Research on mechanical properties of different coating structures reactive fragments

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Abstract. In order to study the dynamic compressive properties of reactive material which coating different shell thicknesses at various strain rates, Split Hopkinson Bar (SHPB) has been used. The stress-strain curves at different strain rates were obtained under uniaxial stress loading condition. The results show that reactive materials and reactive fragments of coated structure have obvious strain rate effect. The yield strength of the 20# steel coating is 10 times higher than internal reactive material. The mechanical properties of coated reactive fragments are greatly affected by the thickness of the coating. The yield strength of the reactive fragments of the shell thickness of 1mm and 2mm cladding is 300MPa and 520MPa, respectively.

1. Introduction
Warhead is the payload of various weapon systems such as ammunition and missiles. It is a terminal damage system that directly destroys specific targets, which the fragment as the smallest damage element inside the warhead, through the driving effect of internal charge explosion, use the kinetic energy of the damage element to penetrate the damage target [1-2]. However, the fragment can’t penetrate and destroy missiles with thicker shells or stronger-protected aircraft targets only relying on kinetic energy. Therefore, we can use reactive fragments to increase the damage power which coupling between kinetic energy and chemical energy.

Reactive fragment is a special energetic material, The reaction material Composition of high polymer , metals and intermetallic compounds, then prepared by special processes. When applied to the warhead, it is required that it is not broken when detonated, and it can react quickly and release energy under the action of high-speed impact [3-5]. Therefore, it is necessary to coat the reactive material to increase mechanical strength.

Reactive fragments are subjected to complex high strain rate loading during impact, so it is important to study the mechanical properties of reactive fragments under high strain rate loading. It use different loading methods according to strain rates. When the strain rate is less than 0.1s⁻¹, use a quasi-static testing machine. When the strain rate is 0.1~10³s⁻¹, the drop weight is used; when the strain rate is 10³~10⁶s⁻¹, the split Hopkinson bar (SHPB) is used [6]. At present, the research on
reactive fragments mainly focuses on the material formulation and preparation process [7-9], the energy release and damage effect of the impact target [10-13], and the mechanical properties of reactive materials under high-speed impact [14,15].

The mechanical properties of reactive fragments are greatly affected by the thickness of the coating. In this paper, the split Hopkinson Pressure Bars (SHPB) has been used to study the reactive materials, and the mechanical properties of reactive fragments with different coating structures under high strain rate are obtained.

2. Experiment

2.1. Sample preparation

The main component of the reactive fragment material is PTFE/Al/W/Zr. Its mass fraction is: PTFE, 16%. Al, 3%. W, 56%. Zr, 25%. The four materials are mixed and compressed according to the mass ratio, and the size of the sample after molding is $\Phi 8 \text{ mm} \times 8 \text{ mm}$ and $\Phi 6 \text{ mm} \times 6 \text{ mm}$, the density is 6.17 g/cm$^3$. The sample after compression molding is shown in figure 1.

![Figure 1. Uncoated sample after compression.](image1)

The compressed sample is coated with 20# steel, and the external dimensions of the fragments are $\Phi 10 \text{ mm} \times 10 \text{ mm}$. The schematic diagram of the coating and coated fragments are shown in figure 2.

![Figure 2. Schematic diagram of coated fragments and coated fragments.](image2)

2.2. SHPB experiment system

The SHPB experimental system is shown in figure 3. The system is mainly composed of a striker bar, an incident bar, a transmission bar, and an absorption bar. The sample is placed between the incident bar and the transmission bar. The bars used in this experiment are all steel with a diameter of 20 mm,
an impact bar with a length of 300 mm, an incident bar with a length of 1800 mm, a transmission bar with a length of 1500 mm, and steel bar with a Young's modulus of 210 GPa. The experiment system is composed of SDY2107A dynamic strain gauge and Tektronic DPO4104 digital oscilloscope. The oscilloscope sampling rate is 10 M/s.

![Figure 3. Experiment system of SHPB.](image)

### 2.3. Theoretical of SHPB experiment

The SHPB experiment is based on the assumption of the one-dimensional stress wave propagation and the uniformity of the sample stress. The incident signal $\varepsilon_i$, the reflected signal $\varepsilon_r$ reflected from the interface between the bar and the sample are measured by the strain gauge on the incident bar, the transmission signal $\varepsilon_t$ in the transmission bar, and then derive the stress-strain relationship in the sample according to the one-dimensional stress wave theory [6].

Stress-strain relationship in the sample:

\[
\sigma_s = \frac{EA_0}{A_s} \varepsilon_i \tag{1}
\]

\[
\varepsilon_s = -\frac{2c_0}{l_s} \int_0^t \varepsilon_r dt \tag{2}
\]

\[
\dot{\varepsilon}_s = -\frac{2c_0}{l_s} \varepsilon_r \tag{3}
\]

Under the assumption that the volume of the material is incompressible, the corresponding relationship between true stress-strain and engineering stress-strain is:

\[
\sigma_T = (1 - \varepsilon_s) \sigma_s \tag{4}
\]

\[
\varepsilon_T = -\ln(1 - \varepsilon_s) \tag{5}
\]

In the above formula, $E$ is the elastic modulus of the experimental bar, $A_0$ is the cross-sectional area of the experimental bar, $A_s$ is the cross-sectional area of the sample, $c_0$ is the speed of sound in the experimental bar, $l_s$ is the length of the sample, $\sigma_s$ is the engineering stress, and $\varepsilon_s$ is the engineering strain. $\sigma_T$ is the true stress, and $\varepsilon_T$ is the true strain.
3. Results and discussion

The samples shown in figure 1 has been load by SHPB respectively, the loading strain rate is 1500–2500 s⁻¹, as shown in figure 4 is the mechanical characteristic curve during the sample loading process. It can be seen from the stress-strain curves, the sample dynamic loading has a strain rate effect, and the sample has experienced elastic phase under dynamic loading. When the material reaches the yield point, the material yields into the plastic deformation phase, the material's yield stress is 75 MPa. With the strain increase, then the material fails, the stress is gradually unloaded.

![Figure 4. Stress-strain curve of uncoated sample loaded with SHPB.](image)

20# steel which column of Φ10 mm×10 mm has been loaded by SHPB at strain rates 300–1100 s⁻¹, the stress-strain curve is obtained as shown in figure 5. It can be seen from the figure that the 20 steel material passes through the elastic phase first, and then begin plastic deformation after reaching the yield point. The material strain increases with the stress. It can be seen from the figure that the yield strength of the 20 steel is about 800 MPa, it is about 10 times higher than the uncoated reactive material.

![Figure 5. Stress-strain curve of 20 steel loaded with SHPB.](image)

Use SHPB to load the 1mm and 2mm coating fragments which shown in figure 2, and study the
mechanical properties of the material. As shown in figure 6, it can be seen that the mechanical properties of the coated reactive fragments are similar to the 20 steel. As the loading strain increases, the material first undergoes elastic deformation. When the stress reaches to the yield point, the material undergoes plasticity deformation, resulting in greater strain. It can be seen from the figure that the average yield stress of the fragments of the 1mm shell is 300MPa, and the 2mm shell is 520MPa, so it can be obtained that the thickness of the fragment shell has a greater effect on the overall mechanical properties of the material, using steel shell to coat the reactive fragments has a significant effect on improving the overall mechanical strength of the fragments.

![Stress-strain curves of reactive fragments of 1mm and 2mm coating.](image)

**Figure 6. Stress-strain curves of reactive fragments of 1mm and 2mm coating.**

**4. Conclusions**

1. The reactive materials and the coated reactive fragments have obvious strain rate effects under impact loading, and both show elastic-plastic mechanical properties during loading, especially the coated reactive fragments have obvious mechanical characteristics of steel.

2. During the impact loading process, the yield strength of the reactive material is 75 MPa, the 20# steel is 10 times higher than the reactive material, and the yield strength of the reactive fragments of 1mm and 2mm coating thickness is 300 MPa and 520 MPa, respectively which show the thickness of the fragment shell has a greater effect on the overall mechanical properties of the material.

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