International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 18 (2019) pp. 3685-3688


# Numerical Study on Reinforced Concrete Beams by Honeycomb Sandwich Panel Structures

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## Abstract

The purpose of this work is to present the results of a simulation investigation on reinforced concrete by fiberglass honeycomb panel structures. The numerical study program included three beam specimens. Flexural compression test were simulated and compared to previous work conducted in our laboratory. The experiment was combined with simulations using finite element analysis (FEA) code Abaqus and revealed that both of them were in a fairly good agreement.

**Keywords:** Concrete beam, Flexure, Honeycomb panel structure, Finite element analysis (FEA).

## 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. The honeycomb sandwich structures is one of the most valued structural engineering innovations developed by the composites industry [4].

Moreover, different forms of simulation models presented in the literature as reviewed in the paper by Nayalet. al [5]. The model developed was used in the study of Wahalathanri et al. [6] and it was applicable for both reinforced and fibre reinforced concrete with only minor changes. Also, this method indicates similarity to the tension stiffening model that is needed for Abaqus concrete damaged plasticity (CDP) model. This tension stiffening model was originally based on the homogenized stress-strain relationship developed by Gilbert et al [7] which accounts for tension stiffening, tension softening and local bond slip effects. Two descending portions of the tensile stress strain graph has 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].

By this study, we intend to contribute to a better understanding the reinforcement of concrete beam effect using honeycomb panel structures and to predict what extent a reinforced concrete structure can resist in the elastic mode.

## 2. MATERIALS AND METHODS

### 2.1 Finite Element Analysis

Finite element software is able to investigate the physical and mechanical behavior of the beams. Moreover, The FEA is applied widely in the calculation of structures with reliable results such as reinforcing structures with honeycomb sandwiches panel one. Also, The FEA makes it possible to solve in a discrete manner a partial differential equation whose approximate solution is sufficiently reliable. Numerical tests were carried out using the well tested commercial finite element Abaqus software (CAE 6.14-1).

The 3D models were built using a parallelepiped shapes. The final models were meshed using rectangular elements 0.1 to 1 mm long for the composite. A mesh refinement with the level set to 0.1 (0.1 maximum length of the mesh elements) was performed for the overlaps. Mesh convergence study carried out using displacement measurements depicts that the above mesh is finer enough to obtain a reliable result.

The model characteristics of the numerical test for the chosen concrete were: linear 3D element 4 point of integration, 8 nodes linear brick, reduced integration, hourglass control (C3D8R).

The mechanical and materials properties used in the simulation for concrete and honeycomb sandwich panel structures were depicted in the table 1-a.

**Table 1-a:** Mechanical properties of concrete.

| Concrete | |
|---|---|
| **Parameter** | ***Value*** |
| *Density* | *2400 kg/m$^3$* |
| *Young's modulus* | *30.02 10$^9$ N/m$^2$* |
| *Poisson's ratio* | *0.2* |
| *Dilatation angle* | *31* |
| *Eccentricity* | *0.1* |
| *K* | *0.666* |
| *Viscosity parameter* | *0* |
| *Compressive strength* | *2.4 10$^7$ N/m²* |
| *Tensile strength* | *2.4 10$^6$ N/m²* |
| $f_{b0}/f_{c0}$ | *1.16* |

The modeling of structures in honeycomb is too long and tiring. The homogenization of the honeycomb allows to acquire solid homogeneous one identical and its modules of stretch to accomplish very efficient simulation: diminish broadly the time of preparation of geometries and mesh sizes, as well as the time CPU.

The classical models of homogenization of honeycomb were systematically represented by Gibson et al. [9].

For the homogenization of the honeycomb, we will use mindlin's theory with an orthotropic material, to perform homogenization; we need to define a Representative Volume Elementary (RVE) of the material as show in the Figure 1.

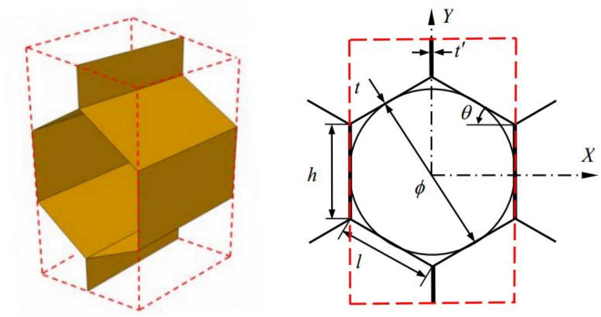


**Fig. 1:** RVE and Geometry of a cell of cardboard honeycomb [9].

analytical expressions of Gibson to determine elastic ownership of the nest of honeycomb.

Young's modulus direction 1 $$E_1 = E_s\left(\frac{t}{l}\right)^3 \frac{\cos\theta}{\left(\frac{h}{l}+\sin\theta\right)\sin^2\theta}$$

Young's modulus direction 2 $$E_2 = E_s\left(\frac{t}{l}\right)^3 \frac{\frac{h}{l}+\sin\theta}{\cos^3\theta}$$

Young's modulus direction 3 $$E_3 = E_s\left(\frac{t}{l}\right) \frac{\left(\frac{h}{l}+2\right)}{2\left(\frac{h}{l}+\sin\theta\right)\cos\theta}$$

Module of shearing in plan XY

$$G_{12} = G_s\left(\frac{t}{l}\right)^3 \frac{\frac{h}{l}+\sin\theta}{\left(\frac{t}{l}\right)^2\left(1+\frac{2h}{l}\right)\cos\theta}$$

Modules of shearing transverse $$G_{13} = G_s\left(\frac{t}{l}\right) \frac{\cos\theta}{\frac{h}{l}+\sin\theta}$$

$$G_{23} \geq G_s\left(\frac{t}{l}\right) \frac{\frac{h}{l}+\sin\theta}{\cos\theta\left(1+\frac{h}{l}\right)} \ (limite\ inf.)$$

$$G_{23} \leq G_s\left(\frac{t}{l}\right) \frac{\frac{h}{l}+\sin\theta^2}{\cos\theta\left(\frac{h}{l}+\sin\theta\right)} \ (limite\ sup.)$$

Poisson's ratio $\vartheta_{21}$ $$\vartheta_{21} = \frac{\left(\frac{h}{l}+\sin\theta\right)\sin\theta}{\cos^2\theta}$$

Poisson's ratio $\vartheta_{12}$ $$\vartheta_{21} = \frac{\cos^2\theta}{\left(\frac{h}{l}+\sin\theta\right)\sin\theta}$$

Poisson's ratio $\vartheta_{23}$ $$\vartheta_{23} = \frac{E_2}{E_3}\vartheta_{32}$$

Poisson's ratio $\vartheta_{13}$ $$\vartheta_{13} = \frac{E_1}{E_3}\vartheta_{31}$$

Poisson's ratio $\vartheta_{31}, \vartheta_{32}$ $$\vartheta_{31} = \vartheta_{32} = \vartheta$$

From the geometry of a honeycomb cell (Fig. 1 and Table. 1.b) and mechanical properties of cardboard paper, we use our homogenization models for calculating the properties of the equivalent homogenized solid (Table. 1.c)

**Table 1-b:** Geometric parameters of a cell of cardboard honeycomb.

| $\emptyset\ (mm)$ | $\theta\ (°)$ | $l = h\ (mm)$ | $t\ (mm)$ | $t'(mm)$ |
|---|---|---|---|---|
| 8 | 30 | 4.62 | 0.19 | 0.38 |

**Table 1-c:** Properties of homogenized solid equivalent to honeycomb.

| $E_1\ (MPa)$ | $E_2\ (MPa)$ | $E_3\ (MPa)$ |
|---|---|---|
| **14.42** | **17.58** | **226.61** |
| $\vartheta_{12}$ | $\vartheta_{13}$ | $\vartheta_{23}$ |
| **0.6474** | **0.0255** | **0.0310** |
| $G_{12}\ (MPa)$ | $G_{13}\ (MPa)$ | $G_{23}\ (MPa)$ |
| **1.09** | **19.99** | **24.71** |
| $\vartheta_{21}$ | $\vartheta_{31}$ | $\vartheta_{32}$ |
| **0.789** | **0.4** | **0.4** |

## 2.2 Materials

Experimentally verification was conducted by preparing test beams with the same dimensions and also with honeycomb sandwich panel structures of the same dimensions. The beams were supported by rollers. 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 2-b (not reinforced one is noted S-Ref). Two of specimens were reinforced by honeycomb sandwich panel structures (noted S-$HC_{t1}$ and S-$HC_{t2}$) with two different thicknesses 3.22 ($HC_{t1}$) and 5.76 mm ($HC_{t2}$)

respectively (Fig. 2), and cross section of the beams were show in Fig. 3.

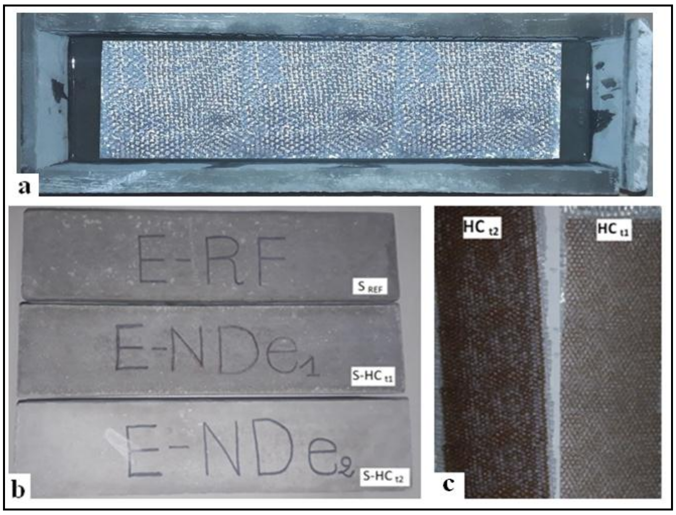


**Figure 2:** a- Honeycomb sandwich panel structure in the concrete beam, b- Rectangular concrete beams, c-Honeycomb sandwich panel structures.

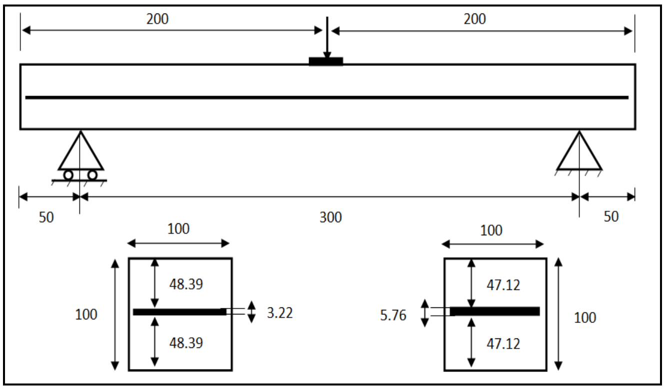


**Figure 3:** Test setup and specimens dimensions for the unreinforced and reinforced concrete beams.

## 3. RESULTS AND DISCUSSION

The FE model of reinforced concrete beam consists of three type of materials, concrete in the absence and in the presence of honeycomb sandwich panel structures. The numerical results on beam loaded in three-points in the absence (S-REF) and in the presence on reinforced by composite with the different thickness ($HC_{t1}$ , $HC_{t2}$ ) are presented in Fig. 3 (a), Fig. 4 (b) and Fig. 4 (c) (stress), and Fig. 5 (a, Fig. 5 (b) and Fig. 5 (c) (strain). The comparison of FEM results on flexing shows that the reinforced beam resists sharp stresses.

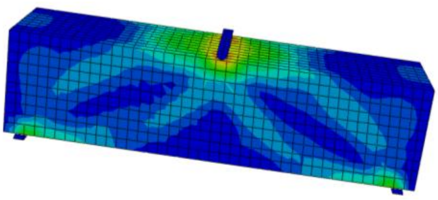

**Figure 4-a :** Stress of beam not reinforced (S-Ref)

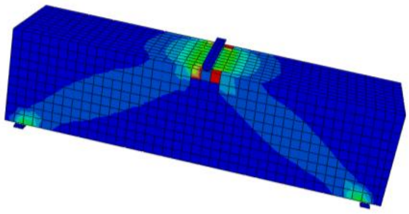

**Figure 4-b :** Stress of reinforced beam ($HC_{t1}$)

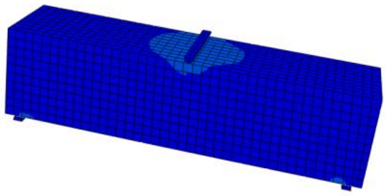

**Figure 4-c :** Stress of reinforced beam ($HC_{t2}$)

Moreover, concrete beam reinforced by honeycomb composite subjected to a load was studied. The results showed that reinforcement was better in the presence of the reinforcement. The location of the insertion of the reinforcement is on the upper side of the concrete and can resist more to the flexion effort. It is therefore proposed that further study is to be conducted on shear behavior and the failure modes of reinforced beams with fibers reinforced polymer sheets because of their mechanical properties which remains largely superior.

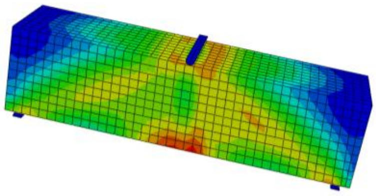

**Figure 5-a:** Strain of beam not reinforced (S-Ref)

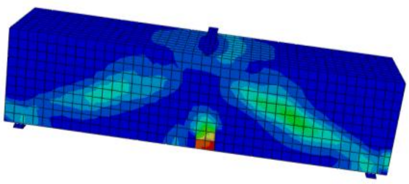

**Figure 5-b :** Strain of reinforced beam ($HC_{t1}$)

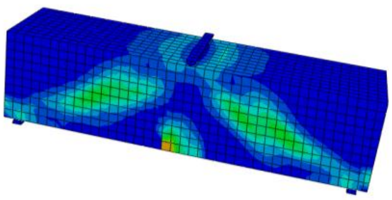

**Figure 5-c :** Strain of reinforced beam ($HC_{t2}$)

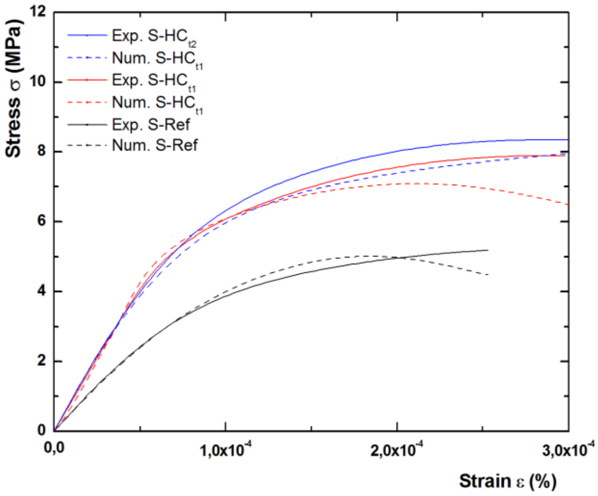


**Figure 6:** Stress- strain curve

Figure 6 presents the shear stress - strain curves for the used specimens, based on both experimental and numerical approaches. It shows that there is a good agreement between experiment and numerical results especially for elastic zone. For the plastic zone, there is similar a good agreement between concrete and the one reinforced by honeycomb panel structures with thickness 2. However, for the honeycomb panel structures with thickness 1, there is a small discrepancies between experiment and simulation. According to the figure 5, let us say that the parameters chosen in simulation for the concrete damaged plasticity is well verified as well as the approximation obtained by the finite element are well satisfied.

## 4. CONCLUDING REMARKS

The study of strengthened and unstrengthened beam by finite element was conducted using abaqus code. Concrete beam reinforced by honeycomb composite subjected to a load was studied. The results showed that reinforcement was better in the presence of the reinforcement. The location of the insertion of the reinforcement is on the upper side of the concrete and can resist more to the flexion effort. It is therefore proposed that further study is to be conducted on shear behavior and the failure modes of reinforced beams with fibers reinforced polymer sheets because of their mechanical properties which remains largely superior. Also, it is envisaged to improve the database on shear reinforcement and then validate the approach of the model proposed in the literature by using a new simulation using different fiber as reinforcement and make experimental study using the same materials of reinforcement.

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