The Impacting Dynamic Response of Energetic Materials PTFE/Al

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ABSTRACT

PTFE/Al is the most representative of a new class of advanced energetic materials. In order to study the dynamics response under impact, carrying out numerical simulation for the pressure changes and plastic deformation which were generated from PTFE/Al with a metal shell penetrating aluminum alloy target by using LS-DYNA. By analyzing the pressure on the observation point, flash and unit deformation characteristic, summarizing Energetic Materials PTFE/Al impact dynamic response. Combining the literature experimental results verify that the simulation is reasonable.

INTRODUCTION

The key of energetic reactive materials can be widely used in the military is not only that there is enough strength to bear the high overload, and that the Chemical reaction can occur after penetrating the target and release chemical energy. The relevant literature[1] shows that PTFE / Al in high-speed crash can occur under deflagration, and heat released is up to 14.9kJ/g and the energy is 3.5 times of TNT, and the unit volume energy is 5 times of TNT. In recent years, many research workers in the world are engaged in research in this area. Lee and Willis[2,3] give the impact initiation criterion under different conditions of bare charge respectively, while the shell charge impact initiation was studied. Xu Songlin[5]used universal material test machine and split Hopkinson pressure bar to study PTFE/Al energetic materials and found that at strain rate$(6~8)\times10^3$ s$^{-1}$ the performance material strain rate is effected; compared with the static loading, dynamic loading of modulus and strength is improved significantly, but the strain rate decreased. However, the research on dynamic response of materials at high speed impact condition with metal shell is less.
For the further study of energetic material dynamic response when impacting on the high-speed, using LS-DYNA software to analysis process of the flat shell energetic material penetrating vertically the target in the paper, studying the rule of dynamic response of penetrating process, analyzing the plastic deformation and pressure change of several important observation parts, comparing result of the reference[2] experiments and summarizing Energetic materials flash phenomena. The research can provide reference for the Energetic materials used in the military.

**NUMERICAL SIMULATION CALCULATION**

**Physical Model**

The physical model used in the numerical simulation is the cylindrical cavity filled with PTFE/Al of energetic fragment, and total mass is 8.67g, while the shell weighs 7.87g and PTFE/Al weighs 0.8g. The shell material is 4340 steel. Length is 12mm. Diameter is 12mm. Target plate is 100mm×100mm square LY-12 Al. Fragment vertical penetrating the target, considering the axisymmetric structure, in order to improve the computing speed, reduce the number of elements and ensure calculation precision, we take 1/4 the energetic fragment and target to model. Plane of symmetry is applied symmetry constraint. A target plate boundary is set to non-reflect conditions. Each entity is adopted by surface to surface erosion of contact. Modeling units is cm-g-µs. Finite element model is shown in Figure 1.

![Energetic fragment finite element model](image)

**Calculation Model**

Fragment is used Lagrange algorithm and the grid unit is SOLID164. Considering the process to reflect the impact of high-intensity, high strain, high-density characteristics, and numerical simulation of fragment using the Johnson-Cook material model and Gruneisen equation-of-state to describe is more practical. The basic formula of Johnson-Cook[5] model:

\[
\sigma_f = (A + B\varepsilon_p^m)(1 + C \ln(\varepsilon/\varepsilon_c))(1 - T^\gamma)
\]

(1)
Where: A yield strength; n and B is the strain hardening coefficient; C is empirical strain sensitivity coefficient; $\varepsilon_b$ for the equivalent plastic strain; $\dot{\varepsilon}$ is strain rate; $\varepsilon_0$ is the reference strain rate; $T^*$ is the reduced temperature, $K$, $T^* = (T_i - T_r)/(T_m - T_r)$, where $T_r$ is the reference temperature; $T_i$ is the test temperature; $T_m$ is the temperature softening effect parameters. Reference [4] and [5] obtaining the relevant material parameters as shown in Table I.

Table I. PTFE/Al energetic materials, je model parameters of fragment shell and ly12 target material.

<table>
<thead>
<tr>
<th>Material</th>
<th>$\rho$ (g cm$^{-3}$)</th>
<th>$E_0$ (GPa)</th>
<th>A (GPa)</th>
<th>B (GPa)</th>
<th>n</th>
<th>C (s$^{-1}$)</th>
<th>$\varepsilon_0$</th>
<th>m</th>
<th>$T_m$ (K)</th>
<th>$T_r$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE/Al</td>
<td>2.27</td>
<td>0.08</td>
<td>0.024</td>
<td>0.195</td>
<td>1.8</td>
<td>0.4</td>
<td>1</td>
<td>1</td>
<td>500</td>
<td>299</td>
</tr>
<tr>
<td>4340Steel</td>
<td>7.83</td>
<td>210</td>
<td>0.792</td>
<td>0.51</td>
<td>0.2</td>
<td>0.14</td>
<td>1</td>
<td>1.03</td>
<td>1793</td>
<td>299</td>
</tr>
<tr>
<td>LY12</td>
<td>2.68</td>
<td>72</td>
<td>0.218</td>
<td>0.546</td>
<td>0.41</td>
<td>0.01</td>
<td>1</td>
<td>1</td>
<td>877</td>
<td>299</td>
</tr>
</tbody>
</table>

NUMERICAL SIMULATION ANALYSIS

Numerical Calculation of the Penetrating Process

The equivalent stress state of energetic fragment penetrating target at a speed of 1200m/s in 10µs, as shown in Figure 2.

![Figure 2. Dynamic stress response of 10µs.](image)

We can see from Figure 2. In the initial stage of energetic fragment impacting the target plate, internal energetic materials is crushed by fragment shell extrusion, producing high amplitude compression wave and making the head of energetic materials to quickly enter the plastic deformation in a short period of time. The front end of Energetic materials is impacted firstly and starts upsetting under the extrusion of fragment shell and rear. The deformation of calculation model is reasonable.

Analysis of the Energetic Material Observation Point Pressure

In energetic materials head, middle and tail along the radial respectively and sequentially selects three observation points A, B and C. Calculating the pressure time histories of each observation point, as shown in Figure 3.

Figure 3(a) seen in the penetrating process of energetic fragment, in the process of penetrating, the pressure of energetic Materials repeated shocks, pressure curve
formation jump about 8µs, the peak pressure is 2.5GPa at A point. During 10–30µs, with the penetration rate decreases, the pressure began to unload, and the energetic shock type unloading rarefaction wave was formed. After 30µs, energetic fragment ran through the target board, the pressure tends to stable. Figure 3(b) shows that compared with energetic materials head’s pressure, middle’s pressure overall decreases, central’s unit is also less deformed, damage is weak, and the pressure trends

![Figure 3](image)

Figure 3. The observation point pressure time history curve of energetic material.

and value of three observation points differ not quite, accord with the axial stress-strain variation regulation of material energetic.

Compared with the dynamic response of the A and B points, the pressure curve trend of the tail is similarly, but overall pressure value is minimum, Wherein point B due to the deformation of the fragments shell extruded, creating a greater pressure, while A, C through compression, stretching two load alternating action but their peaks are always small, see Figure 3(c)

**Penetration Pressure and Flash Characteristics with Different Speed**

Energetic materials with different velocities penetrating the target situation were calculated respectively, get the center unit pressure curve as shown in Figure 4.

![Figure 4](image)

Figure 4. The pressure curve of the observation point with different speed.

From figure 4, the curve of pressure change trend are almost the same when center unit part at a speed of 100, 300, 600, 900 and 1200m/s, reaching the peak pressure at 8µs, and then compression and tension of two kinds of load alternating tend to be stable, but with the velocity increasing, the internal pressure peaks of energetic materials is increasing gradually.

The stress and strain test of energetic materials in high speed impacting is still a difficult problem. Numerical calculation is also rare. Table II summarizes the
experiments by M. Willis. The impact performance of PTFE/Al samples that the content of Al is 26% is tested by air gun, and testing rate is 104~963m/s. The experiment of particle size is 28µm PTFE and 9µm Al. The sample was pressed sintering small pieces and then processed into a rod dieΦ7.59mm×50.8mm, and its theoretical maximum density is 2.27g/cm³. Observing the impact process with high speed camera, and recording the results [2]. Because of its action principle and goal is almost the same with this paper, so there is a very high reference value.

Table II. Hit ignition properties of rod PTFE/Al sample.

<table>
<thead>
<tr>
<th>No.</th>
<th>The impact velocity (m·s⁻¹)</th>
<th>The impact pressure (MPa)</th>
<th>Flash time (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>104</td>
<td>450</td>
<td>untriggered</td>
</tr>
<tr>
<td>2</td>
<td>172</td>
<td>780</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>303</td>
<td>1500</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>614</td>
<td>3530</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>963</td>
<td>6330</td>
<td>4</td>
</tr>
</tbody>
</table>

Energetic Materials at a constant velocity v=1200m/s impact Al target, pressure value of head energetic materials is maximum, tail is minimum and the middle is in between. The peak pressure of the head is 2.5GPa, the peak pressure of the central is 2GPa, and the peak pressure of the head is 1GPa. Experimental results of literature table 2 shows that when the impact pressure is less than 0.78GPa, there will be no flash phenomenon, but with the increase of the impact velocity, impact pressure of energetic materials also increases, and the possibility of occurrence flash of energetic material increases gradually, but also needs shorter time to trigger flash. So the energetic materials on this speed will occur the flash phenomenon and the head first. Seen from Fig.4, the energetic materials impact aluminum target at the speed of 100, 300, 600, 900 and 1200m/s, corresponding to the maximum peak pressure are 0.25, 0.8, 1.05, 1.62 and 1.96GPa respectively. The pressure peak of 100m/s is 0.25GPa which is smaller than the critical flash pressure, so it will not appear to flash phenomenon. And there will be flash phenomenon occurred in the other 4 groups, in this paper, the numerical simulation results and literature results are basically the same.

CONCLUSION

1. The head of energetic materials in high speed impact is mainly affected by high amplitude impact compress, causing plastic deformation obviously. It’s compression is much stronger than the middle and the tail. It can provide reliable basis to determine the flash location of energetic materials.

2. With the energetic fragment velocity increasing, the internal subjected to repeated shock compression function is more and more obvious, while its repeated fluctuations finally tends to be stable, but with the increasing impact velocity the reactive time of energetic materials becomes more quickly, and the flash phenomenon is more obvious.
REFERENCE