Influence of Angle on Armor Protection Performance of Thin Layer Charge Reaction

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Abstract. In order to explore the protective effect of thin layer charge reactive armor on oblique penetration of jet, the experiment will adopt 0.8mm thin layer charge structure and change the normal Angle to study its protective ability against oblique penetration of jet. Meanwhile, finite element software ANSYS/LS-DYNA will be used to conduct numerical simulation on the process of jet and reactive armor. For 0.8 mm thin layer charge structure, it can be clearly seen that the normal Angle is from unexploded at 50 to half burst at 70 and finally to full burst at 75, and the after-effect penetration depth is also significantly reduced from 12 mm to 3 mm, with a decrease rate of 75%.

1. Introduction
Explosive reactive armor (ERA) was first proposed and invented by German scientist Manfred Held in 1970. Its structure is similar to a "sandwich" in which a layer of interlayer explosive is added between two layers of metal or non-metal plates. Under the action of the jet, the interlayer explosive is detonated, driving the upper and lower steel plates to fly out in opposite directions, interacting with the jet within a certain period of time, and the jet element deviates or breaks, which seriously hinders the ability of the jet to penetrate further [1,2]. But we know that the speed of the steel flying plate driven by the explosive reaction armor can be 500~1500 m/s, and the fragments produced can fly hundreds of meters away or even farther [3], which is for the infantry and combat of our own team. Vehicles, helicopters and even the vehicles themselves bring potential threats, especially when the high-speed flying board slams and hits the surface of the vehicle, the instantaneous incident pressure can reach dozens of GPa, which may cause damage to the vehicle’s own structure. Moreover, the incident shock wave may form overpressure inside the armored vehicle, which may cause damage to the vehicle personnel and equipment. These various hazards make us have to explore safer and more effective protection. Kaufmann[4], Bianchi[5], etc. studied low-density materials such as ceramics, polycarbonate, polyethylene, glass fiber reinforced plastics as cladding plates for reactive armor, and...
domestic Wang Ling[6] studied fiber-reinforced composite materials, Li Ruijiang et al.[7] studied the protective performance of alumina and silicon carbide ceramics as the cladding plate of reactive armor, and found that this type of material has a better protective effect and at the same time has a lower collateral damage effect. In addition, it can also change the nature of the interlayer charge and reduce its explosive power [8]. In this paper, a sandwich charge structure with limited thickness is adopted to reduce the detonation energy in order to reduce the collateral damage caused by it.

2. Experiment

2.1. Structure settings
In order to investigate the protection capability of the thin layer charge structure against oblique jet penetration, a 200 mm square Q235 steel (thickness 3 mm) was designed as the face backing material, with rubber sealing around the steel plate and Octogen sandwich (density 1.72 g/cm³), thickness 0.8 mm) in the middle, and the steel plate and rubber sheet were bonded with the blended epoxy resin solution. The structure design is shown in Figure 1.

![Figure 1](image1.png)

Figure 1. Thin layer charge structure diagram.

2.2. Experimental setup
In this experiment, the jet generated under the shaped charge of a PTFE shell with a diameter of 36mm will be used for the detonation experiment. The main charge of the shaped charge is JH-2 (density 1.72 g/cm³), the cone angle of the medicine cover is 60°, the wall thickness is 1 mm, and the explosion height in the test is 110 mm.

Figure 2 is a schematic diagram of the experimental layout of the effect of shaped charges on reactive armor. During the experiment, the shaped charge was placed horizontally, and the distance between the mouth of the test armor surface and the aftereffect target plate was 110 mm and 275 mm, respectively. The inclination angles of the reactive armor are 50° (structure a), 70° (structure b) and 75° (structure c). The aftereffect target is 603 homogeneous armor steel with a thickness of 20mm. The field test layout is shown in Figure 2. After the experiment, the remaining penetration depth was measured to compare the protective performance of the reactive armor.
2.3. Experimental results

It can be seen from Figure 3 that after the jet and the thin layer of charge reacted with the armor, the damage on the surface of the after-effect target formed multiple craters, which were formed by the high-speed impact of jet fragments, which can be roughly divided into two areas, one is The action area of the escape jet (shown by the arrow in Figure 3), the other area is the formation of the after-effect target formed by the debris at the back of the jet after the backplane flies away from the jet axis. Table 1 shows the damage test of the escaped jet to the surface of the after-effect target.

Table 1. Experimental results.

| Structure | Dispersion depth (mm×mm) | Opening depth (mm) |
|-----------|--------------------------|-------------------|
| (a)       | 7×40                     | 12                |
| (b)       | 5.5×39                   | 3.7               |
| (c)       | 5×38                     | 3                 |

Figure 3. Results of penetration test of after-effect target.

3. Numerical simulation

3.1. Calculation model

The ALE algorithm of the nonlinear dynamic finite element ANSYS/LS-DYNA software is used to numerically simulate the action process of shaped charge and reactive armor. Among them, air and shaped charge adopt Euler algorithm, reactive armor and aftereffect target plate using Lagrangian algorithm. According to the symmetry of the structure, a 1/2 calculation model was established, and
symmetry constraints and non-reflective boundary conditions were imposed during the modeling process.

3.2. Material model parameters

The main charge is described by HIGH_EXPLOSIVE_BURN, the state equation is described by EOS_JWL, and its expression is:

\[ p = A(1 - \frac{\omega}{R_1^V})e^{-R_1^V} + B(1 - \frac{\omega}{R_2^V})e^{-R_2^V} + \omega E/V \]  \hspace{1cm} (1)

where \( p \) is the pressure of the product of the explosion, \( \text{Pa} \); \( \eta = \frac{\rho_1}{\rho_2} \); 1 for the density of explosives and 2 for the density of blast products. \( e \) the internal energy of the main charge, which is measured in J. \( A_{\text{JWL}}, B_{\text{JWL}}, R_1, R_2, \) and other parameters in the formula are all constants. The main component of the shaped charge is JH-2, as shown in Table 2.

| Table 2. Calculation parameters of shaped charge. |
|--------------------------------------------------|
| \( \rho(\text{g} \cdot \text{cm}^{-3}) \) | \( A_{\text{JWL}}(\text{GPa}) \) | \( B_{\text{JWL}}(\text{GPa}) \) | \( R_1 \) | \( R_2 \) | \( w \) | \( D(\text{cm} \cdot \mu\text{s}^{-1}) \) |
|--------------------------------------------------|
| 1.72 | 374 | 3.3 | 4.5 | 0.95 | 0.3 | 7.89 |

The main component of the sandwich explosive is HMX, the material model is described by the elastic-plastic model (Elastic-Plastic-Hydro), and the state equation is described by the ignition and growth equation of state (Ignition-Growth-of-Reaction-in-He). The values are shown in Table 3.

| Table 3. Main parameters of sandwich explosive. |
|--------------------------------------------------|
| \( \rho(\text{g} \cdot \text{cm}^{-3}) \) | \( p_{\text{CJ}}(\text{GPa}) \) | 1/\( \text{Ms}^{-1} \) | \( G_1(\mu\text{s}/\text{GPa}) \) | \( G_2(\mu\text{s}/\text{GPa}) \) | \( D(\text{cm} \cdot \mu\text{s}^{-1}) \) | \( \lambda G_{2 \text{min}} \) |
|--------------------------------------------------|
| 1.717 | 27.00 | 4.4 | 310 | 4e-04 | 6930 | 0 |

The jet and reactive armor passing area is set as the air domain, which is described by the LINEAR_POLYNOMIAL equation, and the material model is described by NULL. The LINEAR_POLYNOMIAL equation is expressed as:

\[ P = C_0 + C_1 \mu + C_2 \mu^2 + C_3 \mu^3 + (C_4 + C_5 \mu + C_6 \mu^2)E \]  \hspace{1cm} (2)

where \( P \) is the pressure generated by the internal product and \( E \) is the internal energy.

Air domain parameters are shown in Table 4.

| Table 4. Material model and LINEAR_POLYNOMIAL parameters of air. |
|--------------------------------------------------|
| material | \( \rho(\text{g} \cdot \text{cm}^{-3}) \) | \( E(\text{GPa}) \) | \( C_4 \) | \( C_5 \) | \( V_0 \) |
The mechanical behavior of the red copper type cover and the cladding plate material Q235 steel plate are described by Johnson-Cook model and Grüneison equation of state respectively. The constitutive parameters of the material are shown in Table 5, where $A_1$, $B_1$, $C_1$, $m$, $n$ are Johnson-Cook Model parameters, $c_0$ is the volumetric sound velocity, $\Gamma_0$ is the Grüneiso coefficient, and $s$ is a constant.

Table 5. Computational parameters for copper and Q235 steel.

| Material | $\rho$ (g·cm$^{-3}$) | $A_1$/GPa | $B_1$/GPa | $n$ | $C_1$ | $m$ | $C_0$ (km·s$^{-1}$) | $s$ | $\Gamma_0$ |
|----------|-----------------|----------|----------|-----|------|----|-----------------|----|--------|
| Q235     | 7.85            | 0.792    | 0.51     | 0.26| 0.014| 1.03| 4.57            | 1.33| 1.67   |
| Cu       | 8.96            | 0.090    | 0.29     | 0.31| 0.025| 1.09| 3.94            | 1.49| 1.99   |

4. Numerical simulation results

Figure 4 shows the results of the jet obliquely penetrating the 0.8mm thin-layer charge reactive armor at different angles. It can be seen from the simulation diagram that when $t=18$ $\mu$s, the jet begins to react with the thin-layer charge armor structure (a), (b) and (c) contact. When $t=35$ $\mu$s, it can be seen from Figure 4 that the sandwich explosive of structure (a) is not detonated by the jet but the target plate is deformed and perforated due to the impact of the jet, and the sandwich charge of structure (b) is not completely detonated by the jet but only occurs. Due to local detonation, only a part of the upper and lower panels of structure (b) are deformed and scattered, and the upper and lower panels of structure (c) begin to move in opposite directions under the combined action of the detonation products and shock waves. Structure (a), structure (b) and structure (c) all begin to interfere with the jet at $t=35\mu$s. When $t=58\mu$s, the interference effect of (c) type reactive armor on the jet makes the shaped energy jet have a larger radial velocity during the penetration process, and it is easier to produce radial fractures. It can be seen that the jet is divided into multiple segments as a whole, The penetration ability is greatly reduced. The (b) type reactive armor only has a partial explosion, so the interference effect on the jet is not very satisfactory. The type (a) reactive armor has little interference with jets because it has not exploded. The action of the jet and the three thin-layer charge reaction armor structure ends and the residual jet finally opens holes on the after-effect target plate, as shown in Figure 5. The penetration depth of the after-effect target of structure (a) is 11 mm, the penetration depth of structure (b) is 5.3 mm, and the protection effect of structure (c) is 3.4 mm. From the numerical simulation results, the deviation from the experimental results is 12.6%. And this simulation result is consistent with the generally known conclusion that the larger the normal angle of the jet and reactive armor, the better the protection effect, so the simulation result is more consistent with the experiment.
Figure 4. Typical moment of jet oblique penetration of thin-layered reactive armor.
Figure 5. The remaining penetration depth of the jets obliquely penetrating various types of thin-layered reactive armor.

5. Conclusion
1 For the thin-layer charge reactive armor structure of 0.8 mm charge, the critical angle of initiation is between 70° and 75°.
2 When the jet obliquely penetrates into the normal angle at 75°, the after-effect penetration depth is 9mm lower than that at 50°. Protection capacity increased by 75%.

6. References
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