On the inhomogeneous stress determination of honeycomb core block manufactured by expansion technology

Zhonggang Wang[1] *, Jiefu Liu[2]

1. School of Traffic & Transportation engineering, Central South University; Key laboratory of Traffic Safety on Track, Ministry of Education; State key laboratory of high performance complex manufacturing; Changsha, Hunan, China.wangzhonggang@yahoo.com

2. School of Traffic & Transportation engineering, Central South University; Key laboratory of Traffic Safety on Track, Ministry of Education; Changsha, Hunan, China. liujiefu1992@163.com

Keywords: Honeycomb, inhomogeneous, compression test.

ABSTRACT

Honeycomb structure has been widely used in kinds of engineering fields, due to its outstanding mechanical properties, excellent energy absorption and perfect strength to weight ratios at cost. However, for each piece of honeycomb core block, it faces the challenge of inhomogeneous stress, caused by expansion technology. In this investigation, detailed reasons for this phenomenon in manufacturing process were analysed. Key frames were illustrated in shapes, types and irregular of honeycomb cells. In addition, comprehensive quasi-static experiments were extensively conducted to evaluate the heterogeneity directly, by dividing the original honeycomb core into 12 sub-blokes. Difference in resultant compression history as well as mean plateau stress was determined, so to further improve the expansion process. All these achievements shed a light on the stability maintenance of honeycomb structure.

1 INTRODUCTION

Nowadays, with the rapid growth of vehicle speed, the safety criteria have become more and stricter to reduce the damage of crash incident. In railway transit engineering, kinds of energy absorbers were developed to dissipate huge impact kinetic in crash situation. These kinds of energy absorbers, which evolve from primary thin-walled square or circular metallic tubes to cellular honeycomb cores, were equipped with outstanding advantages, like low density and high specific properties. In the past decades, a number of extensive constructive works have been conducted on the basic behavior [1-3], load-carrying capacity [4-8], engineering applications [9-10], and new creative design [11-13], fruitful results have been obtained.

Up to date, a single honeycomb structure is well-studied. However, there is still a serious problem about such structure among the practical applications. Honeycomb is made primarily by the expansion method. The corrugated process is most common for high density honeycomb materials. As introduced in the Ref. [14] that the honeycomb fabrication process by the expansion method begins with the stacking of sheets of the substrate material on which adhesive node lines have been printed. The adhesive lines are then cured to form a special cubic block, called HOBE® (Honeycomb before expansion) block. After curing to give an expanded block, the given HOBE block would be expanded. Then slices of the expanded block may be cut to the desired T dimension. Alternately, HOBE slices can be cut from the HOBE block to the appropriate T dimension and subsequently expanded. Slices can be expanded to regular hexagons, under expanded to 6-sided diamonds, and over expanded to nearly rectangular cells. The expanded sheets are trimmed to the desired L dimension (ribbon direction) and W dimension (transverse to the ribbon). The whole manufacture process has been clearly depicted in the schematic diagram in Figure 1 as below.

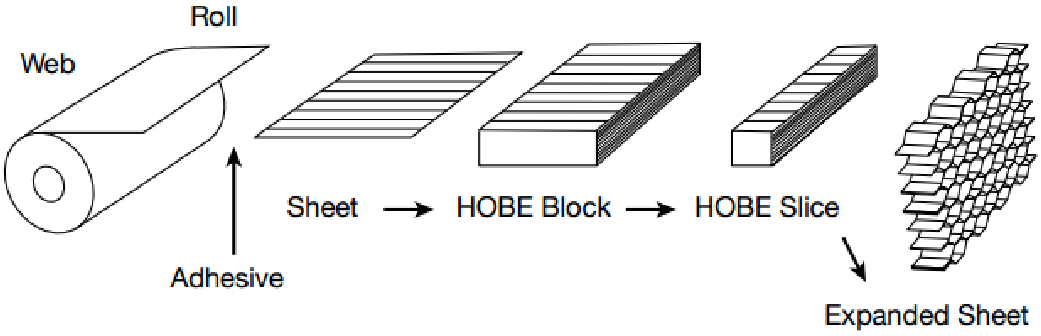

Figure 1: Expansion process of honeycomb core [14].

As the most popular processing technology in engineering application, many types of honeycomb structures have been made with expansion process. The representative one is hexagonal products. However, it faces a new challenge in obtaining perfect products, replaced with some heterogeneity of sub blocks due to rebellious stretching force in such processing. Typical inhomogeneous occurs, as shown in figure 2, particularly in the edge part (see figure 3). Irregular cell distribution here evidently deteriorates its cells' geometric configuration, so to markedly worse the mechanical performance of honeycomb structure.

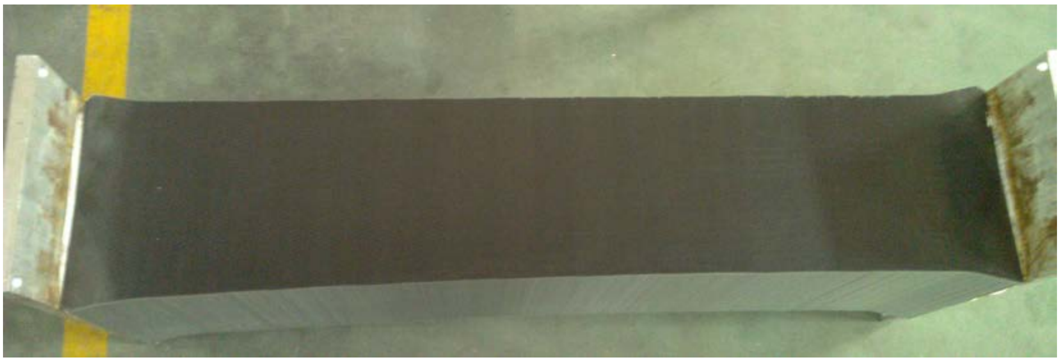

Figure 2: In expansion.

Among all of the existing achievements, there has been rare investigations on the performance uniformity of different components came from a uniform specimen so far. Even though it was commonly used as an entire structure for load carrying and energy absorption, a tiny defect of any part of such structure could results in the divergence of impact load under high strain rate, especially in case of tandem honeycomb situation.

Figure 3: Inhomogeneous of honeycomb core in expansion.

In this paper, an entire specimen was divided into 12 parts by wire-electrode cutting (to avoid the defect from the processing farthest). Each part will be analyzed with a specific comparison in terms of the quasi-static mechanical properties, including compression behavior, energy absorption and load carrying ability. Through such comparison, the uniformity of mechanical properties of each parts from the same specimen could be illustrated which will provide a guideline for the application of honeycomb structure.

2 SPECIMENS AND EXPERIMENTS

All the specimens for experiments were manufactured in HUARUI Honeycomb Company. Ltd® with aluminum foils 5052H18. And the tests were carried out in the universal test machine INSTRON 1342 experiment system (see Fig. 4) for mechanical properties of cellular structures. The scale of the specimen can be described as below (see Figure. 5(a)): 400mm×200mm×240mm（L×W×T）, with the geometric parameters of cells: the wall thickness is 0.06mm; the rib length is 4mm. The division mode can be illuminated in Figure. 5(b) with the sub blocks nominated as F1-F6 on the up-layer, F7-F12 on the sub-layer. They have the same size in overall dimension. The quasi-static compression tests have been carried out on each sub blocks with the under the exact loading condition. As seen in Figure.4, each specimen at quasi-static situation was placed on the lower gripper and moved upwards to the upper one with a speed 1mm/min, at room temperature.

Figure 4: The INSTRON 1342 experiment system.

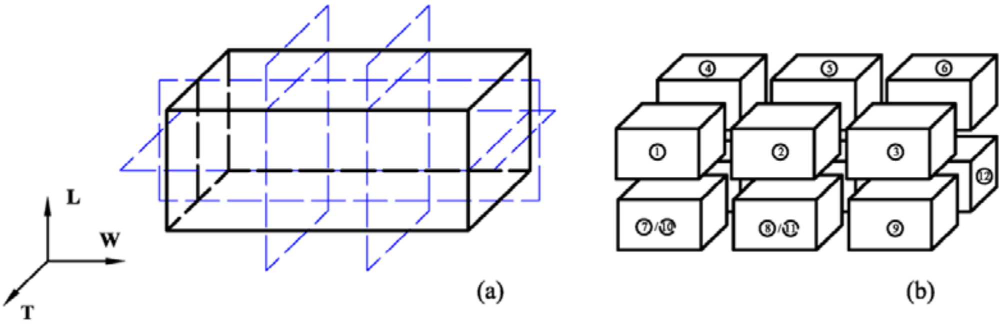

Figure 5: Honeycomb segmentation: a) before segmentation; (b) after segmentation.

The plane stress is calculated as F/A. F denotes the force measured by testing machine, and A is the bearing area of the specimen's surface. In this method, the peak stress as well as the plateau stress can be obtained with the experimental results.

3 RESULTS AND DISCUSSION

By recording the compression history of each specimen, the date of the peak stress as well as the plateau stress can be obtained. Corresponding results can be calculated. The results are shown in table

1. The variances of peak stress and plateau stress have been used to describe the divergence of the compression properties of the specimen, while, the absolute value of difference between the peak stress and their average value were also shown. So did the relative plateau one. To illustrate the compression test results specifically, the histogram with the peak stress and plateau stress was given as Figure.6.

Sample	Peak /Mpa	plateau /Mpa	Distance in peak /Mpa	Distance in plateau /Mpa
F-1	1.12	1.05	0.00	0.00
F-2	1.22	1.15	0.10	0.10
F-3	1.14	1.09	0.02	0.04
F-4	1.11	1.05	0.01	0.00
F-5	1.22	1.09	0.10	0.04
F-6	1.06	1.03	0.06	0.02
F-7	1.03	1.01	0.09	0.04
F-8	1.25	1.16	0.13	0.11
F-9	1.09	1.03	0.03	0.02
F-10	1.09	1.06	0.03	0.01
F-11	1.21	1.17	0.09	0.12
F-12	1.12	1.09	0.00	0.04
Average	1.12	1.05	0.06	0.05

Table 1: Compression tests results for each blcoks.

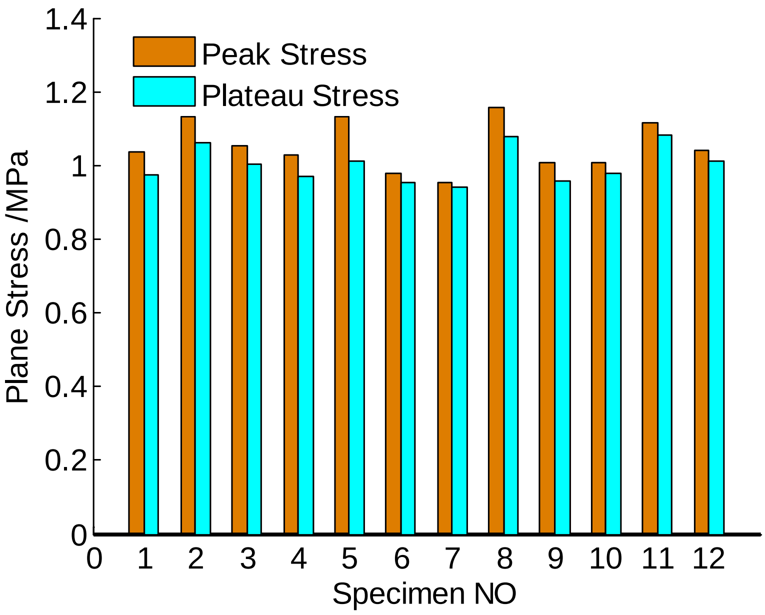

Figure 6: The histogram of compression tests.

From the results given in Table 1, the results showed that the peak stress distribute around the

1.10MPa, the mean value of plateau stress is 1.12 MPa. Take into account the distance, the peak stress and plateau stress were both grained a high homogeneous which means honeycomb structure has a great mechanical stability. Even though there is some gap between kinds of specimens, it is accepted in engineering application.

However, from Figure 6, the peak stress and plateau stress of F-2, F-5, and F-8 sub blocks were relative high comparing with other specimens which represent that the middle of the honeycomb is stronger than the outside area. The reason for this can be explained as that during the process of honeycomb machining, the inhomogeneous of tension force between two ends of the joint.

Considering the average value, the maximum deviation of peak force is 0.13 MPa, 0.12 MPa for plateau stress. It means that the peak stress is more dependent on the producing process which affected by the defects easily. On the contrary, the plateau is relative stable with processing defects.

4 CONCLUSIONS

From above experiments, 12 parts from an equal specimen were tested under quasi-static compression condition. Meanwhile, the statistical results have been presented based on the experimental results. With the results, the oscillation of peak stress and plateau stress was described by the comparisons between the stress of each parts and the average stress. Good homogeneous distribution has been determined. It is an accepted distribution in engineering circles, though there is still some gap between sub blocks. It would be much better if useful optimized technology can be adapted.

While, there are still two points should be concerned about, the first one is the peak stress was easier affected by the producing process. The other one is that the outside area of the honeycomb structure is weaker than the central area which is unavoidable because of the special process. The suggestion is that the large-angle abnormal loading condition should be avoided as much as possible in application.

ACKNOWLEDGEMENTS

This work was financially supported by The National Natural Science Foundation of China (51505502), Independent Funds of State key laboratory of high performance complex manufacturing (ZZYJKT2017-09), National key technology support program (215BAG13B00) and the Open-End Fund for the Valuable and Precision Instruments of Central South University. The authors would like to express their thanks.

REFERENCES

[1] Lu GX, Yu TX. Energy absorption of structures and materials. Cambridge (UK): Woodhead Publishing; 2001.

[2] Wang Z, Liu J, Hui D. Mechanical behaviors of inclined cell honeycomb structure subjected to compression. *Compos Part B*, 110, 2017, pp.307-314.

[3] Gibson LJ, Ashby MF. Cellular solids, structures and properties. 2nd ed. Cambridge, UK: Cambridge University Press, 1997.

[4] Xu SQ, Beynon JH, Ruan D, LU GX. Experimental study of the out-of-plane dynamic compression of hexagonal honeycombs. *Compos Struct*, 94, 2012, pp. 2326-2336.

[5] Ruan D, Lu G, Wang B and Yu TX. In-plane dynamic crushing of honeycombs—a finite element study. *Int J Impact Eng*, 28, 2003, pp.:61-182.

[6] Wang Z, Zhou W, Liu J. Initial densification strain point's determination of honeycomb structure subjected to out-of-plane compression. *Journal of Central South University*, 2017, Acceptance.

[7] Wang Z, Lu Z, Yao Song, et al. Deformation mode evolutional mechanism of honeycomb structure when undergoing a shallow inclined load. *Compos Struct*, 147, 2016, pp. 211-219.

[8] Hu LL and Yu TX. Dynamic crushing strength of hexagonal honeycombs. *Int J Impact Eng*, 37, 2010, pp. 467-474.

[9] Wang Z, Gao G, Tian H,et al. A stability maintenance method and experiments for multi-layer tandem aluminum honeycomb array. *Int J Crash worthiness*, 18, 2013, pp. 483-491.

[10] Wang Z, Tian H, Lu Z, et al. High-speed axial impact of aluminum honeycomb–Experiments and simulations. *Compos Part B*, 56,2014,pp. 1-8.

[11] Wang Z, Yao S, Lu Z, et al. Matching Effect of Honeycomb-filled Thin-Walled Square Tube—Experiment and Simulation. *Compos Struct*, 2016; 157:494-505.

[12] Wang Z, Tian H, Lu Z, et al. Theoretical assessment methodology on axial compressed hexagonal honeycomb's energy absorption capability. *J Mech Adv Mater Struct*, 23, 2016, pp. 503-512.

[13] Wang Z, Liu J, Lu Z, et al. Mechanical behaviour of composited structure filled with tandem honeycombs. *Compos Part B*, 114, 2017, pp.128-138.

[14] Hexcel Corporation. HexWeb® Honeycomb Attributes and Properties, 2016.