Investigation on formation process of a Ta-based dual phase alloy EFP liner

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Abstract. Explosively formed projectile (EFP) has advantages of insensitive to the height of explosion, small interference from reactive armor and large penetration diameter. In this paper, a Ta based dual phase alloy was employed as the charge liner material. The software AUTODYN was used to simulate the formation of EFP under the conditions of different curvature, liner thickness and curvature radius. The following conclusions were obtained: (1) the ratio of length/diameter of EFP decreases with increase of liner thickness. (2) The liner with unequal thickness was proposed, the liner thickness is reduced from the top along the generatrix. The formed EFP from such liner has higher length/diameter ratio, compared to liner with the uniform thickness and the same internal curvature radius. (3) The formed EFP of Ta-based alloy liner could penetrate steel target, the chemical reaction caused by residual mass of EFP could release a large amount of chemical energy.

1. Introduction
The shaped charge bombards the liner through the explosive products, which makes the liner collapse and form EFP to achieve the target penetration and damage. EFP, an explosively formed penetrator, is used to penetrate a target effectively at standoff distances. When detonated, the metal plate is deformed by the explosion and formed into a penetrator [1]. The properties of materials have a great influence on the formation of the EFP. The properties of the liner are rather important in the context of the dynamic EFP formation process and its eventual effectiveness as a penetrator are high density, high ductility, high strength, and a high enough melting point to prevent melting in the liner due to adiabatic heating [2]. In order to attack the target more effectively, most of the existing liner damages the target through a single kinetic energy. In recent years, the related research of multi-functional energetic structural materials (MESMS) has become increasingly active. The research of reactive material liner has been widely concerned. The reactive materials are used to replace the inert liner metal. The tail material of EFP formed by the reactive material enters the target, releasing chemical energy to cause extra damage effect [3-4]. A proper liner material should be use in order to have good penetration capability [5]. Tantalum zirconium liner is a kind of dual phase liner which is mainly composed of tantalum and zirconium. The shaped charge warhead equipped with such charge liner can effectively break through the armor, and cause extra ignite/detonate effect via combustion of the Zr element.

An explosively formed projectile (EFP) liner undergoes extreme, yet controlled, plastic deformation without breaking. This makes designing an optimal EFP a very complicated task [6].
Compared with copper, the ductility of tantalum zirconium material is poor. This paper is based on the research of domestic and foreign scholars on the technology of shaped charge and the application of tantalum based bimetal alloy in reactive liner [7-11]. This paper was initiated to explore the best liner design for Ta-Zr alloy. AUTODYN was employed to simulate the EFP forming process of tantalum zirconium liner with various curvature radius and liner thickness.

2. Simulation
The formation of EFP is a process of high pressure and large strain. In order to obtain the effect of thickness and curvature radius of the liner on the EFP formation process, AUTODYN software was employed to simulate the formation process of EFP. The AUTODYN software integrates a variety of processing technologies such as finite difference, computational fluid dynamics and fluid coding, it is widely used to simulate impact response, high-speed collision and explosion. The EFP forming process can be approximately divided into two stages. The first stage is the detonation stage of high-energy explosive, the instantaneous impact of shock wave is generated by explosive. At this stage, the deformation of liner is small; The second stage is the deformation stage of liner material, which is caused by the velocity gradient between the micro elements inside the liner. In this paper, Euler algorithm [12-15] is used for EFP forming.

In this paper, shaped charge liner models with various curvature radius and liner thickness are established for simulation. Major components of shaped charge are a reactive material liner, high-energy explosive, and a central detonator. The mesh uses a smaller size of 0.3×0.3mm per cell for the Euler domain of 60mm×600mm. The boundary condition of air (Euler) domain was set as “Flow out(ALL EQUAL)” to eliminate the influence of the boundary effect. Figure 1 shows the simulation model.

![Figure 1. Finite element model of the liner.](image1)

(a)Flow out (ALL EQUAL),(b)Explosive,(c)Initiation point,(d) Reactive liner

3. Experimental procedures

![Figure 2. The sketch of EFP charges and image of Ta-based alloy liner.](image2)

In order to study the penetration and post-target characteristics of the liner, EFP charge of Ta-Zr liner was designed, and compared with Cu liner with the same geometry. The sketch of EFP charges is
shown in figure 2, the dimensions are expressed in millimeters. The schematic diagram of the
detonation test is shown in figure 3, the height of main charge was 60mm and the explosive was
initiated by a detonator which placed on the center of the bullet, the high explosive charge has a
diameter of 50mm, a mass of 236g, and a density of 1.63 g/cm³. The target plate was 45# steel, the
thickness of the target plate is 30mm. Standoff is 280mm. Through the target penetration experiment,
the penetration ability of Ta-Zr liner was tested.

![Schematic Diagram of Detonation Test](image)

(a) Detonator; (b) Explosive, (c) Steel plate, (d) Standoff, (e) Case, (f) Reactive liner

**Figure 3.** Schematic diagram of overpressure test.

### 4. Analysis of simulation results

**4.1. The influence of equal liner thickness on formation of EFP.**

In order to study the influence of the liner thickness on the EFP formation of Ta based alloy liner. The
EFP formation of liners with ISO wall thickness was firstly simulated. The inner curvature radius (the
side close to the charge) was set as 32.5mm and the outer curvature radius (the side away from the
charge) was set as 30mm. The liner thickness varied between 2.5 and 3.5 mm. The simulated EFP
formation state at various time after detonation of each liner is listed in table 1.

| Liner Thickness (mm) | 0ms | 0.03ms | 0.05ms | 0.07ms |
|----------------------|-----|--------|--------|--------|
| 2.5                  | ![Image](image) | ![Image](image) | ![Image](image) |
| 2.9                  | ![Image](image) | ![Image](image) | ![Image](image) |
| 3.3                  | ![Image](image) | ![Image](image) | ![Image](image) |

**Table 1.** Formation results of liners with various thickness.
Through comparison, it is found that the increase of the liner thickness delays the formation of the EFP. The formed EFP have similar shape, and the length to diameter ratio of EFP decreases with increasing of liner thickness.

4.2. Influence of curvature radius of constant liner thickness liner on shaped charge.
The curvature radius is an important factor affecting the formation of EFP. According to the theoretical derivation, liner with smaller curvature radius tend to form EFP with higher length to diameter ratio. The following table shows the formation process of liners with the same liner thickness (2.5mm) but different curvature radius.

| Radius of internal curvature (mm) | External curvature radius(mm) | 0ms | 0.03ms | 0.05ms | 0.07 |
|----------------------------------|--------------------------------|-----|--------|--------|------|
| 32.5                             | 30                             |     |        |        |      |
| 36                               | 33.5                           |     |        |        |      |
| 38.5                             | 36                             |     |        |        |      |

It is observed that the liners with larger curvature radius are easier to collapse under detonation. The simulation results show that when the inner curvature radius is 38.5mm and the outer curvature radius is 36mm, the tail of EFP fractures during flight. Meanwhile, it is shown that with the increase of the curvature radius, the mass of EFP projectile center decreases.

4.3. EFP formation of liners with unequal thickness and different curvature radius.
The liners with unequal thickness can be generally divided into two forms: one is to increase the liner thickness from the top of the liner along the generatrix, and the other is to reduce the liner thickness from the top along the generatrix. There is an optimal liner thickness change rate for liners with unequal thickness. Liner thickness change rate refers to the difference of liner thickness of liner on unit length. The simulation calculation starts from the top of the charge liner, and the liner thickness is
reduced from centre to the edge. The liner thickness at the center is 3.3mm. The following table shows the formation results of liners with unequal thickness and different curvature radius.

**Table 3.** EFP formation of liners with unequal thickness and different curvature radius.

| Radius of internal curvature (mm) | External curvature radius (mm) | 0ms       | 0.03ms     | 0.04ms     | 0.06ms     |
|-----------------------------------|-------------------------------|-----------|------------|------------|------------|
| 30                                | 30                            |           |            |            |            |
| 33                                | 33                            |           |            |            |            |
| 36                                | 36                            |           |            |            |            |

Through comparison, it is found that with increasing of the curvature radius, the length to diameter ratio of formed EFP decreases, the mass of EFP head also decreases. It is believed that the liner with larger curvature radius tend to form EFP with better flight stability but lower penetration ability.

5. **Experiment results**

Liners with ISO thickness was chosen to study the post-target characteristics of the liner. The sketch of EFP charges and liners are shown in figure 2. After the static explosion of tantalum zirconium liner, the debris cloud was generated due to the high-speed impact between liner material and target plate after the end of explosive firelight, and the combustible material contacts with air to generate firelight, as shown in Fig. 4. It is demonstrated that the Ta-based alloy liner could form EFP after detonation, the formed EFP could penetrate steel target with thickness of 30 mm, and moreover, the residual mass of EFP generates debris cloud behind the steel target, the chemical reaction caused by these debris release a large amount of chemical energy. Conversely, the copper liner with the same shape has no sigh of exothermic reaction behind the steel target, due to its inertness.
6. Conclusion

In this paper, the influence of liner thickness, curvature radius and unequal liner thickness on the formation of the EFP was analyzed. Then, the damage effect of tantalum based alloy liner was studied by comparing with copper liner.

(1) For the liner with equal thickness, the increase of the curvature radius leads to decrease of the length diameter ratio. When the curvature radius reaches a certain extent, the tail of EFP formed by liner begins to break.

(2) With increasing of the liner thickness, the EFP formation is delayed, the length to diameter ratio of the formed EFP is reduced.

(3) The formed EFP of Ta-based alloy liner could penetrate steel target, the chemical reaction caused by residual mass of EFP could release a large amount of chemical energy.

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