Numerical simulation of anti-penetration performance of corrugated plate/aluminum foam sandwich structure

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Abstract: *In order to study the anti-penetration performance of corrugated plate/aluminum foam composite sandwich structure, LS-DYNA software was used to simulate. The penetration model of 7.62 mm rifle bullet into the sandwich structure was established, and the residual velocities of bullets at five penetration positions were compared and analyzed. The influence of different initial velocity forward penetration and initial velocity 900m/s angle penetration on B is focused. The results show that at different penetration positions, the residual velocity of bullet B is the largest and the anti-penetration performance is the weakest. With the decrease of the initial velocity of the bullet, the movement of the bullet in the structure is different, and the deflection phenomenon occurs when the bullet is penetrating B. When different penetration angles (initial velocity 900m/s) penetrate B, the trajectory of the bullet is approximately a straight line along the penetration angle. When the penetration angle is 30°, it cannot completely penetrate the sandwich structure. The deformation of sandwich structure is mainly shear deformation; under different conditions, the bullet runs through the sandwich structure only at the initial speed of 900 m/s. This study can provide basis and reference for the improvement and application of corrugated plate/aluminum foam composite sandwich structure.*

Keywords: *corrugated plate, aluminum foam, anti-penetration performance*

1. Introduction

As an important carrier of material transportation, containers are not only widely used in the field of people's livelihood, but also widely used in the transportation of military materials. With the continuous upgrading of weapon technology, optimizing the container structure and improving the anti-penetration performance of containers are the urgent difficulties to be solved for the protection of important military materials and the improvement of military logistics transportation capacity.

Foam aluminum material, for the traditional foam aluminum sandwich structure, namely the typical sandwich structure, has distinct characteristics. Compared with the traditional steel plate, its quality is lighter, but the protective effect is better, and the energy absorption effect is better. It has been widely used in all walks of life. Research on its various aspects of performance is also sufficient [1-10].

The aluminum foam sandwich plate in the composite structure considered in this paper is filled with triangular corrugated plate in the traditional aluminum foam core. The overall composition is mainly divided into five parts. The outermost layer is trapezoidal corrugated plate, followed by the upper plane target, the middle is triangular corrugated plate, and the lower layer is the lower plane target. The core is aluminum foam, which is filled between triangular corrugated plates.

Based on the background of 7.62 mm bullet penetrating the new structure of the container, this paper adopts the method of simulation analysis to study and analyze the anti-penetration performance of the new structure of the container, which provides the basis for the optimization and application of the container protection design in the next step.

2. Establishment of Numerical Simulation Model

2.1. Geometric model

Figure 1 is the schematic diagram of sandwich structure. As shown in the diagram, the sandwich structure is divided into five parts: trapezoidal corrugated plate, upper plane plate, triangular corrugated plate, lower plane plate and triangular prism foam aluminum core, each part is jointed. Due to the symmetry of penetration, 1/2 solid model is used for modeling, and hexahedral solid element and Lagrange algorithm are used.

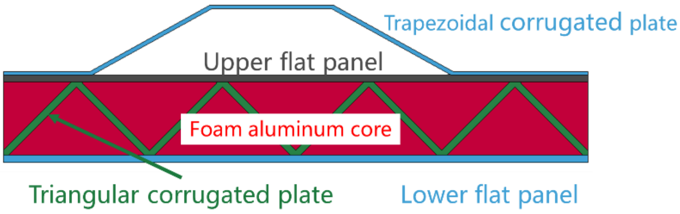

Figure 1: Schematic diagram of sandwich structure.

The specific geometric dimensions of the structure are shown in Figure 2.The container shell is trapezoidal corrugated plate, the thickness is 2 mm, the height is 40 mm, and the angle between the bevel and the bottom is 150 °. The thickness of the sandwich structure of the main body is 48 mm. The thickness of the upper and lower plane plates and triangular corrugated plates in the structure is 4 mm. The angle between the oblique edge of the triangular corrugated plate and the horizontal plane is 45 °. Aluminum foam core is filled in the gap of triangular corrugated plate.

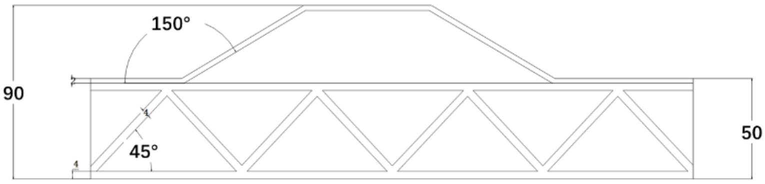

Figure 2: Method 2 Model Diagram.

The bullet model used in this paper is 7.62 mm rifle bullet, the length of the bullet is 26 mm, the diameter of the bullet is 7.62 mm, and the warhead is pointed egg type. Since the size of the sandwich structure in the direction perpendicular to the penetration plane is much larger than that of the bullet, in order to reduce the calculation cost, the size in the direction perpendicular to the penetration plane is set to 200 mm. Figure 3 is a typical penetration model.

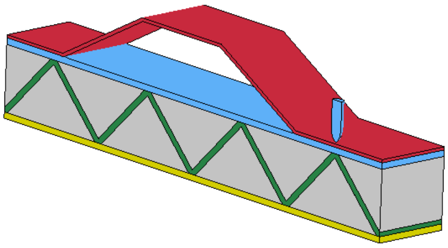

Figure 3: Penetration model.

2.2. Material model

Compared with the deformation of aluminum foam material, the deformation of the bullet can be ignored. In order to simplify the model, the projectile is modeled by a rigid body model (*MAT_ RIGID), with the density of 7850 kg/m^3, Young's modulus of 200GPa and Poisson's ratio of 0.33. The overall mass of warhead model is 4.95 g.

Ladder corrugated plate, upper plane plate, triangular corrugated plate and lower plane plate are modeled by *MAT_JOHNSON_COOK keyword. The main material parameters are density 7830 kg/m^3 and shear modulus 0.77Gpa.

*MAT_CRUSHALBE_FOAM is used to describe aluminum foam materials. This model is simple and can well reflect the real situation of aluminum foam materials. The stress-strain curve is shown in figure 4. The material parameters are: density 250 kg/m^3, Young's modulus 0.4Gpa, yield strength

5.3Mpa.

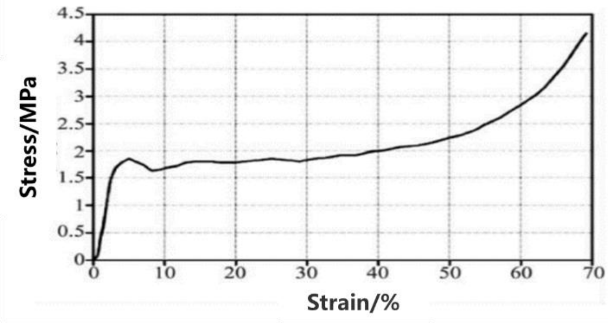

Figure 4: Stress-strain curve.

Due to the use of Lagrange algorithm, the grid will produce negative volume under large deformation, so the failure criterion is used to simulate the failure effect of the core. At the same time, in order to better reflect the penetration results, the percentage of principal strain failure of aluminum foam material is defined as 40%, that is, when it is greater than 40%, these failure units will be deleted.

2.3. Model other information

The penetration of bullets into sandwich structures involves the erosion of bullets on different plates, and there are also erosions between plates, plates and aluminum foam cores. Therefore, the contact between bullets and various parts is defined as: (*CONTACT_ERODING_SINGLE_SURFACE_ID). In terms of boundary conditions, the transmission boundary conditions are adopted at the outer edge of the sandwich structure, and the symmetric boundary conditions are set on the symmetric surface.

3. Simulation results and analysis

3.1. Analysis on results of different penetration positions

Due to the different penetration positions of bullets, a variety of penetration combinations will be involved, resulting in differences in results. In order to compare the residual velocities of bullets at different penetration positions, and to save the calculation cost, five typical penetration positions are selected for analysis on the premise of the forward penetration of bullets with initial velocity of 900 m/s. The five typical penetration positions selected in this paper are shown in figure 5.

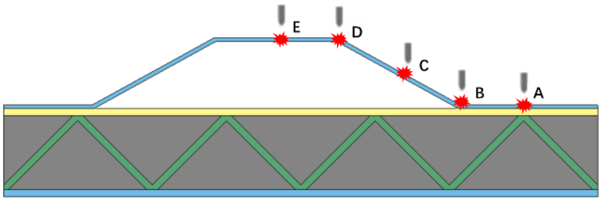

Figure 5: Diagrams of different penetration positions.

Figure 6 is the final deformation results of the projectile under the initial velocity of 900m/s. It can be seen from the figure that the trajectory of bullets in the sandwich structure is different at different penetration positions. The bullets at C and D deflect in the sandwich structure, and the trajectory of each bullet is approximately a straight line.

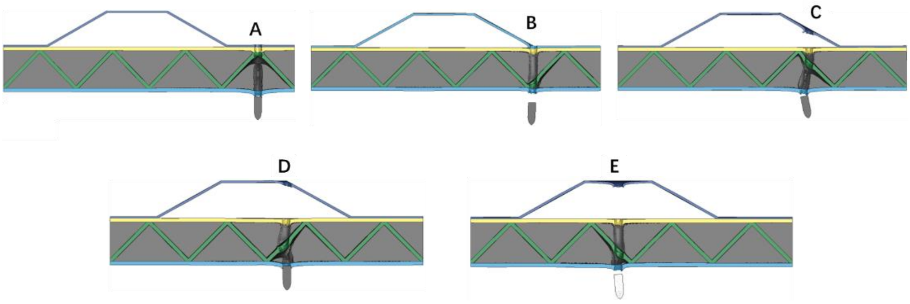

Figure 6: Diagrams of different penetration positions.

Figure 7 is the time history curve of bullet attenuation velocity at different penetration positions. It can be seen from the diagram that the bullet velocity attenuation is in the form of multi-segment exponential. When through the sandwich structure, fly out at a fixed speed.

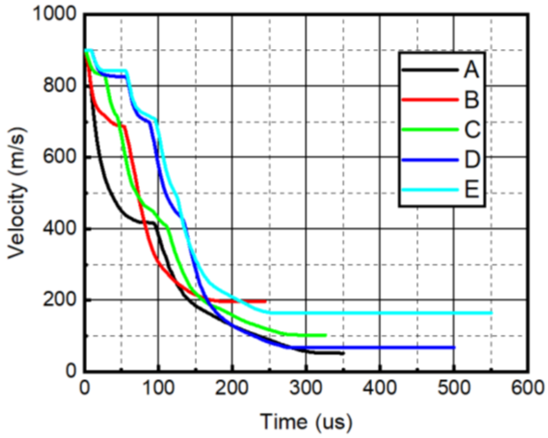

Figure 7: Time history curve of bullet velocity.

When the bullet penetrates the sandwich structure, the kinetic energy of the bullet is absorbed by the sandwich structure. The smaller the residual velocity of bullets is, the more the energy absorbed by the sandwich structure is, and the better the anti-penetration performance is.

Table 1: Residual velocity and loss energy.

Model	A	B	C	D	E
Remaining velocity/m/s	52	197	102	68	164
Lost energy/J	1998	1908	1979	1993	1938

It can be seen from table 1 that the residual velocity of bullet at A is the smallest and the loss energy is the largest, indicating that the sandwich structure absorbs more energy and has better anti-penetration performance than other places. B bullet residual velocity is the largest, the loss of energy is small, the anti-penetration performance is weaker than other places.

3.2. Effective plastic strain analysis at B

Compared with the five forward penetration results, B is the weak place in the sandwich structure. Attention should be paid to this place. The plastic strain results of the sandwich structure at the initial velocity of 900 m/s and the bullet penetrating B are analyzed.

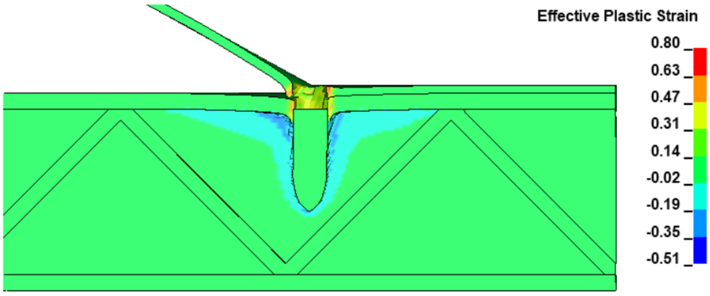

Figure 8: Effective plastic strain nephogram (initial velocity =900m/s).

Figure 8 is the effective plastic strain nephogram. It can be seen from the figure that the strain is mainly concentrated in the trajectory of the projectile and its surrounding. The deformation of trapezoidal corrugated plate and upper plane plate is shear failure. When penetrating the aluminum foam core, as the penetration depth of the bullet deepens, the aluminum foam material under the warhead tends to be, and the deformation of the core is mainly caused by the local shear failure around the projectile and the compression of the core.

3.3. Analysis of positive penetration results of different bullet initial velocities at B

In order to analyze the difference of different bullet initial velocities penetrating B, the bullet initial velocities are set as 600 m/s, 675 m/s, 750 m/s, 825 m/s and 900 m/s, respectively. The final deformation of the sandwich structure with different initial velocities is shown in figure 9.

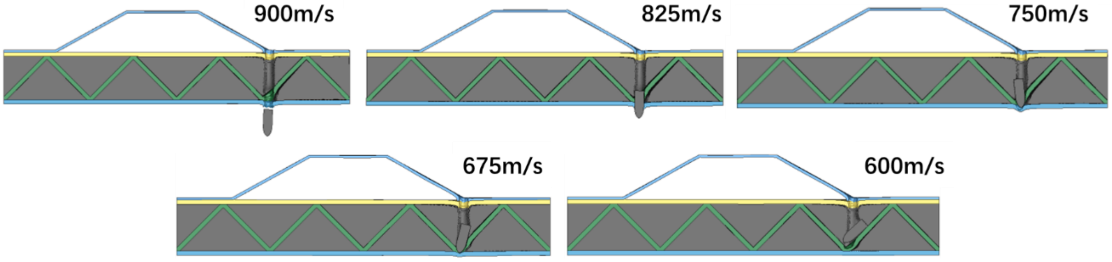

Figure 9: Final deformation of sandwich structure.

It can be seen from the figure that when the bullet penetrates B, when the initial velocity of the bullet is 900 m/s, the trajectory is approximately a straight line. But as the initial velocity decreases, the trajectory deflection occurs. The deflection is caused by the asymmetry of force when the bullet penetrates the triangular corrugated plate. The lower the initial velocity of the bullet, the more severe the deflection, and the greater the internal damage range.

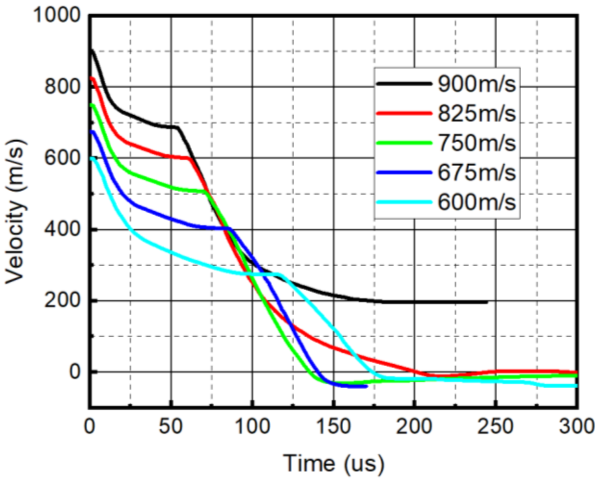

Figure 10: Time history curve of bullet velocity.

Figure 10 is the time-history curve of velocity attenuation of bullet penetrating B at different initial velocities. It can be seen from the diagram that under five different initial velocities at B, the attenuation curve of bullet velocity is very similar, and there are two large velocity attenuations. When the initial velocity is 900m/s, the bullet runs through the structure and flies out at the speed of 200m/s. The four cases appear negative speed. With the decrease of the initial velocity of the projectile, the longer the penetration process of the projectile into the aluminum foam core, the more gentle the curve shows in the diagram.

3.4. Analysis on the results of different penetration angles of bullets at B

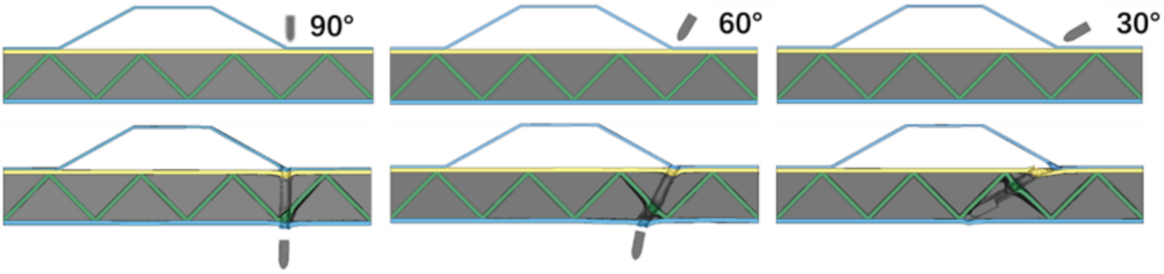

Figure 11: Results of different penetration angles (initial velocity: 900m/s).

In order to analyze the influence of different penetration angles of bullets on position B, the penetration angles of bullets are set as 30 °, 60 ° and 90 ° respectively under the condition of initial velocity of bullets of 900 m/s. The initial state and final results of penetration at different angles are shown in figure 11.

It can be seen from the figure that the smaller the penetration angle, the longer the penetration distance in the sandwich structure. When the penetration angle is 30 °, the bullet cannot penetrate the sandwich structure.

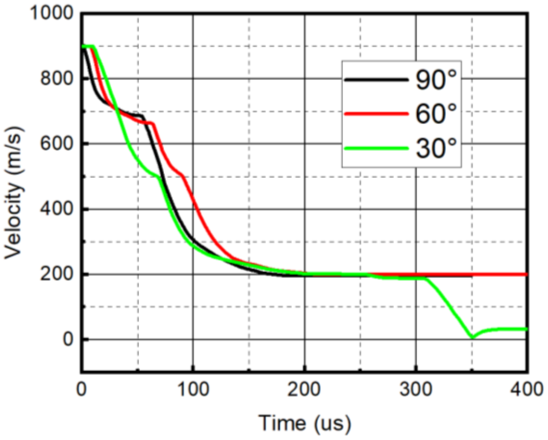

Figure 12: Results of different penetration angles (initial velocity: 900m/s).

Figure 11 is the time history curve of bullet attenuation velocity under different penetration angles. It can be seen from the diagram that the bullet velocity at different angles has been attenuated many times. At 90 ° and 60 °, the bullets run through the sandwich structure and fly out at a speed of 200 m/s. At 30 °, the kinetic energy of the bullet is depleted, and the trajectory rebounds.

4. Conclusion

In this paper, the numerical simulation of corrugated plate/aluminum foam sandwich structure is carried out to analyze the influence of different penetration velocities of bullets on the anti-penetration performance of the structure, and the following conclusions are obtained:

The sandwich structure is completely penetrated only at the initial velocity of 900m/s, indicating that the overall anti-penetration performance of the sandwich structure is good. Compared with the other five places, place B is the weakest anti-penetration performance in sandwich structure.

The damage of the bullet to each part of the structure is mainly shear failure, and the structural strain belongs to plastic strain. When the bullet penetrates the aluminum foam core, the core strain is mainly caused by the local shear failure around the projectile and the compression of the projectile core.

The tensile and fracture of the steel plate and the compression and collapse of the aluminum foam core are the main sources of the kinetic energy of the projectile absorbed by the sandwich structure. The debonding between the plate and the core during the penetration process will also absorb part of the energy.

When the bullet penetrates the sandwich structure, the velocity changes with multiple exponential attenuation. When penetrating B, the smaller the initial velocity under the positive penetration condition, the smoother the curve, and the more prone to deflection of the bullet trajectory. When the initial velocity is 900m/s, the smaller the penetration angle is, the bullet will not completely penetrate the structure.

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