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Research on the characteristics of dynamic response and absorbing energy of honeycomb sandwich panel under blast load

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ABSTRACT

Under the effect of explosion shock load, the plate-shell structure will generate serious vibration and noise. Presently, studies on plate-shell structures are mainly concentrated on smooth plate structures and crossing beam structures, however, the studies of sandwich panels with hexagonal honeycomb cores are deficient. In order to study the properties of dynamic response and reducing noise of hexagonal honeycomb cores under the explosion shock load, based on the theories of fluid-structure interaction and explosion shock, the finite element method is used to research the dynamic response of the hexagonal honeycomb sandwich panels, which are under contact explosion loading and non-contact explosion loading. Under different boundary conditions, the influence of structure parameters of hexagonal honeycomb cores on plastic deformation and reducing vibration is discussed. The results indicate that the parameters such as the distribution density, height and width of the bee cells have a significant influence on the characteristics of vibration and absorbing energy. Meanwhile, the abilities of hexagonal honeycomb sandwich panels for shock resistance and reducing noise under the explosion shock loading are confirmed. Finally, the best distribution density and layout scheme of the bee cells are determined, which will provide a reference for the related designs of sandwich panels structure.

Keywords: Impact load, Honeycomb Sandwich, Reducing Noise, Numerical Simulation I-INCE Classification of Subjects Number(s): 45

1. INTRODUCTION

In case of an underwater explosion load, a ship structure will obtain serious damages along with local damages, therefore, that has been attracting researcher's attention in various countries. At the same time, the drastic noise will occur, which is harmful to worker's health. In addition, the sound waves will radiate a long distance, and sonar equipments have been applied to detect these sound from the targets under water owing to the shock wave, which will expose ourselves undoubtedly to the enemy due to the existence of sound. Therefore, changing the vibration characteristics of underwater equipment and reducing noise are particularly important for these structures, which is related to its concealment and the stability of devices inside. In order to break through the traditional opinions and get stiffened plates more excellent, mainly based on the principle of bionics, honeycomb sandwich panels are designed in this paper, and the dynamic response and the ability of reducing vibration and noise by the honeycomb sandwich are analyzed under explosive load. Honeycomb sandwich structures belong to the special form of composite material, and this structures have the properties of light quality, high stiffness, high fatigue performance and smooth surface, which is applied widely in the aerospace (1-2) at home and abroad, but less in the underwater vehicle. At the same time, the honeycomb sandwich panel is a typical of the cellular structure material, and it is usually applied as the sandwich structure, having good characteristics of absorbing energy .And the honeycomb sandwich panel is composed of two bald panels and hexagonal sandwich cores in the middle. Xue(3) pointed out that when comparing with the homogeneous common plates with the same quality, the metal sandwich structure can absorb a quantity of energy through large deformation of sandwich cores under blast loading, and achieve the purpose of reducing vibration. Zhao Nan, etc(4), based on the finite element analysis software, analyzed the

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energy dissipation mechanism of the hexagonal honeycomb sandwich panels when suffer from shock load at different speeds. Tian etc(5), using the sound-solid coupling theory, analyzed the dynamic response of sandwich plates when exposed to near-field underwater explosion load, and verified the characteristics of shock resistance of sandwich boards. Zhu (6) and Qin (7)etc carried the theoretical research on the damage deformation of the sandwich structure. Dharmasena(8) and Deshpande Ut(9)h studied the dynamic mechanical response of honeycomb core sandwich structures by experiment and finite element simulations.

This paper mainly simulates the dynamic response of honeycomb sandwich panels under the blast load using acoustic-structure coupling method, and analyzed the mechanism of energy dissipation. At last, the parameters of the honeycomb unit such as the width, height and distribution density are tested to verify the law of reducing vibration and noise by the honeycomb sandwich

2. THEORETICAL ANALYSIS

2.1 Basic theory of acoustic-structure coupling

Underwater explosion is related to the problem of fluid-structure coupling, and how to solve the problem involving liquid-structure coupling is still a very complicated engineering problem. In this paper, the fluid is regarded as the acoustic medium, assuming that the small range of pressure be satisfied, the acoustic-structure coupling method is used to simulate the problem of fluid-structure coupling. For non-contact underwater explosion , the impact of blast load on the structure is transmitted through the liquid to the structure. For acoustic-solid coupling method adopted in this paper, the calculation method of structure modal in ideal fluid is to regard fluid pressure as the basic unknown variable, and to solve the problem of structural response. The basic principle is to solve the following equations:

$$\begin{bmatrix} M_s & 0 \\ \rho_0 R^T & M_f \end{bmatrix} = \begin{Bmatrix} \ddot{U} \\ \ddot{P} \end{Bmatrix} + \begin{bmatrix} K_s & -R \\ 0 & K_f \end{bmatrix} \begin{Bmatrix} U \\ P \end{Bmatrix} = \begin{Bmatrix} F_s \\ F_f \end{Bmatrix} \tag{1}$$

Where M, K and F are respectively the mass matrix, the stiffness matrix and the load matrix, s represents the structures, f represents the liquid, R is liquid-solid coupling matrix representing the effective area on each node of the liquid-solid coupling interface ,and the pressure of fluid is converted into the load in structure; Where ρ_0 is the density of liquid, U and P nodes represent respectively the displacements matrix of node and acoustic pressure matrix of the fluid.

2.2 Calculation of the shock load

In engineering, the empirical formulas obtained by similar theories are usually used by engineers, while there are some differences among the empirical formulas given by different scholars. the calculation formula of the shock wave pressure given by Cole has been adopted by the researchers all over the word, and it is a classic formula of shock wave. Through a lot of experiments and analyzing the law of explosion, for spherical charge, *P(t)* and θ, the law of shock peak changing over time due to underwater explosion, can be given according to the similarity law of underwater explosion (10).

$$P(t) = P_m e^{-t/\theta} \tag{2}$$

$$P_m = K\left(W^{1/3} / R\right)^{\alpha} \tag{3}$$

$$\theta = K_\theta W^{1/3} \left(\frac{W^{1/3}}{R} \right)^{\alpha_\theta} \tag{4}$$

Where R is the distance from stagnation point to explosion point (m), W is the mass of the charge (kg), P_m is the peak of pressure (MPA), and K, K_θ, α , α_θ are respectively the similar constant and coefficient in underwater explosion; For TNT, where K=52.4MPa, α=1.13, K_θ=0.084ms, α_θ=-0.23.

3. CACULATION MODEL

3.1 Fluid model

In order to reflect the influence of fluid media surrounding the structures on structure, the acoustic units are used to simulate the fluid , and the radius of the fluid body should be about 6 times as much as the radius of the structure. The units of fluid are given by AC3D8R , which is the acoustic medium unit . Generally, in order to make the analysis results more consistent with the experimental result, the size of grids on the structure and fluid field surrounding the structure should meet the conditions where there are 10 to 25 meshes within the length of a shock wave. But for outer fluid field , 1 ~ 5 grids are enough(11). “Tie”, a way of connection, is used to the connection between the structure and the fluid, and in this way, the acoustic-structure coupling method is applied to deal with the problem of low efficiency by using fluid-structure coupling method.

3.2 Structure model

In this paper, the specification of the honeycomb sandwich panels is a × b(250mm × 250mm), the size is invariant during the whole process of simulation. Because we mainly study the parameter such as the height H, width B and thickness P of the bee cell and its effects of absorbing energy and reducing vibration by the sandwich cores under the blast load, other variants must keep instant, and the change of quality caused by the changeable parameter will not be controlled. The structure of honeycomb panels and the bee cell are shown in figture1 and figture2 below

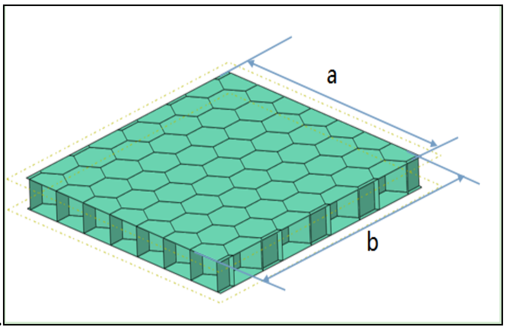

Figure 1–The whole structure of hexagonal honeycomb sandwich panels

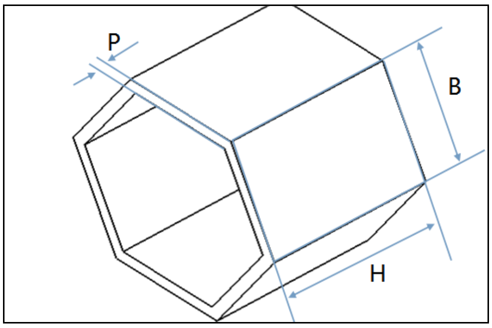

Figure 2–The structure of a bee cell

3.3 Material properties

In this paper, the materials of sandwich panels adopted are steel, only to explore the influence of the structures with the same material on reducing vibration and absorbing energy by sandwich cores. Then the steel material is defined as followings:

Table 1- Material properties of sandwich panel

Elastic modulus /GP	Poisson ratio	Density t/m3	Extension coefficient Nmm/tK
2.1×10^{5}	0.3	7.86×10^{-9}	4.52×10^{8}

Secondly, using johnson-Cook to define the elastic and plastic properties of the model , and its properties are set as shown in table 2.

Table 2-Elastic-plastic parameters of Johnson-cook

A /GP	B /GP	C	n	m	ε_0
400	1500GP	0.045	0.4	1.2	0.001

For the materials of metal sandwich, the temperature should also be set, and the melting temperature is 1800K, and the transition temperature is 293K. The initial temperature of any nodes in the model is 273K, and the fluid is generally assumed to be water material, and its properties are set: Density: $1\times10^{-9}t/m^3$, Bulk modulus : 2240.

3.4 Calculation conditions

In the simulations, the blast load will generate impact on the honeycomb sandwich panels , and the mass of TNT charge equals to 0.5kg, and the stand-off distance R is 1m. According to the calculation formula of shock wave load, the strength of load is primarily related to $W^{1/3}R$, namely within a certain density of explosive, the strength load depends on the distance R from the stagnation point to the explosion point. Therefore ,the strength of shock involved in all working conditions should remain unchanged. As is shown in Figure 3. The instantaneous impact load comes into being by explosion shock, and the peak of the load is 2.4×10^7 pa.

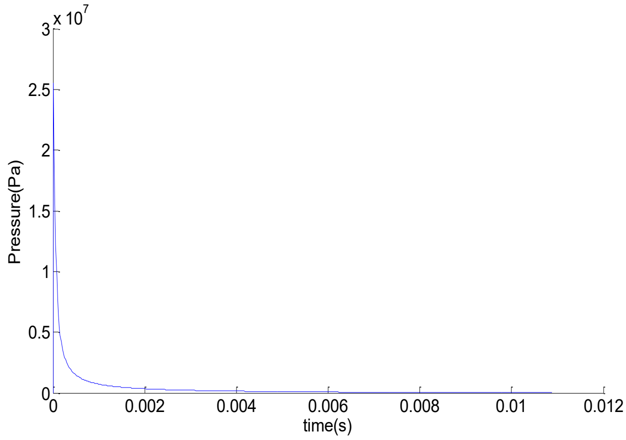

Figure 3–Impact load

4. SIMULATION RESULTS AND DISCUSSIONS

4.1 Effect of the thickness of bee cell on absorbing energy

In this case ,the thickness of the bee cells is regarded as the basic variable, and the thickness of both of the bald plates are restricted to 5mm, and keep unchangeable. The height of sandwich layer is 20mm, while the thickness of the bee cells will be changed:1mm, 2mm, 3mm, 4mm, 6mm, 8mm.The curves of energy are shown in the figures below.

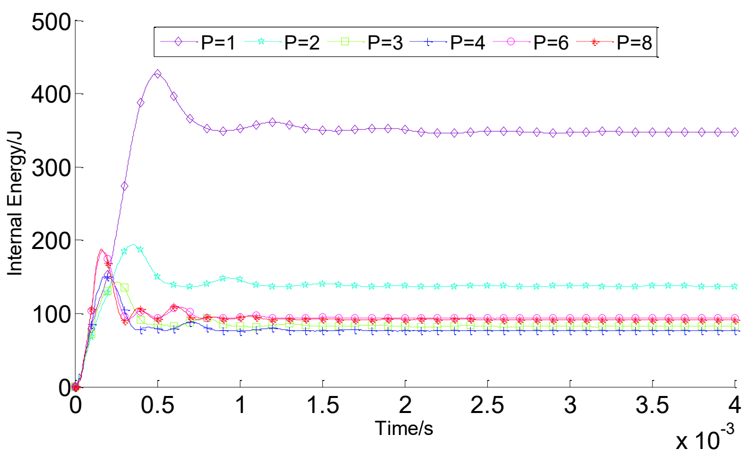

Figure 4–Internal energy of the upper panel in different

thickness of bee cells

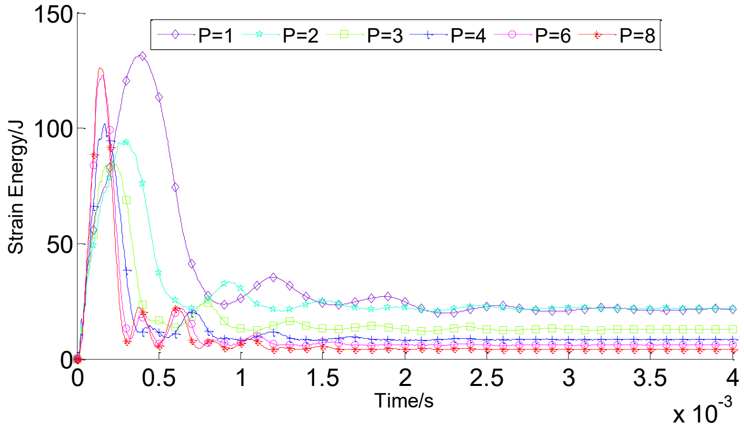

Figure 5–Strain energy of the upper panel in different thickness of bee cells

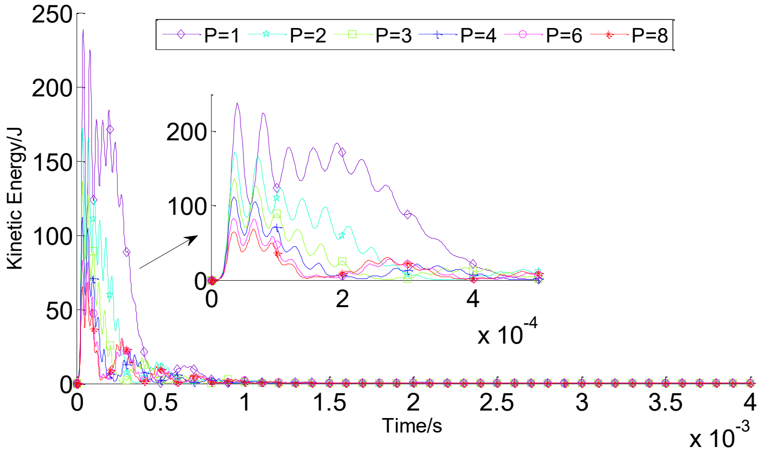

Figure 6– Kinetic energy of the upper panel in different thickness of bee cells

After being impacted by the explosion, the honeycomb sandwich plate will absorb energy, then elastic and plastic deformation will occur, resulting in violent vibration and noises. Through comparing and analyzing the different situation of obtaining energy after the honeycomb sandwich panels being impacted, the vibration conditions caused by the change of the parameter of the bee cell can be obtained. The curve of internal energy is shown in figure 4.After the structure being impacted, the internal energy of upper plate rapidly reach the peak within 0.5ms. For P=1mm,the peak of internal energy reach about 420J; For P=3mm, the peak decreases to about 90J. Similarly; the curve of strain energy is shown in figure 5,for P=1mm,the peak of strain energy got by upper plate is about 130J. For P=3mm, the peak decrease to about 80J. That indicates that, within a certain range, the effect of absorbing energy by honeycomb sandwich get enhanced along with the thickness of bee cell increasing. Subsequently, when the thickness change from 4mm to 6mm, the internal energy of the upper plate increase to 150J to 180J, and the strain energy increase from 100J to 125 J around, so the effect of absorbing energy by honeycomb sandwich get weaken. The curve of the kinetic energy shown in figure 6, when the thickness of the bee cells change from 1mm to 8mm, the peak of the kinetic energy decrease from 230J to 60J correspondingly, and the trend of absorbing energy by honeycomb sandwich gets enhanced along with the thickness of the bee cell increasing gradually ;As for the curves of the energy above such as figure 4,figure 5 and figure 6,along with the thickness of the bee cells increasing, it takes less time to finish the process of energy changing. it indicates the energy maybe change suddenly , therefore, although the ability of absorbing energy by honeycomb sandwich get enhanced , the stability of the structure get weaken .

4.2 Effect of the height of bee cell on absorbing energy

In this case , the height of the bee cell is regarded as the variable, and the thickness of both sides of the plates is restricted to 5mm, and kept constant. At the same time, the side's length of the bee cell is 20mm, and kept constant. While the height of bee cells will be changed:10mm, 20mm, 30mm, 40mm, 50mm, 60mm.Then,the curves of energy are shown in the figures below.

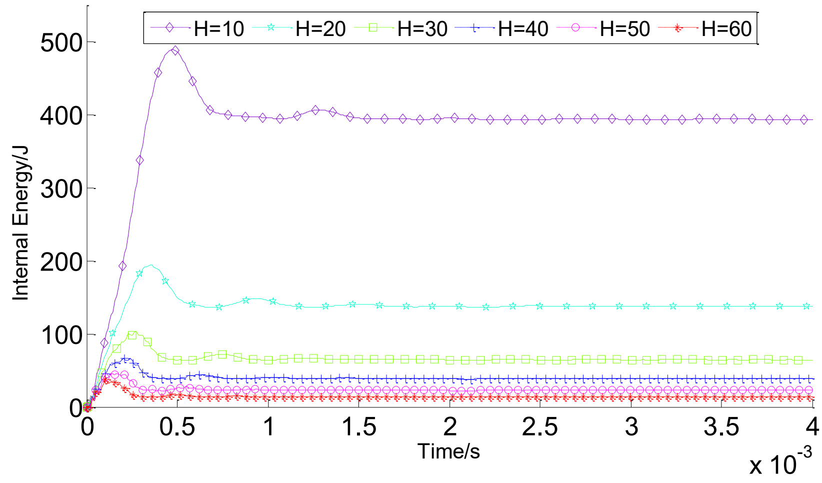

Figure 7–Internal energy of the upper plate in different height of bee cells

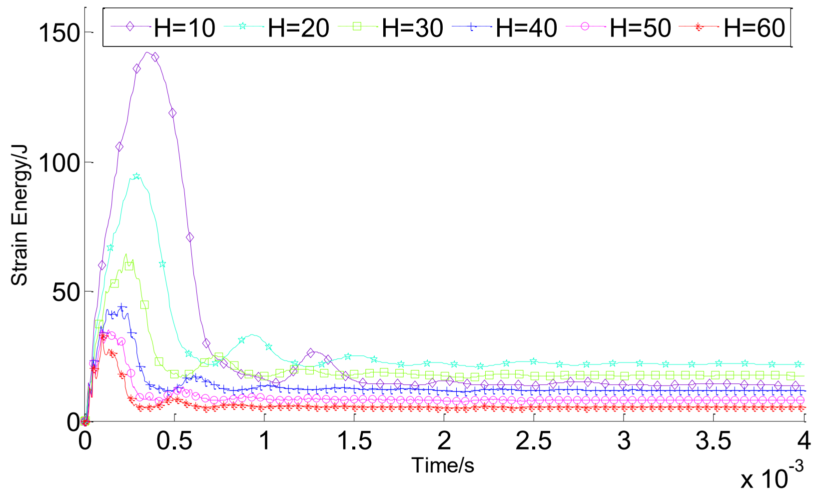

Figure 8– Strain energy of the upper plate in different height of bee cells

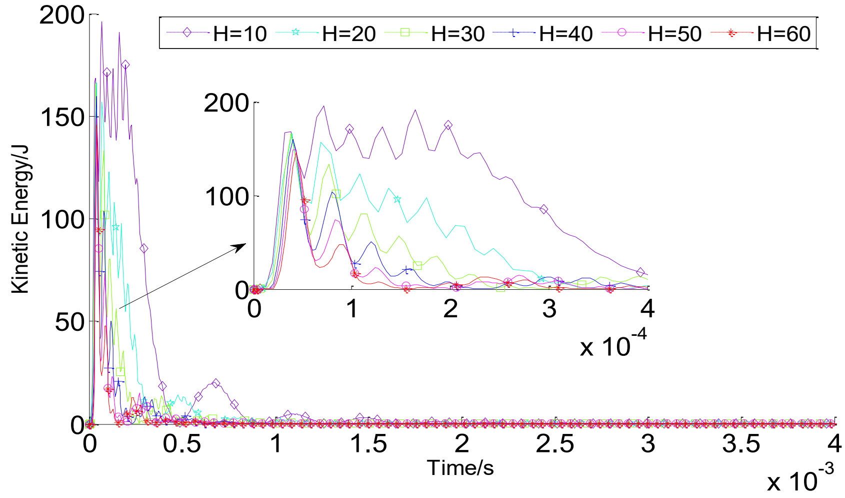

Figure 9–.Kinetic energy of the upper plate in different height of bee cells

The curves of energy are shown from Figure 7 to figure 9. After the honeycomb sandwich panels suffering impact load, at the initial moment, the impact load of the structures is the highest and the energy of upper plate rapidly reach a peak. Among the three kind of curves, internal energy account for the largest proportion, and strain energy and kinetic energy are equivalent. When H changes from 10mm to 60mm ,the peak of internal energy changes from 500J down to 50J, and the peak of strain energy changes from 140J down to about 26J, and the peak of kinetic energy changes from 200J down to 180J. So we can see that the energy peak of the upper plate decrease a lot, so the result shows that the effect of absorbing energy by the honeycomb sandwich is obvious . For H=50mm and H=60mm, the difference of peaks become small, and that is to say, along with the height increasing, the ability of absorbing energy by honeycomb sandwich layer is improved , but the increasing trend get weaken. For H=10mm, the internal energy curve is shown in figure 7, it takes about 0.75ms to complete the fluctuation of the energy, but for H=60mm, this process only need 0.2 ms, namely the peaks of energy curves move to the left with the height increasing, and the energy change more swiftly. Like that, the peaks of strain energy and kinetic energy move to the left, too. Therefore, although the ability of absorbing energy and reducing vibration by honeycomb sandwich is greatly enhanced to a certain extent, the stability of the overall structure get down. For H=10mm, the peak of kinetic energy reach the maximum 180J around, lasting for 0.15ms around. At this time ,the vibration amplitude is very high, and the lasting time is long. But with height increasing, the peaks value of the kinetic energy gradually decreased, and the lasting time get shorter. The results show that the effect of absorbing kinetic energy by honeycomb sandwich is greatly enhanced.

4.3 Effect of the distribution density of bee cell on absorbing energy

The distribution density of bee cells is another important parameter that affects the ability of absorbing energy and reducing vibration by honeycomb sandwich. The length of the sides of the bee cell is regarded as the designed variables, and the specification of honeycomb sandwich stays unchanged :250mm×250mm, and the thickness of two bald plates is 5mm, and the height of honeycomb sandwich is 20mm, and the thickness of wall is 2mm. moreover, the strength of impact load and distance remains unchanged. The side of bee cell is regarded as the variable:15mm, 20mm, 25mm, 30mm, 35mm, 40mm. Then, the curves of energy are shown in the figure10 to figure 12.

From figure 10 to figure 12, are respectively the curves of internal energy, strain energy and kinetic curve energy .From the curves we can see, that internal energy got by the upper plate is the most, and the second is the kinetic energy , and the least is strain energy. Therefore, most of the energy from impact load is transformed to the internal energy, which make the temperature of the structure rise. For B=15mm, the peak of internal energy got by the upper plate is about 150J, and the strain energy is about 75J, and the kinetic energy is about 100J. However, when the length of side increase to 45mm, the peak of internal energy increases to 450J, and the strain energy reaches 150J, and the kinetic energy is 280J. so it can be observed that with the length of the side of bee cells increasing, the distribution density of the bee cells will decrease, and the energy got by the upper plate will increase, and the ability of absorbing energy by the honeycomb sandwich gets weakened correspondingly. At the same time, with the distribution density decreasing, three kinds of energy curves move to the right, and the time taken to reach the peak of energy is prolonged, and it illustrates that the energy of the structure may change suddenly under the impact load with the distribution density decreasing, so the structure becomes unstable. For B=15mm ,when the time changes from 0.05ms to 0.4ms and, the curve of the kinetic energy fluctuates for 8 times. But for B=45mm , the curve fluctuates for 3 times. So with the distribution density increasing, the vibration frequency of the upper plate get increased .Therefore, the noise with small loudness and high frequency may be produced along with distribution density increasing when suffer from the explosive shock.

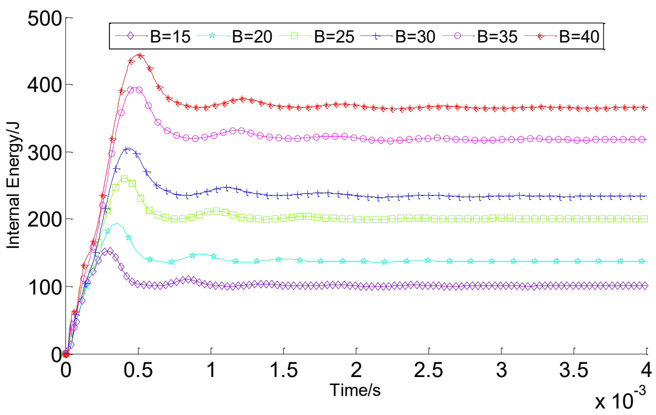

Figure 10– Internal energy of the upper panel in different distribution density of bee cells

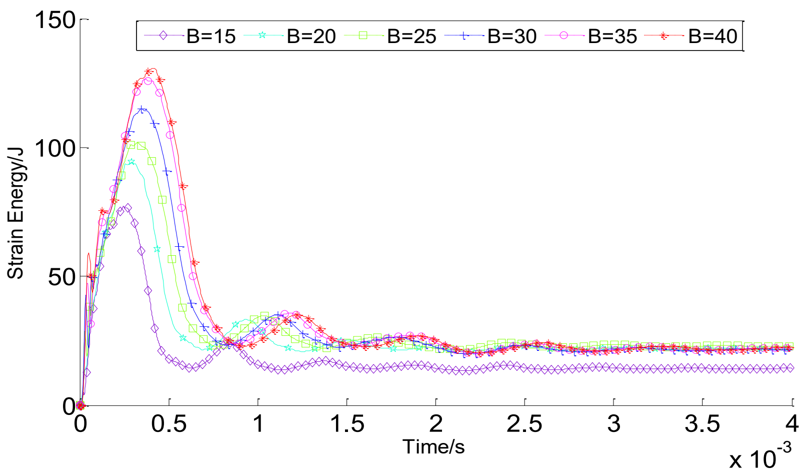

Figure 11–.Strain energy of the upper panel in different distribution density of bee cells

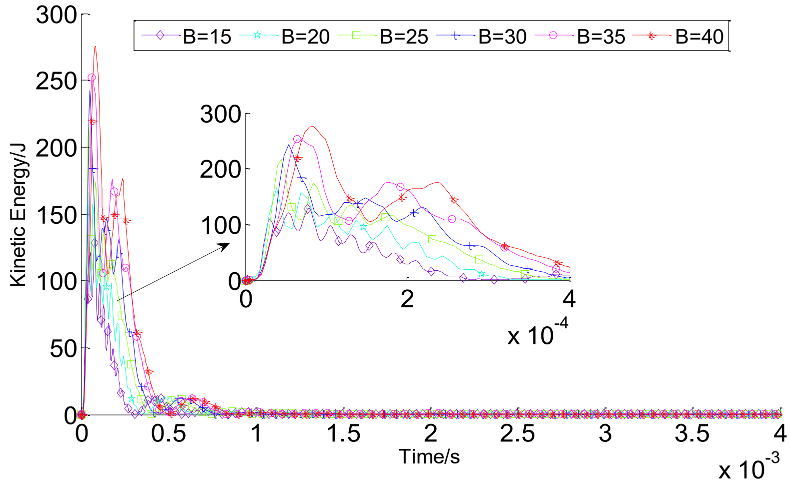

Figure 12–.Kinetic energy of the upper panel in different distribution density of bee cells

5. CONCLUSIONS

The finite element analysis software is used to verify the ability of absorbing energy and reducing vibration by honeycomb sandwich panels when suffer underwater explosion load, the results show that the thickness, height and distribution density of the bee cells have a great affect on the characteristics of absorbing energy and reducing vibration indeed.

(1).When suffer shock load, the honeycomb sandwich panels will generate elastic deformation , plastic deformation, vibration and noise owing to the input of energy, and the main form of energy is the internal energy of the structures.

(2). When explosion load is in the near field, within a certain value, the peak of the energy absorbed by the upper plate decrease obviously with the thickness of the bee cell increasing, and the effect of absorbing energy by the honeycomb sandwich gets enhanced; when the thickness of cell wall exceed 4mm, the effect of absorbing energy gets weaken. Therefore, the vibration get strong, and the stability of the whole structure will descend with the thickness of bee cells increasing.

(3).When the explosion load is in the near field, along with the height of honeycomb sandwich increasing, the effect of absorbing energy and reducing vibration get enhanced, and the energy obtained by upper plate get low, and the amplitude of vibration get weaken; At the same time, the trend of energy changing decrease, and the stability of the whole structure will descend .

(4).When the explosion load is in the near field, along with the distribution density of bee cell decreasing, the energy of the upper plate gets increased, and the effect of absorbing energy by honeycomb sandwich get weaken; when the length of side reach 35mm, the effect of absorbing energy by honeycomb sandwich becomes constant nearly, and at this time ,increasing the distribution density of the bee cell is of small significant, in contrary, this will increase the weight of the structure.

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