Studies on Impact Damage Characteristics of PTFE/Al/W Reactive Materials

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Abstract. Reactive material is a promising new energetic material. In this paper, the damage characteristics of PTFE / Al / W reactive material impacting on double-layer aluminum target are studied by experiments, and the experimental process is simulated by numerical simulation. The experimental results show that when the reactive material impacts the double-layer thin aluminum target, there is almost no reaction when it impacts the first target plate, and the reaction mainly occurs when it impacts the second target plate. Compared with the simulation results, it is proved that the ignition growth model can be used in the simulation calculation of reactive materials.

1. Introduction
Reactive materials are energetic materials with relatively high structural strength. Different from the general energetic materials, the reactive materials have certain mechanical strength and are relatively stable and insensitive under normal conditions [1]. However, the extreme forces upon impact cause the components to react with each other and release more energy than highly explosive components. At present, the common reactive materials mainly include thermite, intermetallic compounds, metal/polymer composites, metastable intermolecular complexes, and so on. Among the reactive materials, the energy density of PTFE/Al is quite high, which can reach 3 times that of TNT with the same mass [2]. It is precisely because of these excellent characteristics of reactive materials that a large number of researchers have conducted in-depth exploration and research in recent 40 years.

Around 2003, Vasant [3] and Nielson [4] put forward the process of preparing PTFE reactive materials with higher strength. Firstly, PTFE/metal powder is made into the required shape by cold pressing, and then the strength of the material is improved by sintering. In this way, the yield strength of PTFE/Al can reach about 20 MPa. After that, some scholars have further improved the mechanical properties of PTFE/Al materials by studying the sintering temperature, particle matching and other preparation processes [5, 6]. However, the density and strength of PTFE/Al reactive materials are relatively low, so there are some defects when PTFE/Al reactive materials are used in the warhead to replace metal damage structures. In order to further improve the mechanical properties and density of PTFE/Al, tungsten can be added to it [7, 8]. Quasi-static compression results show that the increased mass ratio of tungsten has no obvious influence on the strength of W-PTFE-Al composites. Dynamic compression results show that the strength enhances with the increased mass ratio of tungsten, while the critical failure strain shows no obvious difference. Therefore, it can be considered that adding W to PTFE/Al is a reasonable choice.
For reactive materials, we are generally concerned about their impact reaction characteristics. In this paper, the preparation and impact reaction of PTFE/Al/W are analyzed by theoretical, experimental and numerical simulation. Firstly, the selection of raw materials and preparation technology of PTFE reactive materials were introduced. Then, through ballistic gun test, the damage characteristics of the reactive material impacting on the double aluminum target are studied. After that, a suitable model was selected and the experimental process was numerically simulated and analyzed.

2. Experimental preparation and results

2.1. Preparation of reactive materials
The reactive materials were prepared by cold pressing sintering process. The reactive material is composed of PTFE (35μm), Al (10μm) and W (10μm) powders. The preparation process of the reactive materials was mainly divided into the following steps: 1) Mix the material evenly in proportion and press it into shape with a mold. 2) Place the sample standing for 24 hours in the sintering furnace, vacuumize or fill with inert gas. 3) Sintering reactive material. The sintering curve is shown in Figure 1.

![Figure 1. Sintering temperature curve.](image1)

2.2. Experimental procedures
In the experiment, PTFE/Al/W reactive materials prepared by ourselves were used as projectiles, which was fired by a 12.7mm caliber ballistic gun to impact the double-layer aluminum target. The impact velocity is controlled in the range of 600-100 m/s by adjusting the amount of propellant. The projectile is a cylinder with a diameter of 10.5mm and a length of 11mm, as shown in Figure 2. The target plate is made of aluminum with a thickness of 3 mm, and the interval between the two target plates is 200 mm.

![Figure 2. Reactive material projectile.](image2)

The diameter of the projectile is smaller than that of the gun, so the nylon sabot is needed to launch the projectile. In order to ensure that the sabot can be separated from the projectile, the distance between the muzzle and the target plate was set at 10m. The velocity measuring instrument uses a sky screen target, which is placed between the muzzle and the target plate. A high-speed camera was arranged on
the side of the range to capture and record the whole collision process. Figure 3 is the experimental layout.

![Experimental layout diagram](image)

**Figure 3.** Experimental layout diagram.

The experimental results show that the single hole in the first target is usually a cylinder, while the holes in the second target are irregular. However, the bullet hole on the second target plate is approximately axisymmetric, and it can also be described as a circle. We use diameter to describe the size of the bullet hole. The experimental results are shown in Table 1. $d_1$ is aperture on front target, and $d_2$ is Aperture on rear target.

### Table 1. Experimental results of impact of reactive materials

| Projectile velocity (m/s) | $d_1$ (mm) | $d_2$ (mm) |
|---------------------------|------------|------------|
| 622                       | 13         | 30         |
| 740                       | 13         | 39         |
| 945                       | 14         | 76         |
| 1092                      | 14         | 83         |

From these experimental results, it can be clearly found that the aperture on the first layer of the target is almost not affected by the change of velocity. There are many reasons for this phenomenon. First of all, the compression time of projectile is relatively short due to the thin target plate. Secondly, it is related to the energy release characteristics of the reactive materials. The hole on the second target plate is much larger than the diameter of the projectile, and the size of the hole increases with the increase of impact velocity. This is precisely because the projectile breaks through the first target plate and undergoes chemical reaction, which leads to the increase of the damaged area of the projectile. The faster the speed, the more intense the reaction of the reaction material, so the greater the damage range.

### 3. Numerical Simulation

In the real experiment, we can get limited data, but we can know a lot of experimental details through numerical simulation. Reactive materials are different from ordinary explosives, so it is necessary to choose an appropriate equation of state to describe them. In this paper, the finite element analysis software LS-DYNA was used for simulation.

#### 3.1. Numerical simulation model and setup

The model of numerical simulation is consistent with the actual experimental situation, which is two 3mm thick target plates with an interval of 200 mm. The projectile is a cylinder with a diameter of 10.5mm and a length of 11mm. The overall model is shown in Figure 4.
Figure 4. Numerical simulation model.

Ale fluid structure coupling method is used in the simulation. Mainly related to keywords such as *CONTROL_ALE, *INITIAL_VOLUME_FRACTION_GEOMETRY and *CONSTRAINED_LAGRANGE_IN_SOLID. The reactive material projectile and air were set as ALE model, and the target plate was set as Lagrange model. Choose to use Ignition and Growth Reaction Rate Equation to describe reactive materials. Some model parameters are shown in Table 2.

| ρ (g/cm³) | G (Gpa) | Y (Mpa) | E (Gpa) | r1 (Gpa) | r2 (Gpa) |
|----------|--------|--------|--------|--------|--------|
| 7.4      | 0.306  | 16.6   | 0.848  | 4855.17| -112.56|

3.2. Numerical simulation results

Figure 5 shows the process of numerical simulation. The results are in good agreement with the experimental results. When the projectile passes through the first target plate, the aperture on the target plate is similar to that of the projectile. The projectile gradually reacts during flight, causing greater damage to the second target plate. Therefore, the aperture of the second target plate is much larger than that of the first target plate.

Figure 5. Numerical simulation process.
When the projectile impacts the target plate at the velocity of 1092 m/s, the damage result of the target plate is shown in Figure. 6. It can be observed that not only the aperture of the two-layer target is similar to the experimental results, but also the failure mode is similar to the real situation.

![Figure 6. Damaged target.](image)

The comparison between simulation and experimental results is shown in Table 3. D1 and D2 are relative numerical simulation results. The simulation results and experimental results are in a reasonable error range. So, it can be considered that this simulation method is feasible.

| Projectile velocity (m/s) | d1 (mm) | D1 (mm) | relative error (%) | d2 (mm) | D2 (mm) | relative error (%) |
|---------------------------|---------|---------|--------------------|---------|---------|--------------------|
| 622                       | 13      | 13      | 0                  | 30      | 32      | 6.7                |
| 740                       | 13      | 14      | 7.7                | 39      | 43      | 10.3               |
| 945                       | 14      | 14      | 0                  | 76      | 80      | 5.3                |
| 1092                      | 14      | 14      | 0                  | 83      | 88      | 6.0                |

### 4. Conclusion
In this paper, the experiment of reactive material projectile impacting thin target is carried out, and the numerical simulation is used for comparison. And we got the following conclusions:

When the whole reactive material impacts the thin aluminum target, it can't be initiated effectively. However, after the reactive material has a certain degree of failure, it is easy to be triggered reaction. The ignition growth model can be used to simulate the reaction materials. So as to make more in-depth research on the reactive materials.

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