering innovations developed by the composites industry [5].

The results of an experimental investigation on Reinforced Concrete (RC) T-beams retrofitted in shear with prefabricated L-shaped Carbon Fiber Reinforced Polymer (CFRP) plates were presented by Mofidi et al. [6]. They show that the performance of the specimens strengthened with partially and fully embedded L-shaped CFRP plates in the beam flange was superior to that of the beams strengthened Externally-Bonded (EB) with FRP sheets and L-shaped CFRP plates with no embedment. Rena et al. [7] studied one of the most devastating failure models in reinforced concrete structures i.e. the diagonal tension failure. Numerical model was used capable of dealing with both static and dynamic crack propagation.

Moreover, different forms simulation models presented in the literature as reviewed in the paper by Nayalet. al [8]. The model developed was used in the study of Wahalathanri et al. [9] and it was applicable for both reinforced and fiber reinforced concrete with only minor changes. Also, this method indicates similarity to the tension stiffening model that is needed for Abaqus concrete damaged plasticity model (CDP). This tension stiffening model was originally based on the homogenized stress-strain relationship developed by Gilbert et al [10] which accounts for tension stiffening, tension softening and local bond slip effects. Two descending portions of the tensile stress...
strain graph have accurately captured the response caused by primary and secondary cracking phenomena. The layered tension stiffening parameters used is replaced with a single set of stiffening parameters applicable to the entire tensile zone by the Nayal et al. [8].

Mofidi et al studied the behavior of T-beams, shear-reinforced with unidirectional Carbon Fiber Polymer CFP in EB the form of "U". Twelve beams of dimensions of 152 mm × 406 mm × 4520 mm were tested, whose objectives were to study experimentally and analytically the effect of the parameters that influence the shear strength of the Fiber Reinforcement Polymer FRP and to propose a set of equations of design to calculate the FRP contribution to the shear strength of reinforced concrete beams. The set of results to be achieved that the FRP contribution to shear strength was significantly higher for reinforced concrete beams without transverse reinforcement than for beams with transverse reinforcement [6].

The aim of this study is to present a new technique of the concrete reinforcement of beam by using honeycomb structures and to predict what extent a reinforced concrete structure can resist in the elastic mode. First material preparation with honeycomb sandwich panel structures and test setup is conferred. Results and discussion in term of reinforcement is presented.

2. Materials preparation and test setup

Specimens of rectangular concrete beams were prepared by mixing Portland cement with strength of 45 MPa (CPJ45), gravels, send and water with normalized proportion of ingredients. Honeycomb sandwich panel structures are introduced in the center of the rectangular concrete beam (Fig 1-a). Crushed sand with a granular class 0/5 was used. The gravel used in our concrete formulation was a granular class of 6.3/10. The mix proportions of concrete, namely the ratio of gravel, sand, cement, and the water / cement ratio was 0.55. The beams specimens were cured in the forms for 24 hours. At this time the specimens and cylinders were taken from the molds and were cured under water at 20° for 28 days. Then, they were stored to air-dry in a room at constant humidity and temperature until the time of test. Al used specimens had 400 mm in height and an overall length of 100 mm with a span length of 100 as can be seen in Fig 1-b (not reinforced one is noted S-Ref). Two of specimens were reinforced by honeycomb sandwich panel structures (noted S-HCt1 and S-HCt2) with two different thicknesses 3.22 (S-HCt1) and 5.76 mm (S-HCt2) respectively (Fig. 1-c).

![Figure 1](image)

Figure 1: a- Honeycomb sandwich panel structure in the concrete beam, b- Rectangular concrete beams, and c- Honeycomb sandwich panel structures.
Moreover, recently the use of honeycomb sandwich materials was very pronounced especially to strengthen structures [11-12]. It’s formed by adhering two high-rigidity thin-face sheets with a low-density honeycomb core possessing less strength and stiffness. In our experimental study, the composite was made using fiberglass reinforced honeycomb. The illustrative scheme of sandwich panel concrete, composite (fiber glass / honeycomb / fiberglass) is sketched in Fig. 2. The fibre material was glass of the E type, while honeycomb and epoxy employed as matrix material. The ultimate strength parallel to the strong direction was specified by the supplier, whereas the volume fraction of fibres and the ultimate strain corresponding to the two principal material directions were not precisely known. The ratio of the two volume fractions of fibers, where the subscripts \( s \) and \( w \) stand for strong and weak directions, respectively, was estimated in the ratio of 2 to 1 by the supplier. The young’s modulus parallel to the strong direction was established from uniaxial tests performed on small specimens. Because fiberglass behaves in tension in a linear elastic manner up to failure, we can determine the ultimate tensile strain from Hooke’s law knowing the ultimate stress and the Young’s modulus.

![Scheme of sandwich panel concrete / composite (fiber glass / honeycomb / fiberglass) / concrete.](image)

**Figure 2:** Scheme of sandwich panel concrete / composite (fiber glass / honeycomb / fiberglass) / concrete.

The tests of the prepared concrete were carried out using hydraulic jack of capacity 1500 kN. They were tested on the loading frame under axial compressive and flexion loading. The axial load is applied through hydraulic jack of 1500 kN capacity. The sectional properties of the specimens for uniaxial load are 400 mm x 100 mm x 100 mm. Flexion were tested under three-point bending until failure (Fig. 3-a and Fig. 3-b). The rate of loading was 0.1 mm/min, and the tests were continued up to 3 mm mid-span deflection. Two point loads with a distance of 300 mm were applied the load to the top of the specimens at the middle one-third of the span. The sectional properties of the specimens are shown in Fig. 4. The width of the composite was 3.22 mm and 5.76 mm. Moreover, The Young’s modulus \( E \) of two honeycomb structures are obtained by the following relation:

\[
E = E_{FG} \left(1 - \frac{cs^3}{h^3}\right) \nu_{FG} \cdot 1
\]

Where \( E_{FG} \) is the fiberglass Young’s modulus, \( cs \) is the honeycomb thickness and \( h \) designate the sandwich thickness. According to equation 1, the Young’s modulus of S-HCt1 is 70 GPa and for S-HCt2 71 GPa.
Figure 3: Scheme of sandwich panel concrete / composite (fiber glass / honeycomb / fiber glass) / concrete.

Figure 4: Test setup and specimens dimensions for the unreinforced and reinforced concrete beams

3. Results and discussion
The experimental results giving stress-strain curve on beams in axial load and flexion are presented in Fig. 5-a and Fig. 5-b respectively. Generally, the results of the uniaxial load and flexion show that the mechanical properties of the reinforced beams increase with the used composites. Indeed, and for uniaxial load, the tensile strength increase from 30 020 MPa for unreinforced beam to 32 495 MPa and 33 198 MPa for the beam reinforced by honeycomb sandwich structures with respectively 3.22 and 5.76 mm of thickness. We have registered that the reinforced beam resists sharp stresses and can reach up to a factor of 2.40 for compression. On the other hand, the same behavior was depicted for flexion and remains to be increases by a factor of 1.60. The comparison of results for compression and flexion
are resumed in figure 6. A similar phenomenon was experimentally observed by Mofidi et al. [6] with beam strengthened by fiber-reinforced polymer. They affirm that the use of polypropylene fiber will enhance strength and behavior of reinforced concrete also improves resistance against impact loading and fire. The residual ultimate strength is larger than the corresponding strength of beams without polypropylene fibers by more than 60%. No sudden failures are observed in all beams containing polypropylene fibers. Mofidi et al. [4] investigated that CFRP (carbon fiber–reinforced polymer) does provide improved impact resistance with increasing volumes of fibers. A CFRP mixture does provide reductions in permeability provided that the water-cement ratio remains below 0.5. Increased percentages of fibers further decreased the permeability provided the mixture remained workable. The study indicates a reduction in plastic shrinkage with increasing amounts of fibers. The polypropylene fibers decrease plastic shrinkage provided the water-cement ratio remains below 0.5. Wear resistance of PFRC has not been widely studied, but one study found an increase in the wear resistance with increasing fiber contents.

### Table 1: Compressive strength, flexural strength and Young’s modulus value

|                | Flexural strength (MPa) | Compressive strength (MPa) | Young’s modulus (MPa) |
|----------------|------------------------|----------------------------|-----------------------|
| S-Ref          | 25                     | 5.20                       | 30020                 |
| S-HCt1         | 46.11                  | 7.89                       | 32495                 |
| S-HCt2         | 59.68                  | 8.37                       | 33198                 |

As reported by Table 1, the compressive strength of unreinforced concrete is 25 MPa while for a reinforced concrete, the resistance is respectively 46.11 MPa and 59.68 MPa for a concrete reinforced with honeycomb sandwich panel structures with thickness of 3.22 mm and thickness of 5.75 mm. Also the bending strength for an unreinforced concrete varies from 5.20 MPa to 8.34 MPa, while for a concrete reinforced by honeycomb sandwich panel structures with thickness of 3.22 mm the value was about 7.89 MPa, for a reinforced concrete by the composite with thickness of 3.76 mm the resistance was 8.37 MPa. Finally, it is very clear that the concrete reinforced with honeycomb sandwich panel structures with thickness 5.76 mm is the best one comparing it with the other two, because the greatest value of mechanical properties.

![Figure 5: Experimental stress-strain curves for studied specimen; a- compression, b- flexion](image)
Experimental results show that the fiber-reinforced composite controls concrete cracking, including limiting crack opening and transforming the fragile behavior of concrete into ductile behavior. Concrete always has micro cracks due to different causes such as shrinkage, thermal stresses etc. when a cracked concrete is subjected to tension, the tension lines bend and the stresses at the ends of the crack increase. This inflection is due to the fact that the load cannot be transmitted through the crack. For a concrete without fibers subjected to tensile stress, its low tensile strength is quickly reached or even exceeded. A crack then appears and spreads freely leading to a brittle fracture. In the case of a concrete with fibers, stressed in tension, part of the stress is taken up by the fibers bridging the cracks, this prevents the material from breaking brittle because the propagation of cracks would require greater energy. Indeed, since the maximum length of a micro crack is of the order of the largest aggregate size and the average length of a fiber is greater than the size of the aggregate, each micro crack propagating in the matrix can be bridged by one or more fibers. Thus, micro cracks can only be enlarged by the elastic or plastic elongation of the fibers or the rupture of the fibers. These tensile and shear stressed fibers absorb some of the energy required for crack propagation and prevent uncontrolled propagation of concrete cracking. More energy and effort would then be required to propagate this cracking. The greater the quantity of fiber and the greater the anchoring length, the more effective the fibers.

4. Conclusion
The experimental test is performed on simple three-point bending tests on rectangular beams and crush tests on both sides of rectangular beam after bending fracture with reinforcement by fiber reinforced honeycomb structure. Of glass in the form of a sandwich. The results obtained show that adding the composite can significantly increase the compression beam capacity by about 24%. The ultimate strength and modulus of elasticity of reinforced concrete reinforced by the composite differ from the ultimate strength and modulus of elasticity of the concrete matrix. Nevertheless, the presence of the composite in the concrete increases the deformation at break and thus confers a greater ductility to the concrete. As with bending, the composite provides a slight increase in the bending strength of reinforced concrete with a 16% increase and some ductility of post-fracture behavior of the composite. The presence of fibers plays an important role in composite bending behavior. Comparing the two reinforcements by the composite thickness 3.22 and composite thickness 5.76, the results show that increasing the thickness of the reinforcement increases the contribution vis-à-vis the shear capacity and especially in compression.

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