# Numerical simulation of three interior double-layer bulkhead structures

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**Abstract**: When anti-ship missiles penetrate into the ship armor, fragments and shock waves caused by explosion will severely destroy the personnel and equipment on the ships. In this study, three double-layer bulkheads with different interior sandwich structures were investigated, including X and hexagonal combined sandwich structure, cross-type honeycomb sandwich structure and cell growth type honeycomb sandwich structure. The penetration processes of three different bulkhead structures were simulated by software ANSYS/LS-DYNA. The simulation shows that the double-layer bulkhead with cross-type honeycomb sandwich structure is the most suitable. Finally, the dynamic response characteristics of the cross-type sandwich bulkhead structure are analyzed.

**Key words**: cross-type sandwich structure; forging fragments; dynamic response; ship armor; anti-ship missile

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## 0 Introduction

With the promotion of modern naval equipment and the continuous confrontation among military forces, the relation of anti-ship missiles and warship armors is just like the spear and shield and becomes intenser and intenser. There are many types of anti-ship missile warheads, such as shaped armors that penetrate through the ship armor depending on the jet, semi-armor-piercing warheads that destroy the ship depending on the warhead kinetic energy, etc. Most of them can penetrate the ship's outer thin armor and then enters into a certain interior cabin, where explosion occurs due to the existence of delay fuze. A large number of fragments and shock waves, especically the former, do a lot of severe damage to the double-layer bulkhead structure. It is necessary to analyze the defensive capability of the double-layer bulkhead structure. By studying different types of spherical fragments penetrating into the ship armor, the form of fragments with a better penetrating ability was obtained[1-6], but there is not enough research on the double-layer bulkhead structure. Therefore, it is important to study the middle structure double-layer of the bulkhead to promote its defensive capacity.

## 1 Evaluation criteria of anti-penetration performance

### 1.1 Residual speed of fragment

The initial speed of the fragment is very high. If the residual speed through the target plate is not much reduced, it will ignite or detonate the targets, resulting in losses of defensive ability and combat capability in a short time. Therefore, the superior structure type needs to lower the residual speed of the fragment as much as possible to reduce the damage caused by residual characteristics[7].

### 1.2 Energy absorption characteristic of target structure

The energy absorption characteristic of the target structure in the process of fragment penetration is also an important index for the evaluation of the damage. The more energy the target plate absorbs in the process of piercinging through the fragments, the

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more the penetration ability of the fragments decreases and the less penetration effect decreases[7].

# 2 Selection of material parameters and finite element model of fragment and target plate

## 2.1 Selection of material parameters

Software ANSYS/LS-DYNA was applied to simulate the process of the fragments penetrating into the armor. Tungsten alloy was seleted as the fragment material. Because the fragment with high flying speed can instantaneously penetrate the armor, rigid body model is used for the fragment model. In addition, the model of the target plate has large deformation, and therefore the John-Cook model and the Gruneisen equation of state are adopted. In order to save the calculation time, only 1/2 model is established and the target plane is constrained by the symmetry plane in this study.

The material parameters of two model are listed in Tables 1 and 2, respcetively.

**Table 1 Material parameters of tungsten alloy**

| $\rho$(kg/m) | $E$(GPa) | $u$ | $A$(MPa) | $B$(MPa) |
|---|---|---|---|---|
| 18.7E3 | 314 | 0.28 | 1 506 | 1 770 |

**Table 2 John-Cook material model parameters of target plate**

| $\rho$(kg/m) | $E$(GPa) | $u$ | $T_r$(k) | $T_m$(k) | $A$(MPa) | $B$(MPa) | $n$ |
|---|---|---|---|---|---|---|---|
| 7 800 | 158.5 | 0.3 | 298 | 1 763.5 | 898.6 | 356 | 0.022 |
| $c$ | $m$ | $D1$ | $D2$ | $D3$ | $D4$ | $D$ | |
| 50.586 | 1.05 | 0.8 | 2.1 | 0 | 0.002 | 0.6 | |

## 2.2 Establishment of finite element models

The upper and lower panels of the double-layer bulkhead are 4 mm thick, the interor layer is 250 mm thick, and the thickness between the interior layers is 2 mm. Since the structure is complex, appropriate length and width are selected to simplify the model and reduce the calculation. The front end of the fragment is spherical and the back end is a cylinder with a height of 1.5-fold sphere radius. The finite element models of three different types of cabin sandwich structures are shown in Fig. 1.

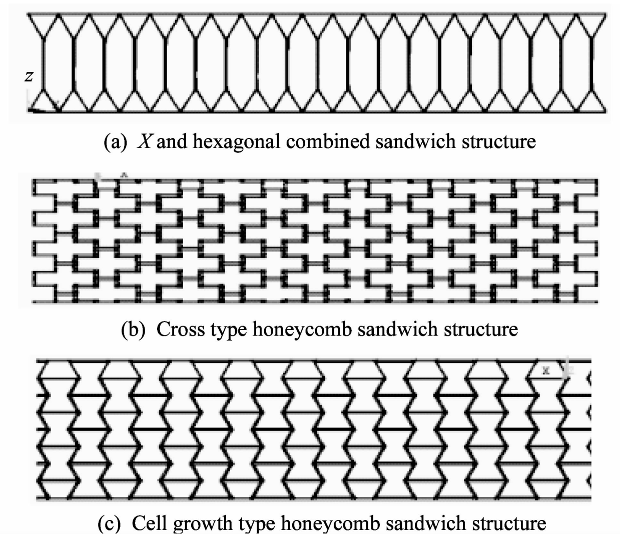


**Fig. 1 Finite element models of thress inner sandwich structures**

## 2.3 Anti-penetration effect analysis of three interior sandwich structures

The fragment respectively penetrated three targets with different interior sandwich structures at a speed of 1 200 m/s. The diameter of the fragment was 20 mm, The speed attenuation curves of three sandwich structures are shown in Fig. 2.

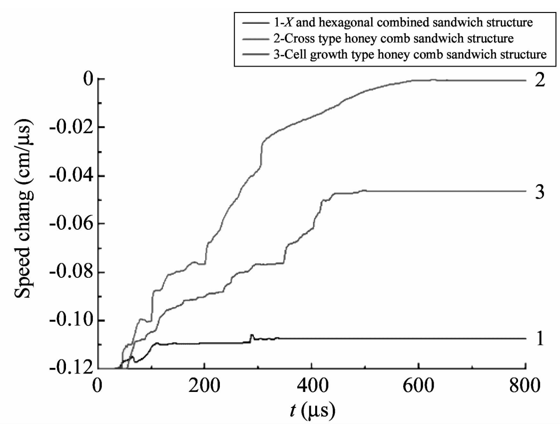


**Fig. 2 Comparison of velocity attenuation of three interior sandwich structures**

For X and hexagonal composite sandwich structure, the attenuation rate is 124.8 m/s; the cross type honeycomb sandwich structure, 1 200 m/s; and cell growth type honeycomb sandwich structure, 737.45 m/s. It is noted that the fragments fail to penetrate the target plate for cross type honeycomb sandwich structure. Table 3 lists the velocity changes of three sandwich structures.

**Table 3 Comparison of velocity changes for three sandwich structures**

| | X and hexagonal combined sandwich structure | Cross type honeycomb sandwich structure | Cell growth type honeycomb sandwich structure |
|---|---|---|---|
| Velocity change (m/s) | 124.8 | 1 200 | 737.45 |
| Percentage (%) | 10.4 | 100 | 61.45 |

The changes in the interior layer energy for the three targets with diffreent sandwich structures during the penetration of the fragments are shown in Fig. 3. It can be seen that the cross-type honeycomb sandwich structure has the largest energy change and the best energy absorption, which can effectively reduce the kinetic energy of the fragments to prevent the fragments from penetrating.

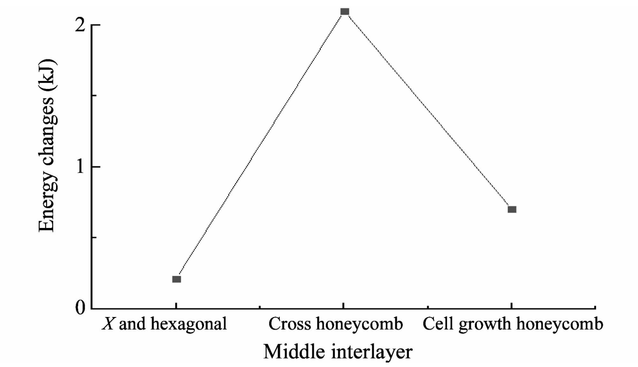


**Fig. 3 Energy changes of interior layers for three sandwich structures**

## 2.4 Anti-penetration effect analysis of cross-type sandwich honeycomb structure

The fragments penetrated the cross-shaped sandwich honeycomb structure at initial velocities of 1 000, 1 200, 1 400, 1 600, 1 800 and 2 000 m/s, respectively. The residual speed change curve of the fragment is depicted in Fig. 4.

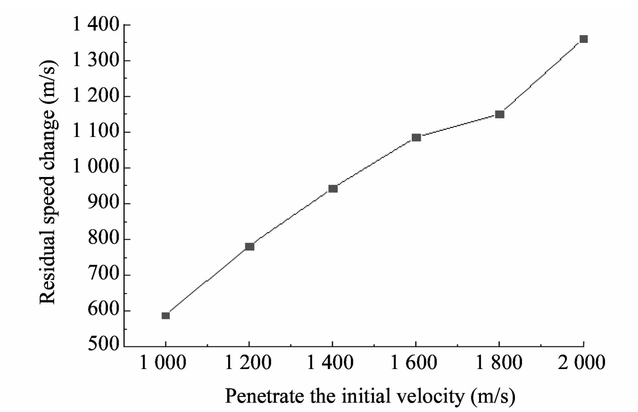


**Fig. 4 Curve of residual velocity of fragment with different initial velocities**

In the penetration process, the residual velocity change is approximately linear. And the ultimate penetration velocity of the fragments is 950 m/s when the fragment diameter is 20 mm.

With the increase of the speed of the fragment, the energy absorption effect of the target also changes. The energy change of the cross-type honeycomb sandwich structure increases with the increase of the initial velocity. When the speed exceeds a certain value, the energy of the target tends to be smooth.

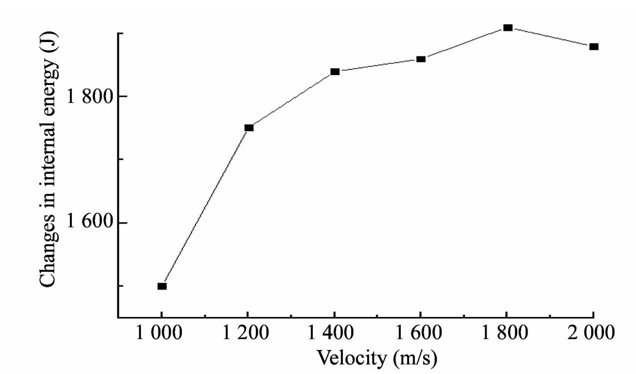


**Fig. 5 Internal energy change of cross-type sandwich target**

## 2.5 Dynamic response of cross-type sandwich honeycomb target to fragmentation with different radii

When the fragments with the different radii penetrated the target with cross-type sandwich honeycomb structure at the initial speed of 1 200 m/s, the penetration depth changes, as shown in Fig. 6.

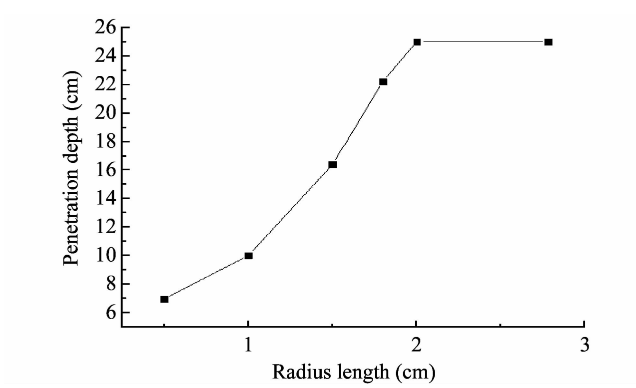


**Fig. 6 Penetraing depth into target for fragments with different radii**

With the radius of the fragment increasing, penetration depth gradually increases. When the radius of the fragment increases to a certain value, it can penetrate the cross-type honeycomb target.

## 3 Conclusions

1) The three types of bulkheads with different sandwich structures were studied. The results show that the bulkhead with cross-type interior sandwich structure has the strongest penetration ability.

2) When the fragments with different initial velocities penetrate the bulkhead with the cross-type sandwich honeycomb structure, the residual velocity of the fragment is linearly related to the initial velocity, and the ultimate penetration speed of the fragment is 950 m/s when the diameter of fragment is 20 mm. Moreover, the energy of the target plate varies with the initial velocity. It is found that the energy change of the target plate is great with the increase of the initial velocity. When the velocity reaches a certain value, the energy of the target plate tends to be stable.

3) When the fragments with different radii penetrate the targe with cross-type sandwich honeycombt structure, the penetration depth increases with the radius increasing. When the radius reaches 18 mm, the fragments can penetrate the target with the cross-type honeycomb sandwich structure.

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# 三种内夹层双层舱壁结构的数值仿真

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**摘　要：** 反舰导弹在侵彻进入舰艇装甲内部时，爆炸产生冲击波和飞散破片对人员和舰艇内部设备具有严重毁坏性。研究了三种不同内夹层结构形式的双层舱壁结构：X型与六边形组合夹层结构、十字型蜂窝夹层结构以及细胞增长型蜂窝夹层结构。采用ANSYSY/LS-DYAN模拟了自锻破片对三种不同舱壁结构的侵彻过程。根据破片的速度衰减和靶板的能量变化可知，十字型蜂窝夹层结构的双层舱壁结构最适合作为舱壁的中间结构，并对其动态响应特性进行了分析。

**关键词：** 十字型蜂窝夹层结构；自锻破片；动态响应；舰艇装甲；反舰导弹

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