Simulation Study of Tc Composite Bullet Penetrating Ceramic Composite Target

LI Shiji, RONG Yinlong

The 713th Research Institute of China Shipbuilding Industry Corporation, Zhengzhou, Henan, 450015, China

*Corresponding author’s e-mail: lishiji641@163.com

Abstract. In this paper, using ls-dyna numerical simulation software to simulate the penetration process of ceramic composite target. Studying respectively the penetration ability of TC/steel composite bullet and conventional steel bullet, TC/tungsten alloy composite bullet and conventional tungsten alloy bullet. Finally, finding the different results of the four kinds of kinetic energy projectile penetrating ceramic composite target under the same size and speed conditions. The results show that the penetration ability of TC composite bullet with high-speed is better than that of the conventional metallic bullet.

1. Introduction
Recent years have seen greater attention paid to light composite armors. This study finds that the ballistic performance of composite armors composed of high-strength ceramics and armored steel is significantly better than those composed of armored steel [1]. When the conventional armor-piercing projectile hits the ceramic composite target at a high speed, it is passivated, abraded, or broken due to the high compressive strength and high hardness of the ceramic material, so its penetration ability is drastically reduced. Therefore, it is of great significance to study new armor-piercing projectiles that can effectively damage the ceramic composite armor. Li Ge et al. [2] have found that the ability of the 14.5 mm TC composite projectile to penetrate the ceramic/steel composite target is better than that of the standard armor-piercing projectile by combining simulation and experiment. Fu Jianping et al. [3] studied the high-speed impact dynamic performance of zirconia ceramic projectiles. This paper designs two kinds of TC composite projectiles, and stimulates the process of steel and tungsten alloy projectiles with TC heads penetrating to ceramic/steel composite targets using LS-DYNA software [4]. The results are compared with the simulation results of conventional steel and tungsten alloy projectiles.

2. Analysis of material characteristics
Steel and tungsten alloys are common materials used in the armor-piercing projectile. Tungsten alloys are the main materials for armor-piercing equipment adopted by many countries. High-density tungsten alloys not only have high density, but also boast many other excellent properties, such as high strength, high hardness, and good ductility. The hardness of TC material is several dozen and even several hundred times higher than that of ordinary metal materials. The TC warhead, toughened by TC materials, features high hardness, high melting point, high compressive strength, abrasion resistance, high toughness, and low cost.
2.1. Model and parameters of ceramic material
At present, the most widely used dynamic material constitutive model of the ceramic material is the Johnson-Holmquist II (JH-2) model, which is mainly used to simulate the strength, strain rate effect, and damage and deterioration of brittle materials such as ceramics under large deformation, high strain rate, and high pressure. Based on the JH-1 model, the JH-2 model describes the gradient failure of the material by adding a continuous damage degradation effect caused by strength. The elastic property appears first and the damage begins when the stress reaches the yield limit of the material. As the damage accumulates, the ceramic material deteriorates and eventually breaks completely. The JH-2 model contains the strength model parameters and state equation parameters, $K_1$, $K_2$, and $K_3$, and the damage model parameters, $D_1$, $D_2$, and $f$. [5]

The TC warhead and ceramic target in this paper all adopt the JH-2 material model. For the parameters [5], see Table 1.

| Parameter       | Value | Parameter       | Value |
|-----------------|-------|-----------------|-------|
| $G$ (GPa)       | 133   | SFMAX           | 1.0   |
| $R_0$ (g/cm³)   | 3.7   | HEL (GPa)       | 2.79  |
| $A$ (GPa)       | 0.85  | PHEL (GPa)      | 1.46  |
| $B$ (GPa)       | 0.5   | BETA            | 1.0   |
| $C$             | 0.0135| $D_1$           | 0.01  |
| $M$             | 0.3   | $D_2$           | 1.00  |
| $N$             | 0.3   | $K_1$ (GPa)     | 193   |
| EPSI            | 1.0   | $K_2$ (GPa)     | 212   |
| $T$ (GPa)       | 0.22  | $K_3$ (GPa)     | 185   |

2.2. Model and parameters of metal material
The steel, tungsten alloy and copper materials adopt the Johnson-Cook model and the Mie-Gruniesen equation of state. For the parameters, see [6] and [7]. The Johnson-Cook model is used as the constitutive model of materials under large deformation, high strain rate, and high temperature conditions, and can be applied to many materials, including most metal materials.

3. Finite element simulation of the penetration of projectile to ceramic composite target
The three-dimensional model of the projectile and the target plate is pre-processed using TrueGrid software, and the penetration process is numerically simulated using the LS-DYNA software.

3.1. Numerical modeling
Since the projectile and the target are both symmetric, this paper takes 1/4 of the model for analysis, while symmetrically constraining the symmetry plane. The calculation model adopts the Lagrangian algorithm to divide grid with an 8-node 3D solid 164 hexahedral unit-pair model. For the finite element calculation model of the projectile and the target plate (cm-g-μs), see Figure 1. The size of the projectile is smaller than that of the target, so the edge of the target is less affected by the hit. To save CPU resources and shorten the calculation time, the modeled target is smaller than the actual one, and the central area of the projectile is more densely divided than the other areas.

1) The TC/steel composite projectile has a diameter of 16 mm and a mass of 60.2 g, containing the copper shell, the steel core, and the TC warhead; the steel projectile has a diameter of 16 mm and a mass of 60.2 g, containing the copper shell and the steel core.

2) The TC/tungsten alloy composite projectile has a diameter of 16 mm and a mass of 103.4 g, containing the copper shell, the tungsten core, and the TC warhead. The tungsten alloy projectile has a diameter of 16 mm and a mass of 103.4 g, containing the copper shell and the tungsten core.

3) For the ceramic/steel composite target, surface plate: 100 mm * 100 mm * 15 mm ceramic target; back plate: 100 mm * 100 mm * 15 mm armor steel.
3.2. Analysis of simulation results
The TC/steel composite projectile, steel projectile, TC/tungsten alloy composite projectile, and tungsten alloy projectile all hit the ceramic/steel composite target at a high speed of 1200 m/s. Figure 2 shows the damage of the back of armor steel plate. It can be seen that when $t=82$ us ($t$ refers to the penetration time), the TC/steel composite projectile almost completely penetrates the back of armor steel plate, while the steel projectile does not; TC/tungsten alloy composite projectile and tungsten alloy projectile both completely penetrate the back of armor steel plate. Therefore, the penetration depth of the TC/steel composite projectile is greater than that of the steel projectile in equal times, while the penetration depth of the TC/tungsten alloy composite projectile and the tungsten alloy projectile is almost the same in equal times.

Figure 3 shows the velocity change of the projectile with the penetration time. It can be seen that during the penetration process, the velocity decline of the corresponding conventional metal projectile is greater than that of the TC composite projectile. At the end of penetration, the residual speed of TC/steel composite projectile is greater than that of the steel projectile, and the residual speed of the TC/tungsten alloy composite projectile is greater than that of the tungsten alloy projectile.
Figure 3 shows the change of reverse acceleration velocity of the projectile with the penetration time. It can be seen that the corresponding conventional metal projectile has a larger reverse acceleration velocity than the TC composite projectile, indicating that the conventional metal projectile is subjected to larger resistance than the TC composite during penetration. That is why the velocity of the conventional projectile declines rapidly, as shown in Figure 3. It can be seen that the reverse acceleration speed of all the four projectiles first increases and then decreases. A high compressive stress is formed when the projectile hits the ceramic plate, which passivates the projectile. With the deformation of its head, the penetration resistance increases. Later, the warhead begins to be sharper and the projectile penetration resistance begins to decrease.

Figure 4 shows the mass change of the projectile with the penetration time. It can be seen that the mass decline of the TC composite projectile is faster than that of the conventional metal projectile at 0-20 us, which is because the TC warhead will be completely broken at the moment of contact with the projectile. But the TC warhead is only 1.36 g, so the mass change is not significant. As penetration continues, the projectile is gradually abraded. The residual mass of the TC composite projectile is greater than that of the conventional metal projectile.
Based on the analysis of the damage of the armor steel back plate, the residual velocity and the residual mass of the projectile, it can be concluded that the ability to penetrate the ceramic composite target of the TC composite projectile at a high speed is better than that of the conventional metal projectile. The ability to penetrate the ceramic/steel composite target of the TC composite projectile at a high speed is significantly better than that of the conventional metal projectile, which, based on the analysis of the penetration resistance, is because that the conventional metal projectile receives more resistance than the TC composite projectile in the penetration process.

When the conventional metal projectile hits the ceramic composite target, its head is gradually passivated because the ceramic is much harder than the metal, thus increasing the penetration resistance of the projectile. However, when the TC composite projectile whose warhead made of abrasion-resistant and high-hardness TC material hits the ceramic composite target, the ceramic surface is seriously damaged, thus reducing the abrasion of the ceramic surface target to the subsequent metal core. In this way, the integrity of the core is protected, and the penetration resistance of the projectile is reduced.

4. Conclusion
This paper finds that TC composite kinetic energy projectile can effectively damage the ceramic composite armor by adopting the finite element simulation technology. The main conclusions are as follows:

1) The ability of TC/steel composite projectile and TC/tungsten alloy composite projectile to penetrate ceramic/steel composite target at a high speed is better than that of steel and tungsten alloy projectiles.

2) The TC composite projectile with the high-strength TC warhead hits and damages the ceramic plate, which protects the integrity of the subsequent metal core to a certain extent, reducing its penetration resistance, thereby increasing its the ability to penetrate ceramic composite armor projectile at a high speed.

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