Research on Shock Responses of Three Types of Honeycomb Cores

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Abstract. The shock responses of three kinds of honeycomb cores have been investigated and analyzed based on explicit dynamics analysis. According to the real geometric configuration and the current main manufacturing methods of aluminum alloy honeycomb cores, the finite element models of honeycomb cores with three different cellular configurations (conventional hexagon honeycomb core, rectangle honeycomb core and auxetic honeycomb core with negative Poisson’s ratio) have been established through FEM parametric modeling method based on Python and Abaqus. In order to highlight the impact response characteristics of the above three honeycomb cores, a 5 mm thick panel with the same mass and material was taken as contrast. The analysis results showed that the peak values of longitudinal acceleration history curves of the three honeycomb cores were lower than those of the aluminum alloy panel in all three reference points under the loading of a longitudinal pulse pressure load with the peak value of 1 MPa and the pulse width of 1 $\mu$s. It could be concluded that due to the complex reflection and diffraction of stress wave induced by shock in honeycomb structures, the impact energy was redistributed which led to a decrease in the peak values of the longitudinal acceleration at the measuring points of honeycomb cores relative to the panel.

1. Introduction
With outstanding impact resistance and energy absorbing capability\cite{1}, cellular solids such as honeycomb and foam have been widely used in the military and civil industry.

Previous researches on the impact properties of honeycomb cores mainly focused on their energy absorption characteristics\cite{2-6}, while the shock responses and propagation or attenuation laws of stress wave caused by shock in them were rarely involved. In this study, the shock responses of aluminum alloy honeycomb cores with three different cellular configurations were investigated.

2. Configurations of honeycomb cores
The most common honeycomb cores were based on aluminum and aramid fibre paper dipped in phenolic resin which was known as Nomex, and currently, gluing or welding metal sheet or Nomex in a specific contact area was the mainstream honeycomb cores manufacturing methods\cite{7-9}. In view of the above situation, the thickness of the bonding or welding areas of the honeycomb cores were two times of the rest areas, and in this analysis, these two thickness values were set to 0.1 mm and 0.05 mm respectively, as shown in Figure 1.

In practical applications, hexagon honeycombs were the most widely used honeycomb structures. However, with the continuous research and development of new material and structure, rectangle honeycombs and auxetic honeycombs with negative Poisson’s ratio have also gained a lot of attention.
and investigation[10-12]. In the present study, these two honeycomb configurations were also considered, and their specific geometric parameters were shown in Figure 1.

![Honeycomb Configurations](image)

(a) Hexagon honeycomb  (b) Rectangle honeycomb  (c) Auxetic honeycomb

**Figure 1:** Three types of honeycomb cores

3. FEM models of honeycomb cores

Considering the complexity of the real geometric configuration and the unique structural periodicity of honeycomb structures, the finite element models of the real honeycomb structures have been constructed by the parametric modeling method based on Python and Abaqus. According to the current main processing methods of honeycomb cores, the thickness of the bonding or welding areas in the honeycomb cores was set to two times of the rest areas, as illustrated in Figure 1. The mass of the three types of honeycomb cores and the reference object aluminum alloy panel was 0.051 Kg. The FEM geometry models for analysis were illustrated in Figure 2, and the materials used for each component and their properties were shown in Table 1.

The half-sine pulse load was applied on the bottom of the base 1 and each model was in the unconstrained free state. On the top of the base 2, three reference points have been set to obtain the acceleration responses.
Figure 2: FEM models of honeycomb cores and the aluminum alloy panel

Table 1: Material properties

| Part           | Material     | Density [Kg/m³] | Young’s Modulus [GPa] | Poisson’s Ratio |
|----------------|--------------|-----------------|-----------------------|-----------------|
| Honeycomb core | Aluminum Alloy | 2700            | 70                    | 0.33            |
| Panel          | Aluminum Alloy | 2700            | 70                    | 0.33            |
| Base           | Steel        | 7810            | 200                   | 0.33            |

4. Results
The acceleration responses induced by shock load of all three reference points (RF₁, RF₂, RF₃, as illustrated in Figure 2) were obtained by explicit dynamics analysis. The longitudinal acceleration history curves were illustrated in Figure 3 to Figure 5 for instance. Extract the peak values of all reference points’ acceleration history curves in all three directions, as shown in Table 2 to Table 4. It could be seen that because of the honeycomb cores’ unique geometry configuration, the acceleration peak values have decreased in y and z direction and increased slightly in x direction compared with the aluminum alloy panel.
Figure 3: Acceleration history curves of reference point 1 in y direction

Figure 4: Acceleration history curves of reference point 2 in y direction

Figure 5: Acceleration history curves of reference point 3 in y direction
Table 2: Peak values of acceleration history curves in x direction

| Reference Point | Panel | Hexagon Honeycomb | Rectangle Honeycomb | Auxetic Honeycomb |
|-----------------|-------|-------------------|---------------------|-------------------|
| 1               | 3096g | 1722g             | 1853g               | 1679g             |
| 2               | 0.0021g | 0.0473g          | 0.0253g             | 0.0313g           |
| 3               | 3096g | 1722g             | 1853g               | 1679g             |

Table 3: Peak values of acceleration history curves in y direction

| Reference Point | Panel | Hexagon Honeycomb | Rectangle Honeycomb | Auxetic Honeycomb |
|-----------------|-------|-------------------|---------------------|-------------------|
| 1               | 5269g | 2958g             | 2189g               | 1943g             |
| 2               | 6750g | 2513g             | 2419g               | 3442g             |
| 3               | 5269g | 2958g             | 2189g               | 1943g             |

Table 4: Peak values of acceleration history curves in z direction

| Reference Point | Panel | Hexagon Honeycomb | Rectangle Honeycomb | Auxetic Honeycomb |
|-----------------|-------|-------------------|---------------------|-------------------|
| 1               | 0.0017g | 0.0007g          | 0.0006g             | 0.0005g           |
| 2               | 0.0018g | 0.0010g          | 0.0009g             | 0.0007g           |
| 3               | 0.0017g | 0.0007g          | 0.0006g             | 0.0005g           |

5. Summary
By means of the FEM parametric modeling method based on Python and Abaqus, the finite element models of honeycomb cores with three different configurations have been established. The results of shock dynamics analysis showed that due to the complex reflection and diffraction of stress wave induced by shock in honeycomb structures, the impact energy was redistributed which led to a better shock suppression ability and a decrease in the peak values of the longitudinal acceleration responses at the measuring points of the three honeycomb cores relative to the aluminum alloy panel. It could be seen that honeycomb structures not only had an excellent energy absorption capability under the destructive impact conditions, but also had an outstanding vibration isolation characteristics in the nondestructive shock conditions.

References
[1] Y. Hua, T. Yu. Mechanical behaviour of cellular solids[J]. Advances in Mechanics. 21(4), 457-469(1991)
[2] W. Baker, T. Togami, J. Weydert. Static and dynamic properties of high-density metal honeycombs[J]. International Journal of Impact Engineering. 21(3), 149-163(1998)
[3] M. Hazizan, W. Cantwell. The low velocity impact response of an aluminum honeycomb sandwich structure[J]. Composites: Part B. 34, 679-687(2003)
[4] T. Anderson. An investigation of SDOF models for large mass impact on sandwich composites[J]. Composites: Part B. 36, 135-142(2005)
[5] Y. Liu, Z. He, H. Wu, X. Zhang. In-plane dynamic crushing of functionally layered metal honeycombs[J]. Explosion and Shock Waves. 31(3), 225-231(2011)
[6] X. Zhang, Y. Liu, N. Li. In-plane dynamic crushing of honeycombs with negative Poisson’s ratio effects[J]. Explosion and Shock Waves. 32(5), 475-482(2012)
[7] K. Karlsson, B. Åström. Manufacturing and applications of structural sandwich components[J]. Composites: Part A. 28A, 97-111(1997)
[8] T. Tsuchihashi, T. Nishida. Process for the manufacture of honeycomb core structures[P]. US Patent: US19970859351, 1999-11-9
[9] M. Zhang, J. Yu. Development of the mental sandwiched panels and their manufacturing methods[J]. Welding Technology. 32(6), 21-23(2003)
[10] W. Yang, Z. Li, W. Shi, B. Xie, M. Yang. Review on auxetic materials[J]. Journal of Materials Science. 39, 3269-3279(2004)
[11] Y. Liu, H. Hu. A review on auxetic structures and polymeric materials[J]. Scientific Research and Essays. 5(10), 1052-1063(2010)
[12] V. Carneiro, J. Meireles, H. Puga. Auxetic materials – a review[J]. Materials Science - Poland. 31(4), 561-571(2013)