Study on the buffering properties of composites during high-speed penetration

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Abstract. In order to solve the problems of heavy overload, poor buffer performance of cushion and low reliability of fuze in high-speed penetration process of the projectile, this paper proposes a composite structural cushion using foamed aluminum and rubber. Through the establishment of the projectile model with different material cushions, the Ls-dyna software is used to simulate the high-speed penetration process and analyze the fuze acceleration curve. The results show that the composite cushion has a significant buffering effect in the process of high-speed penetration, which can reduce the impact overload of fuze and improve the reliability of fuze.

1. Introduction

In modern warfare, with the development of intelligent weapons and the protection of important military targets, the acceleration and penetration depth of penetrating projectiles continue to increase. As the "brain" of penetrating projectiles, fuze plays a vital role in the attack process[1]. In the process of penetration, the warhead will be impacted and produce elastic-plastic stress waves. The propagation of stress waves will cause sudden changes in the displacement, velocity, stress, and acceleration of the internal nodes of the projectile. When the amplitude of impact stress is large enough, the internal structure of the fuze and the reliability of the circuit components will be destroyed, causing the fuze to fail[2]. Therefore, the research on fuze protection measures has important practical significance.

Impact isolation is a commonly used protective measure. Appropriate buffer materials are used to prevent the stress wave from the projectile and reduce the impact of fuze. Chen Lujiang[3] used rubber for penetration fuze protection and found it played a buffering role in the process of high-speed impact. Wang Jiankun discovered that rubber deforms and absorbs a large amount of energy when the force is applied, but most of the energy is released as rubber rebounds after the force is unloaded, so the energy absorption of rubber is limited. After that, researchers gradually adopted foamed aluminum instead of rubber as a buffering material. Yang Zhe found the buffering performance of foamed aluminum material was better than PTFE, and detected that adding foamed aluminum can greatly reduce the acceleration of fuze. Xu Pengchao[4] made cushions with foamed aluminum and performed simulation calculations, but failed to obtain the ideal cushion thickness. On this basis, Jiang Xingchen[5] analyzed foamed aluminum cushions of different thicknesses, discovered that only increasing the thickness had little effect.

Through the above researches, it can be seen that rubber and foamed aluminum have their own advantages as buffer materials. This paper proposes to use a composite structural material composed of rubber and foamed aluminum as penetration fuze cushions. LS-DYNA software is used to simulate
the penetration process and obtain the acceleration of fuze. The buffering performance of the cushions is characterized by the fuze acceleration, which provides guidance for fuze protection design.

2. Cushion material

2.1 Rubber
Rubber is a buffering material used to isolate vibration. It has the characteristics of small elastic modulus, high elongation and chemical resistance. When the impact propagates from the warhead to fuze, the viscoelastic effect and lateral inertia effect of the rubber can make the stress wave amplitude attenuation and waveform dispersion. However, the energy absorption of rubber depends on its own deformation. After the force is unloaded, most of the energy is released with rubber rebound, so that the buffering effect of rubber in practical applications is limited.

2.2 Foamed aluminum
Foamed aluminum is made by adding additives to aluminum and processed by a foaming process. It has the characteristics of low density, large surface area, looseness, porosity, and easy processing. Figure 1 shows the stress-strain curve of the foamed aluminum. Under the action of load, the foamed aluminum undergoes three stages: the elastic bending stage, the yield platform stage and the compaction stage. Under the compressive load, the foamed aluminum first enters the elastic bending stage, and the walls of the pores in the porous material are bent. When the strain value continues to increase beyond the critical value, the foamed aluminum enters the yield platform stage, and the pores collapse due to elastic bending, plastic yield and creep. When the strain continues to increase, the material enters the compaction stage, the cavities almost completely collapse, the strain compresses the solid itself, and the stress rises rapidly. Due to the unique structure of foamed aluminum, it can effectively absorb impact acceleration. Therefore, the foamed aluminum can keep the stress constant in a large strain range, and has a good buffering performance. However, when the impact is large, the porous structure of foamed aluminum is easily crushed and loses its buffering ability.

![Figure 1. Stress-strain curve of foamed aluminum](image)

2.3 Composite structure
Considering the disadvantages of rubber and foamed aluminum buffering performance. This paper proposes a new composite structure for high-speed penetration cushions. The composite structure combines rubber and foamed aluminum, changes the structure and proportion of each part, and compares its buffering performance.

3. Computational simulation

3.1 Geometric model
The modelling software ProE is used to model the projectile, cushions, fuze and C40 concrete target, the Hypermesh software is used to mesh the model, and the simulation software Ls-dyna is used to simulate the penetration of projectile into the target. As shown in Figure 2, (a) is the overall model of the projectile penetration into the target plate with fuze and cushion, (b) is the enlarged view of the
fuze part with rubber cushion 1 or foamed aluminum cushion 2, (c) and (d) are enlarged views of the fuze part with composite structure cushions. According to literature [6], a rod-type projectile with a length-to-diameter ratio of 4:1 is selected. The diameter of the projectile is 100mm, and the length is 400mm. The diameter of fuze is 80mm, and the length is 80mm, the cushions are 80mm in diameter and 3mm in thickness, respectively installed at contact point between fuze and projectile. The size of the C40 concrete target is 1000mm×1000mm×500mm. The cushion parameters are shown in Table1. The models are all symmetrical structures, and the research object of this paper is forward penetration, so a quarter of all models are used for simulation.

![Simulation model](image)

**Figure 2. Simulation model**

| Serial number | Material parameter                                      |
|---------------|---------------------------------------------------------|
| 1             | 3mm rubber                                              |
| 2             | 3mm foamed aluminum                                     |
| 3             | 1.5mm rubber, 1.5mm foamed aluminum                     |
| 4             | 1mm foamed aluminum, 1mm rubber, 1mm foamed aluminum    |

### Table 1. Cushion parameters

**3.2 Material parameters**

The material parameters are shown in Table 2. The projectile material is 35CrMnSi and the fuze material is 30CrMnSi. Both the projectile and the fuze use the MAT_PLASTIC_KINEMATIC model, the rubber uses the MAT_MOONEY-RIVLIN_RUBBER model, and the foamed aluminum model is MAT_CRUSHABLE_FOAM. The C40 concrete model adopts the MAT_RHT model, which considers the third invariant of pressure hardening, strain hardening, strain rate hardening, compression, and tensile meridian, damage effects, etc. It can also simulate the damage distribution of concrete target cracks and collapse after the target. The failure mode of the concrete target is set to
MAT_ADD_EROSSION. The initial velocity of the projectile is 1000m/s. The calculation time is set to 2000us, and the recording time interval is 1.5us.

| Material          | Density / (g/cm$^3$) | Young's modulus /GPa | Poisson's ratio $\mu$ |
|-------------------|-----------------------|-----------------------|------------------------|
| Projectile 35CrMnSi | 8.00                  | 210                   | 0.284                  |
| Fuze 30CrMnSi     | 7.85                  | 210                   | 0.3                    |
| Cushion Rubber    | 1.01                  | 0.24                  | 0.5                    |
| Cushion Foamed aluminum | 1.20              | 12                    | 0.3                    |

4. Simulation result analysis
The fuze acceleration curves are extracted by simulating the ejection models of four kinds of cushions, as shown in Figure 3 (a) - (d). Among them, 0-700us is the stage of projectile penetration into the target plate, and 700us-2000us is the stage of projectile exit.

![Figure 3. Fuze acceleration curve](image)

Figure (a) shows the acceleration of the fuze with rubber cushions. The maximum acceleration of the fuze at 259us is 61300g, and the pulse width above 30,000g is 334us. In the stage of penetration into target plate, the acceleration of fuze fluctuates greatly and oscillates seriously. While projectile exits the target, the acceleration of fuze is continuously reduced, but the oscillation is still severe and the buffering performance of the cushion deteriorates. This is because the rubber cushion absorbs energy and deforms in penetrating the target plate. After exiting the target, the rubber rebounds and releases energy to act on the fuze, so that the fuze still accelerates without external force.

Figure (b) shows the acceleration of the fuze with foamed aluminum cushions. The maximum acceleration of the fuze appears at 424us, the peak value is 52700g, and the pulse width above 30,000g is 339us. Compared with figure (a), the peak acceleration decreases by 14%. This is due to the foamed aluminum is in the yielding platform stage, and there is a high and wide pressure platform, which makes the strain lag behind the stress, and the energy of the stress is absorbed in the buffering process.
Foamed aluminum cushion can play an effective role in buffering, prolongs the impact time and improves the reliability of fuze. However, after the projectile leaves the target, the foamed aluminum strain gradually increases beyond the limit and enters the stage of compaction. The absorption effect of oscillation has weakened and the buffering performance has reduced.

It can be seen from the above that rubber and foamed aluminum have their own advantages. In order to achieve a better cushioning effect, combine the two and analyze their cushioning performance.

Figure (c) shows the acceleration of the fuze with cushion3, the peak of the fuze acceleration is 252u, the peak is 51900g, and the pulse width is 337us above 30,000g. Compared with figure (a), the acceleration of the fuze equipped with the composite structure cushion is reduced by about 10%, the pulse width is wider, and the vibration is reduced. The vibration due to the characteristics of the rubber is avoided. Compared with figure (b), the peak acceleration of the fuze is smaller, the pulse width is wider, and the oscillation is reduced. The oscillation is better than the foamed aluminum cushion. It can be seen that the composite structure is more suitable as a fuze protection material.

Figure (d) shows the acceleration of the fuze with cushion 4, the peak acceleration appears at 301us, the peak value is 50160g, and the pulse width above 30,000g is 356us. Compared with figure (c), the peak acceleration decreases 1740g and the pulse width increases about 20us, the buffering effect of the cushion is significant, and the shock impact of the fuze is reduced. In addition, increasing the proportion of foamed aluminum in the composite structure delays the acceleration peak by 49us and prolongs the impact time. When the projectile exits the target, the acceleration amplitude of the fuze is reduced by 50% compared to figure (c), the fluctuation of the acceleration curve is significantly reduced, the shock impact is greatly reduced, and the buffering effect is extremely obvious.

5. Conclusion
This paper proposes a composite structure to manufacture a buffer cushion for a high-speed penetration fuze. Through modeling and simulation shows that: Rubber and foamed aluminum can play a buffering role for high-overload penetration fuze, but they also have some defects. The composite structure formed by compounding rubber and foamed aluminum as a cushion has a significant effect. Increasing the proportion of foamed aluminum in the composite structure can better reduce the impact of the fuze and the buffering performance is the most obvious.

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