A Numerical Simulation Study of Sandwich Structure Shield Against Invasion

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Abstract. Using ANSYS simulation software, the experimental simulation and numerical analysis of anti-12.7 mm tungsten alloy armor-piercing in different mezzanine layers of sandwich structure protection plate were carried out. The upper and lower panels of the sandwich structure are armored steel and the mezzanine is aluminum alloy. The anti-intrusion performance of the protective plate in different mezzanine structures is simulated and analyzed. The results show that the sandwich structure porous shield has excellent performance against kinetic energy, and the protective performance is better than the holeless shield plate structure under the same surface density condition. In the simulated three sets of tests, the porous shield with an aperture of 3 mm has better anti-intrusion protection performance.

1. Introduction
Large-scale group confrontation is less and less likely to occur in future wars, and rapid response warfare has become the mainstream of future wars. The construction of light synthetic combat units is an important part of China's military reform, and compared with the traditional mechanized heavy armor troops, the advantages of light synthetic units are higher mobility and deployment, can achieve rapid response throughout the country, especially suitable for the Qinghai-Tibet Plateau near South Asia and other places of complex terrain[1].

However, the lighting of armor is contradictory to wheeling and elasticity. The multi-hole shield of light armored vehicles studied in this topic is a process that is not too complex to use on the basis of traditional protective plates, which is both economical and lightweight while ensuring elastic energy, so as to enhance the mobility and survivability of light armored vehicles on the battlefield at the same time as rapid deployment. This technology can be applied not only to new armored vehicles, but also to improve the protection of older armored vehicles, thereby improving their ability to accomplish military missions in the new situation with lower military expenditures[2].
2. The configuration model and state equation

2.1. The configuration model
Choosing different material models has a decisive effect on the results of numerical simulation. This paper studies the material dynamics of the projectile intrusion shield and simulates the anti-aggression behavior of the shield. So adopt Johnson-Cook (J-C) model. Because this material model is calculated more accurately and can better react to the stress strain and temperature softening of the metal material.

Johnson-Cook the material model divides the material strain stress analysis into two stages:

The first stage is the elastic phase, i.e. the material strain-stress relationship conforms to Hooke's law:

\[ \sigma = E\varepsilon = 2G(1 + v)\varepsilon \]  \hspace{1cm} (1)

Where, \( \sigma \) and \( \varepsilon \) are the \( \sigma_0 \) and \( \varepsilon_0 \) at room temperature.

The second stage is the stress yield phase, where the yield stress is:

\[ \sigma_y = (A + B(\varepsilon^p)^n)(1 + C \ln \varepsilon^p)(1 - T^m) \]  \hspace{1cm} (2)

The first bracket in the method describes the hardening strain effect \( A \) is yield stress constant, \( B \) is strain constant of flexure, \( \varepsilon^p \) is equivalent plastic strain, \( n \) is hardening strain index \(^3\).

The second bracket describes the sensitivity of the material strain rate, \( \varepsilon^p \) is equivalent plastic strain rate, \( C \) is strain rate correlation constant.

The third bracket describes the softening effect of the material caused by the increase in temperature.

Johnson-Cook model defines a failure criterion in order to avoid mesh distortion caused by too large deformation of the shield, Damage to the shield is measured by the degree of damage \( D \). The value of \( D \) is between 0 and 1. When the \( D=1 \) states that the guard plate is completely damaged, When \( D=0 \), the shield is completely free of damage. Damage \( D \) is defined as:

\[ D = \Sigma(\Delta \varepsilon^p / \varepsilon^f) \]  \hspace{1cm} (3)

In the equation: \( \Delta \varepsilon^p \) is equivalent plastic strain increment, \( \varepsilon^f \) is failure strain:

\[ \varepsilon^f = [D_t + D_2 \exp D_3 \sigma^*][1 + D_4 \ln \varepsilon^*][1 + D_5 T^*] \]  \hspace{1cm} (4)

In the equation: \( \sigma^* = P / \sigma_{eff} \), \( P \) is the material impact pressure value at a certain time, \( \sigma_{eff} \) is the equivalent stress of the moment.

2.2. State equations
State equations are used to describe the interrelations between pressure, volume, and temperature (or energy), and the metal shield can have very large shape variables during the anti-invasion process. Gruneisen state equations are the most commonly used high-voltage state equations, so Gruneisen state equations are used to describe the deformation of the shield. The Gruneisen equation is shown below:

\[ P = \frac{\rho_0 C_T^2}{[1 - \gamma(\gamma - 1)]} + \frac{\gamma \mu}{(\gamma + 1) \mu} + \alpha \mu E_0 \]  \hspace{1cm} (5)

Where, \( E_0 \) represents the inner energy per unit volume, \( C \) represents the intercept of the vibration wave-particle velocity curve, \( S_1, S_2 \) and \( S_3 \) represent the slope coefficient of the vibration wave-particle velocity curve, \( \gamma \) represents the Gruneisen coefficient, \( \alpha \) represents the volume correction factor, \( \mu \) represents the compression factor \(^4\).
The bullet material is tungsten alloy, the panel and back plate of the protective plate are armored steel, and the mezzanine is aluminum alloy material. The performance parameters of the material used in the model are shown in Table 1.

### Table 1. Material performance parameter.

| Material        | Density (g/cm³) | Poisson ratio (µ) | Wave velocity (C) | Elastic modulus (EX) | Melting point (TM) |
|-----------------|-----------------|-------------------|-------------------|----------------------|--------------------|
| Tungsten alloy  | 18              | 0.28              | 0.4029            | 3.44                 | 1850               |
| Steel alloy     | 7.83            | 0.32              | 0.4596            | 2                    | 1793               |
| Aluminium alloy | 2.78            | 0.35              | 0.4251            | 0.69                 | 877                |

3. Anti-infringement numerical simulation of the shield

3.1. Building the model

This simulation uses China's 84-type 12.7 mm tungsten core shell-through armor-wearing bomb. The warhead diameter is 12.74 mm, the core diameter is 7.9 mm, the core diameter/warhead diameter is 0.62, the bullet speed is about 810 m/s to 825 m/s and the core diameter is 22 g[5]. In order to simplify the projectile structure, when simulating simulation, the core diameter is set to 8 mm and the core length is 20 mm. For the convenience of calculation, set the speed of the projectile to 850 m/s.

The size of the target plate is much larger than the projectile size, so the target plate can be considered an infinite target. In this case, the target plate and projectile can be considered axis symmetry. In order to save time and reduce the amount of computational work, only 1/4 model can be built for simulation during modeling, as shown in Figure 1. Tungsten alloy warheads and target plates in the simulation model are divided by 3D solid modeling solid164 units. In order to make the calculation results more accurate, specially encrypted the mesh of the area where the projectiles come into direct contact with the target board, the target plate is a sandwich structure, each layer of the target plate thickness of 10 mm, the target plate interval is 4 mm, the size is 100 mm×100 mm.

![Figure 1. Numerical calculations model.](image)

An erosion algorithm is used between the target plate and the projectile, which means *CONTACT_ERODING_SURFACE_TO_SURFACE* algorithm. A non-reflective boundary is applied at the
target plate boundary and symmetrical constraints are applied to the symmetric boundary. The calculation time is 1000 µs and the simulation results are output every 5 µs. Initial stress, strain, displacement, and acceleration all default to 0. In the process of invasion, the effect on material properties caused by local large deformation of the target plate is ignored.

3.2. Numerical simulation
Using the above-mentioned model and material parameters, aluminum alloy mezzanine is selected as a solid plate, a diameter of 3 mm well plate and a 6 mm hole plate for research, and they are recorded as 1~3 groups.

(1) The mezzanine is a solid aluminum plate
The simulation results are shown in Figure 2. At the 200th stage of the projectile invasion, the projectile is about to penetrate the first layer of protective plate, at which point the pellet speed is about 690 m/s, which is 20% lower than the initial speed; At the 500 s, the projectile basically penetrates the second layer of the target plate, and the speed of the projectile drops to 570 m/s, which is 33% lower than the initial speed. When the simulation is up to 1000 s, the speed of the projectile drops to 180 m/s, which is 79% lower than the initial speed. Bending, deformation and breaking of the first layer plate, as well as the plastic deformation of the mezzanine material, can greatly reduce the speed of the projectiles.
The mezzanine is a 3 mm porous plate. The simulation results are shown in Figure 3. Simulates the anti-aggression capability of aluminum alloy porous protective plates with a diameter of D-3 mm. The following image shows the speed cloud map of the 12.7 mm tungsten alloy armor-penetrant bomb invading the porous shield at three different times.

In the simulation simulation of the pellet-intrusive aperture of 3 mm aluminum laminated porous protective plate, the initial estate speed is still 850 m/s. The pellet basically penetrates the first layer of protective plate during the intrusion process at 200 s, at which point the bounce speed is about 690 m/s, which is 20% lower than the initial estate speed; At the simulation of 500 s, the projectiles are about to penetrate the mezzanine, at which point the bounce speed is approximately 450 m/s, a decrease of 47% compared to the initial speed; At the time of the 1000 s, the projectiles were invading the third-tier target plate at 85 m/s, a 90% decrease from the initial speed. The bounce speed at this point is not sufficient to penetrate the third layer of the target plate.
The mezzanine is a 6 mm porous plate. The simulation results are shown in Figure 4. In addition to the variable change of aperture size, the remaining parameters are unchanged, in the process of invasion, the projectile appeared obvious thick and congestion phenomenon. The initial speed of the projectile is 850 m/s, and by the time of the invasion process, the projectile has basically penetrated the first layer of steel plate at a speed of 690 m/s, a decrease of 20%; The projectiles basically penetrate the second layer of steel plate at a speed of about 520 m/s, a decrease of nearly 40%, during the invasion process of 500 µs; The projectiles were still on the third-floor target plate at a speed of about 140 m/s, a decrease of 84% when the process was 1000 s. At this time, the projectiles still did not penetrate the third layer of protective plate.
Results Analysis: The simulation end time is 1000 s, the initial speed is 850 m/s. At the end of the simulation, the projectile speed of the armor-penetrated reduced to about 180 m/s. At the end of the simulation, the bullet speed of the armor-penetrated dropped to about 85 m/s. The porous shield with a aperture of 6 mm has a pellet speed of about 140 m/s at the end of the simulation of the anti-motulation projectile. This shows that the porous plate with a aperture of 3 mm has better protection.

4. Conclusion
Because of the presence of holes, the projectiles in the process of punching through the shield, in a contact with the mezzanine when the role of the symmetrical force, the bullet body invasion may change, the projectile swing deflegation and thus the ballistic change, greatly reducing the ability of the projectile to invade the armor.

By designing a certain uniform through hole in the shield, the weak points in the internal structure are artificially set on the shield, and the force state changes in the process of the small and medium-caliber armor-penetrated intrusive on the shield. At the same time, when the porous shield is hit by a projectile, the porous structure near the ballistic hole is torn by force, so that the armor-penetrating energy of the dynamic energy bomb can be dispersed to a range, rather than concentrated at a certain point in the ballistic, thus greatly improving the elastic energy of the shield.

Under the same conditions, the size of the aperture will also be able to counter elasticity can cause a certain impact, from the experimental results, the aperture of 3 mm porous laminate plate resistance is better than the aperture 6mm porous mezzanine version.

5. References
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