Fabrication of Woven Honeycomb Structures for Advanced Composites

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ABSTRACT

A honeycomb woven fabric was designed and produced on a sampling loom. After weaving cells in the fabric were opened by polytetrafluoroethylene (PTFE) sticks and an epoxy resin was applied to fabric. For comparison half of the fabric sample was impregnated with resin without opening the cells. Resulting fabric samples were subjected to low-velocity impact test by using drop weight impact testing machine, CEAST Fractovis Plus – 7526.000. To evaluate the impact behaviour of the samples the contact force, contact time, deflection, and absorbed energy values were recorded by data acquisition system (DAS). The energy absorbed by honeycomb structure was around 7 Joule. The energy absorbed by flat sample, on the other hand, was too low and out of the detection range of the testing equipment.

KEYWORDS

Honeycomb fabric, Reinforcement, Composite, Energy absorption

INTRODUCTION

Fibrous structures have been used extensively as preforms since they meet successfully the various requirements of composite reinforcements. In general, unidirectional and two dimensional (2D) laminated woven structures are the main forms of reinforcement. Even though these 2D laminated woven structures have been used with success for over 60 years, their use in many structural applications is limited due to their high price as a result of labour intense manual lay-up process, their poor impact damage resistance, and their delamination cracking under impact loading [1,2]. In order to overcome these limitations the development of advanced 3D textile structures has gained great attention over the past 40 years. Advanced 3D textile structures offer structural integrity and fibre continuity by providing multiaxial in-plane and out-of-plane fibre orientation [3, 4].

One of the advance d 3D textile structures is 3D honeycomb structure. This structure has the geometry of a honeycomb to allow the minimization of the material used to reach minimal weight and maximum strength. Thus the composites reinforced with honeycomb structure are light weight, energy absorbent, and strong [5, 6]. Chen et al. [7, 8] studied honeycomb fabrics and defined them based on the number of fabric layers involved and the lengths of the free and bonded cell walls. A free cell wall is created by one layer of fabric. A bonded cell wall is created by combining two adjacent fabric layers. By arranging the length of the free and bonded cell walls the size of the cells can be adjusted. In another study, the mathematical modelling of honeycomb structure was studied and an algorithm was created for the computerized design and manufacture of this type of fabrics [6].

In this study a honeycomb woven fabric was designed and produced and the impact resistance of the composite structure reinforced by this fabric was determined.

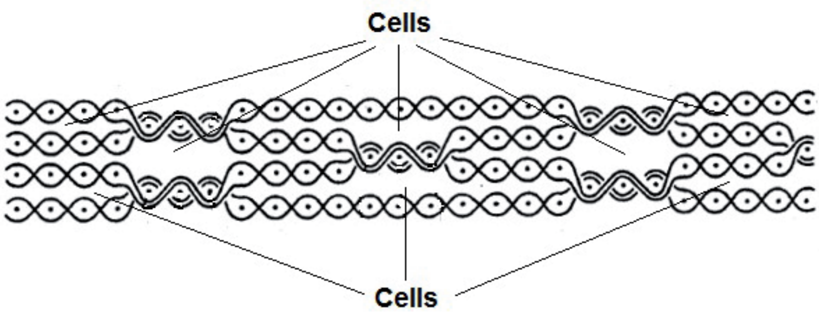


Figure 1. Cell openings in honeycomb fabric design

EXPERIMENTAL

Production of Honeycomb Fabric

A honeycomb woven fabric was designed and produced on a CCI Evergreen S8900 sample loom using the multilayer principle [9]. The 300 denier (335F96T) polyester filament yarn was used after plied with a twist of 140 turns / meter. The fabric had four layers and the adjacent layers were combined and separated at arranged intervals (Figure 1). The peg plan of the weave is given in Figure 2. The vertical lines indicate the heald shafts, and the horizontal lines indicate the wefts. Grey squares represent that the heald shaft will be lifted during the weft insertion. Open spaces between layers allowed to obtain a 3D structure with honeycomb shaped cells in the cross-section with the non-flat top and bottom surfaces.

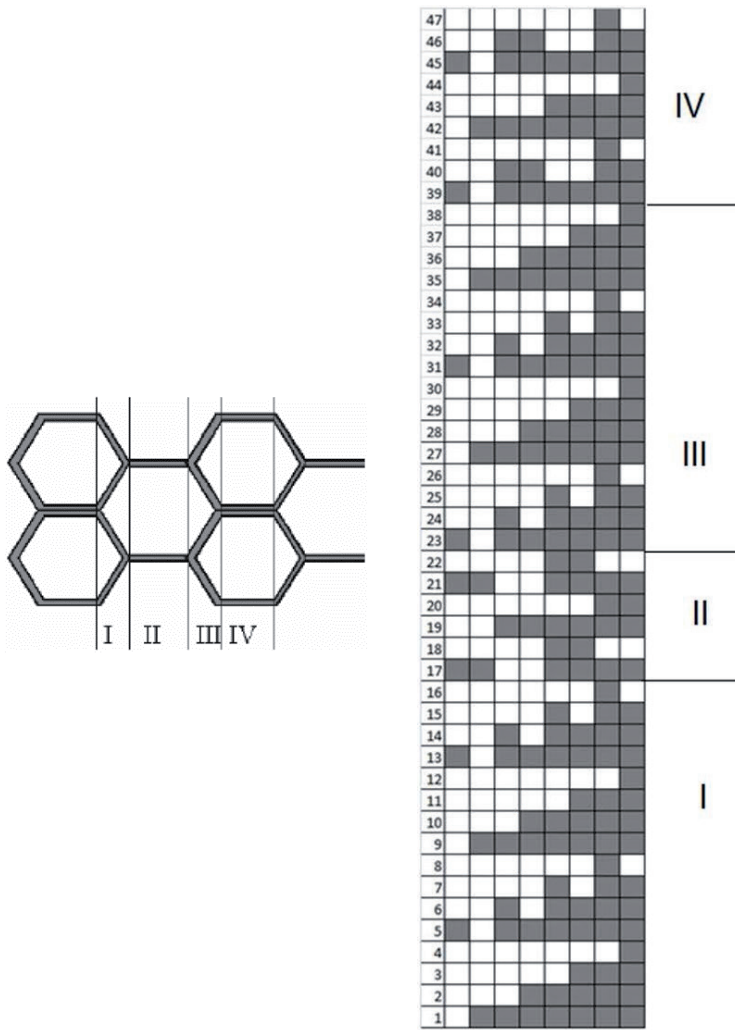


Figure 2. Peg plan

Production of Composite

The honeycomb fabrics are in a flat form with close cells when they leave the loom due to the nature of weaving. In order to turn fabric into a 3D honeycomb structure polytetrafluoroethylene (PTFE) sticks were inserted into the top and bottom rows of the tunnels before impregnation (Figure 3). Then, an epoxy resin mix (FiberMak Composites F-1564 Epoxy Resin and F-3486 Hardener) was applied to both sides of the fabric using a paintbrush. Curing was carried out in an autoclave at 100 ^{0}C for 90 minutes. For comparison some fabric were impregnated with resin in flattened form without placing the sticks.

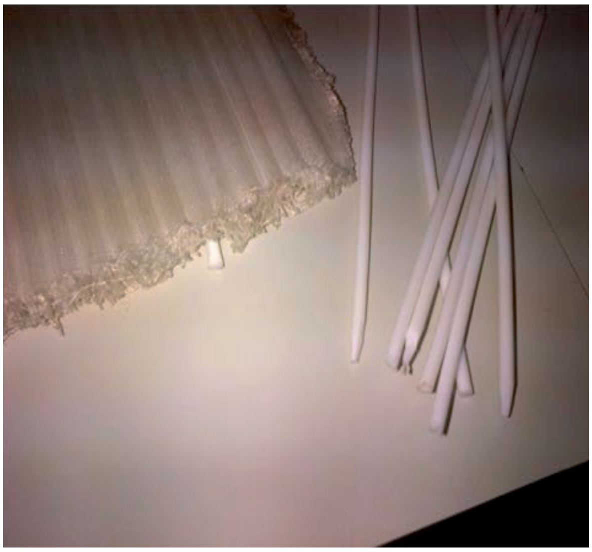


Figure 3A.Honeycomb fabric

3B. Fabric reinforced with PTFE sticks

Drop Weight Impact Test

The samples were subjected to low-velocity impact test by using drop weight impact testing machine, CEAST Fractovis Plus – 7526.000. The impact tests were performed by using hemispherical steel impactor tup of 12.7 mm diameter with a total mass of 5.02 kg. The maximum loading capacity of the impactor was 22.4 kN. According to ASTM D3763, the clamped specimens were impacted with impact energy level of 10 J at room temperature. The test velocity was 1.99 m/s. In order to evaluate the impact behavior of the samples, parameters such as the contact force, contact time, deflection, and absorbed energy values were recorded by data acquisition system (DAS) during the impact test.

RESULTS AND DISCUSSION

In this study a honeycomb woven fabric was produced using four layers. The resulting fabric cell has a height of 6mm, free wall length of 5 mm, bonded wall length of 5 mm and an opening angle of 53^0 (Figure 4).

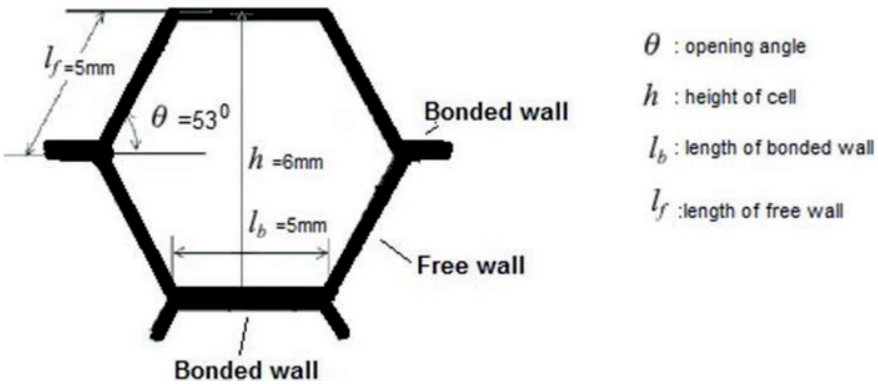


Figure 4 Cell size

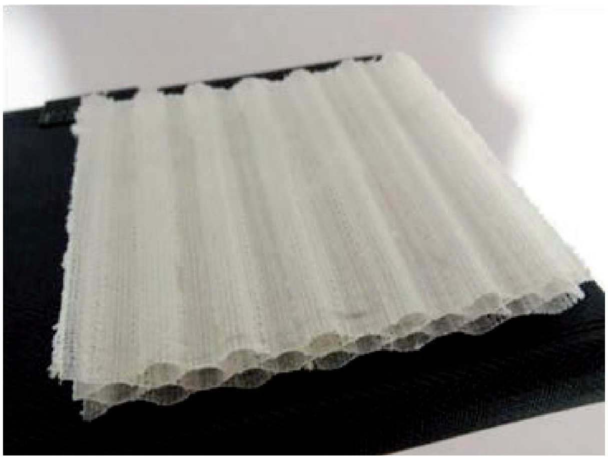
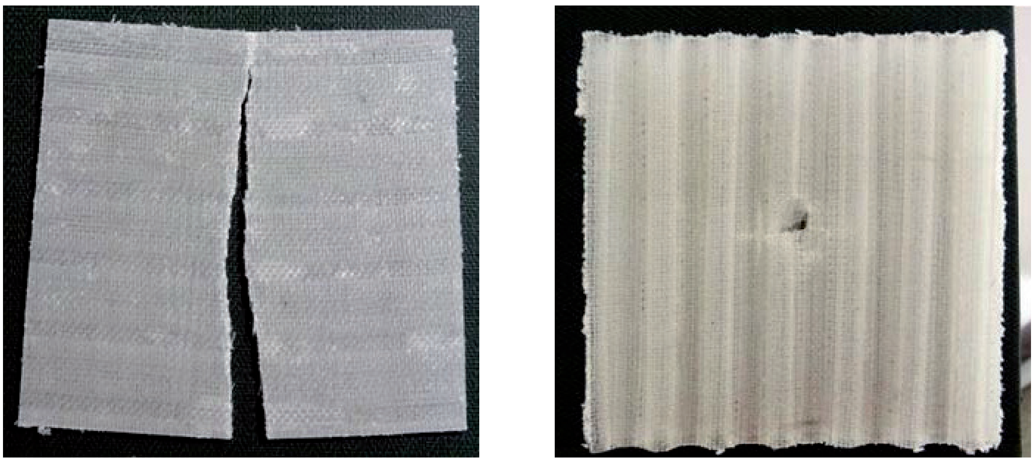


Figure 5. Honeycomb fabric

The fabric turned into a honeycomb composite by applying an epoxy resin mix (Figure 5). Before resin application cells in the fabric were opened using PTFE sticks. Half of the fabric was left in the flattened form for comparison. Then, the fabrics were subjected to low velocity impact test. In a honeycomb composite structure, the impact energy is absorbed not only by the elastic and plastic deformation of the fabric structure but also the collapse of the cells. If the honeycomb structure cannot absorb the whole energy the force is transmitted to structure underneath the composite and cause damage. Thus the energy absorbed by the structure is significant. Figure 6(a) shows the composite structure made from the designed fabric without opening the cells. As seen from the figure the composite structure could not resist the impact force and was broken apart. The test result was out of the detection range of the impact tester. Figure 6(b) shows the composite structure made from the designed fabric with the open cells. The damage was restricted to a small area. Clearly, open cell structure absorbed some of impact energy.



a) Sample with closed cells b) Sample with open cells

Figure 6. Fabric samples after impact test

Figure 7 shows the contact load–displacement plots of honeycomb composite structure with open cells at 10 J impact energy. The load–displacement curves show an increase of the load up to a maximum load termed peak load, followed by a drop after the peak load. The peak load was 805 N. The area under the curve gives the energy absorption. Calculated energy was 7,043 Joule. Unfortunately, close cell structure did not produce any results since the values measured were too low for the test equipment.

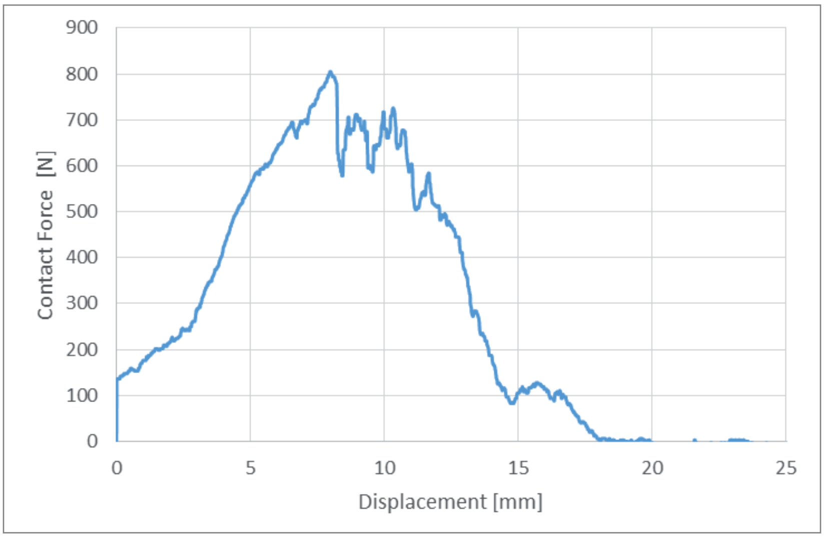


Figure 7. Load–displacement curve for low-velocity impact test

CONCLUSION

This is a preliminary work to investigate the potential of honeycomb structures in advanced composites. In this study we designed and produced a four layer honeycomb fabric as reinforcement material and investigate the impact resistance of the composite structure made from this preform with and without opening the cells. The composite structure with closed cells did not resist the impact force and was broken apart. The test equipment could not detect any signal. The hollow structure created by opening the cells, on the other hand, resisted to impact force and absorbed an energy of 7,043 Joule. The test conducted in this study was limited due to the time constrains. The further experiments and statistical analysis will be carried out to found out the effect of impact site on results.

We believe that honeycomb structures have great the potential in advanced composites. Their properties should be further explored. It is not difficult to weave this type of structure by a regular loom but opening up cells is time consuming job. A simplified method would increase their usage.

Acknowledgements

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The paper presents a preliminary work on honeycomb woven structures for advanced composites, first presented at the 8th International Textile Conference, Tirana, Albania, on October 18-19, 2018. Experimental part of the study offered limited information. The paper presents a preliminary communication. Future research will produce more results on top of which an original scientific paper will be published.