Research on the Cushioning Effect of Protective Materials under High Impact

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Abstract—Aiming at the protection of the internal components of the projectile during penetration, the cushion performance of common protective materials such as polyurethane, felt, polytetrafluoroethylene (PTFE), and copper were tested. The test results show that the copper and felt have a certain cushioning effect, which can reduce the acceleration amplitude by 23,000 g by 18\% and extend the pulse width of acceleration overload. The cushioning effect of PTFE material is not obvious, but it can play a role in mechanical filtering, making the acceleration curve smoother. Polyurethane material will increase the acceleration amplitude of the buffered part, it is not suitable as a buffer material.

1. INTRODUCTION

In modern wars, core facilities such as aircraft carrier hangars, missile silos, and underground command posts have gradually become the key targets for countries to carry out strategic strikes. Therefore, many countries have invested a large amount of manpower and material resources to develop penetrating ammunition that can penetrate the target protection layer and effectively destroy the target\cite{1}. When the penetrating ammunition penetrates the target hard protective layer, its internal components will be overloaded by tens of thousands of g acceleration in a very short time\cite{2-4}. In this environment, the warhead of the ammunition may explode due to the impact, and the components in the fuze will also face problems such as damage and failure \cite{5}. Therefore, reducing acceleration overload to improve the reliability of ammunition has become a hot issue in the research of penetration ammunition.

To reduce the acceleration overload, protective materials must be used to cushion the weak part \cite{6}. Aiming at this problem, this paper uses a Machete Hammer device to test several commonly used materials and analyzes the cushioning effect of each material through the acceleration curve.

2. PROTECTIVE MATERIALS AND TEST METHODS

2.1 Introduction of Protective Materials

Duo to the limited internal space of the projectile, the protective material is usually made as a gasket and placed in front of the weak part. When the weak part is subjected to acceleration overload, it moves forward and squeezes the protective material. The protective material deforms while being squeezed,
which prolongs the speed change time of the weak part. At the same time, the protective material transforms the kinetic energy of the weak part into its own internal energy through deformation, so as to achieve the effect of reducing the acceleration amplitude.

The protective materials tested in this paper are felt, polyurethane, copper, and polytetrafluoroethylene (PTFE). The samples are shown in Figure 1. Among them, polyurethane and PTFE are used as protective materials under high impact due to their stable chemical properties and good mechanical properties. Copper and felt as traditional gasket materials have been widely used in cushioning and vibration isolation.

![Figure 1. Samples of protective materials](image1)

2.2 Introduction of Test Methods

The testing methods of protective materials can be divided into static testing method and dynamic testing method. The static testing method uses a material compression testing machine to apply a quasi-static compressive load to a certain area of protective material. Through the displacement and the pressure acting on the material calculates the stress-strain curve of the protective material. The test method is easy, but it can not reflect the strain rate effect of the material under high impact.

The dynamic testing method uses a weight with a certain mass to impact the material, describes the cushioning performance of the material through the mass, speed, and acceleration overload of the weight. Common dynamic tests include falling-weight test [7], air-cannon test [8], artillery test [9], and Machete Hammer test [10]. Taking into account the material characteristics, overload characteristics, assembly environment, test cost, and other factors, this paper selects the Machete Hammer device to test the protective material.

3. Protective Material Tests

In the impact tests for simulating large overload, Machete Hammer is a more commonly used device. It uses a hammerhead to connect the part to be loaded and uses the falling weight to provide a rotating torque for the hammer handle. Through the collision of the hammerhead and the rigid anvil, an acceleration overload of tens of thousands of g can be generated. The test device is shown in Figure 2.

![Figure 2. Machete Hammer device](image2)
This paper uses a Machete Hammer device to provide acceleration overload with high $g$ value. In order to make the loading environment of the Machete Hammer closer to the actual working conditions, the simulated loading device shown in Figure 3 was designed.

![Schematic diagram of simulated loading device](image)

Figure 3. Schematic diagram of simulated loading device

The simulated loading device is fixedly connected with the hammerhead by the thread below, rotates with the hammerhead and strikes the anvil. The mass block in the middle is used to replace the protected part in actual working conditions, protected by protective materials, the bottom cover of the upper part compresses the whole inside, and provides a certain preload by tightening.

When the hammerhead strikes the anvil, the simulated loading device is impacted together with the hammerhead. If no protective material is used, the measured value of the sensor is the acceleration overload of the device. When adding the protective material, the measured value of the sensor is the acceleration overload of the mass block after buffering. By comparing the acceleration signals of the mass block when using different protective materials, the cushioning effect of the protective materials can be analyzed.

4. **TEST RESULTS AND ANALYSIS**

Using this test method, polyurethane, felt, PTFE, and copper were tested. The mass of the mass block in the simulated loading device is 260g, the inner diameter of the shell is 63mm, the pre-tightening torque of the bottom cover is 20N·m, and the thickness of the protective material is 8mm. The sensor used in the test is a piezoelectric sensor, and the output signal of the sensor is converted by a charge amplifier and recorded by an oscilloscope.

Remove the protective material below, and apply a 20N·m pre-tightening torque to the bottom cover. The measured acceleration-time curve is shown in Figure 4.

![Acceleration curve without protective material](image)

Figure 4. Acceleration curve without protective material

It can be seen from Figure 4 that the amplitude of acceleration value without buffering is about 23,000 $g$, and the pulse width is about 200μs. Integrating the first acceleration pulse, the velocity of the hammerhead striking the anvil is about 21m/s.
Add 4 polyurethane gaskets with a thickness of 2mm under the mass block and apply a pre-tightening torque of 20N·m. The measured acceleration curve is shown in Figure 5. The outer diameter of the 4 gaskets is 63mm, and the inner diameter is 26mm.

![Figure 5. Acceleration curve buffered by polyurethane](image)

It can be seen from Figure 5 that the acceleration amplitude after being buffered by polyurethane is about 30,000 g, which is significantly larger than that of unbuffered acceleration. And the amplitudes of the acceleration curve after 1000μs are also larger than that without the protective material. Indicating that the polyurethane material aggravated the acceleration overload and not suitable for use as a cushioning material alone.

Replace the polyurethane gaskets with felt gaskets of the same size, and apply a pre-tightening torque of 20N·m. The acceleration curve obtained by the test is shown in Figure 6.

![Figure 6. Acceleration curve buffered by felt](image)

From Figure 6, we can find that the acceleration amplitude buffered by the felt material is reduced to about 19000 g, and the pulse width is also extended. It shows that the felt material has a certain cushioning effect under the high impact.

It should be noted that the zero-drift phenomenon occurred in the felt test, that is, the output of the sensor did not return to the voltage zero at the end of the impact. However, since this test is a single impact test and the initial value of the acceleration signal is voltage zero, it is considered that the measured amplitude value and pulse width are still accurate.

Under the same conditions, the felt gaskets were replaced by polytetrafluoroethylene (PTFE) gaskets for testing, and the acceleration curve obtained is shown in Figure 7.
As can be seen from Figure 7, the amplitude of the acceleration signal after buffering by PTFE is reduced to about 22,000 g, with no obvious cushioning effect. However, compared with Figure 4, the acceleration curve is relatively smooth, indicating that PTFE can reshape the stress wave and play a role in mechanical filtering.

Replace PTFE gaskets with 16 copper gaskets with a thickness of 0.5mm. The acceleration curve obtained by the test is shown in Figure 8.

It can be seen from Figure 8 that the copper gaskets have no mechanical filtering effect, but it can reduce the amplitude of acceleration overload. The cushioning effect of copper is similar to that of felt.

The specific values of the test results are shown in Table 1. Table 1 shows that the acceleration amplitude of the simulated loading device in the Machete Hammer test is 23257 g and the pulse width is 204μs. In this kind of overload, copper has the best cushioning effect, which can reduce the acceleration amplitude by 19%, followed by felt, which can reduce the acceleration amplitude by 18%. The cushioning effect of PTFE is not obvious, it reduces the acceleration amplitude by 6%. Polyurethane has no cushioning effect, it increases the acceleration amplitude by 30%, which may damage the structure of the protected part and make it out of action in actual work.

### TABLE 1. BUFFER TEST RESULTS

| Figure | Acceleration Parameter | Amplitude decrease |
|--------|------------------------|--------------------|
|        | Acceleration amplitude /g | Acceleration pulse width /μs |                      |
| 4      | 23257                  | 204                | 0%                   |
| 5      | 30285                  | 203                | -30%                 |
6  19125  297  18%
7  21795  229  6%
8  18857  226  19%

5. CONCLUSION
The Machete Hammer was used to generate an acceleration overload with an amplitude of about 23,000 g and a pulse width of about 200us on the simulated loading device. Four protective materials with a thickness of 8mm were used to buffer the mass block in this kind of overload, and the acceleration curves of the mass block buffered by polyurethane, felt, PTFE, and copper were obtained. The cushioning effects of the four protective materials were compared through the acceleration signal.

The test results show that copper has the best cushioning effect, which can reduce acceleration amplitude of 23,000 g by 19%; followed by felt, which can reduce acceleration amplitude by 18%; the cushioning effect of PTFE is not obvious, but it can play a role in mechanical filtering, making the acceleration curve smoother; polyurethane may increase the acceleration amplitude, it is not suitable for use as a buffer material.

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