Experimental study on fabrication and impact characteristics of PTFE/Al/W reactive materials with different molding pressures

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Abstract. Here we focus on the impact characteristics of polytetrafluoroethylene/aluminum/tungsten (PTFE/Al/W) reactive materials under various molding pressures. Reactive materials of the density of 3.0 g/cm³ were fabricated via pressing and sintering processes. Drop weight tests were carried out to study impact characteristics of the reactive materials. Experiment shows that, critical forming pressure and compaction pressure are approximately 5MPa and 100MPa, separately, and meanwhile, the sintering cycle could enhance the strength of the material pressed under the critical forming pressure. Furthermore, reactive materials show strain rate effect on impact characteristics, and the increase of mounding pressure attributes to the transition from inertness to sensitivity of the material. Within the molding pressure range of 15MPa, impact sensitivity of the material increases exceedingly, whereas, the impact sensitivity remains relatively stable when the molding pressure ranging from 15 MPa to 100 MPa. Phenomenologically, with the increase of the molding pressure, the drop impact induced initiation flame transits from weak and unsustainable to intense and continuous. From the point of initiation mechanism, low molding pressure introduced high porosity plays negative role against the formation and growth of the hot spots in the microstructure of the material, which was demonstrated by the experiments. The conclusion drawn from this research reveals that a well pressed condition would be beneficial for increasing the impact sensitivities of low density reactive materials.

1. Introduction

The reactive material is a bunch of energetic material which consist of several inert materials and could initiated violently under impact conditions [1-3]. PTFE matrix powder (73.5 wt.%) mixing with Al particles (26.5 wt.%) are the most widely used formula in decades [2]. W particles can enhance the strength of the material and can be considered as inert components as W particles aren’t participate in the redox reaction [4-5]. Reactive materials are cold isostatic pressed (CIPed) and high temperature sintered (HTSed) by well mixed PTFE/Al/W powders. The reactive material undergoes CIP and HTS processes can be initiated by plastic deformation under dynamic load and the chemical energies caused violent explosion and deflagration reaction [6-8]. The formulation design, mechanical properties, impact initiation and energy release characters of reactive materials were studied [9-10]. For the preparation process of reactive materials, there are researches on mixing process and sintering process, but there are few researches on the preparation process of reactive materials [11].
In this paper, fabrication characters mainly focus on density transitions are studied statistically and impact characteristics of polytetrafluoroethylene/aluminum/tungsten (PTFE/Al/W) reactive materials under various molding pressures are investigated by the drop hammer experiments, and the relationship between forming pressure and impact sensitivity was analyzed qualitatively. It provides feasible guidance for the design of reactive materials from experimental point of view.

2. Experimental setup

2.1. Sample fabrication

For this work powders of 51.0 wt.% PTFE (DuPont, type MJ 1500J), 18.4 wt.% Al (25 mm, FW-1-200) and 30.6 wt.% W (20 mm, type FLPN291.1) were selected to achieve reactive materials with density of 3.2 g/cm³ via a dry mixing process. Then the mixed powder were fabricated by increasing molding pressure (3 MPa, 5 MPa, 10 MPa, 15 MPa, 25MPa 50MPa, 100MPa) and held the pressure for 10 min with the same mass of 0.75 ± 0.02g. Pressed reactive materials samples were placed at ambient 20 °C for 24 h to ensure avoiding trapped air or residual stresses.

After mixing and pressing, the samples were placed into an argon atmosphere protected vacuum oven for undergoing a sintering cycle. Heating temperature rose firstly from 20.0 °C up to 370.0 °C in 180 minutes and then held at the sintering temperature for 120 min for heat exchanging sufficiently. After that stage samples were cooled in the vacuum oven via annealing cooling and the whole sintering cycle are depicted in figure 1.

![Figure 1. The temperature history of the sintering cycle.](image)

2.2. Drop weight test

Here the standard drop weight apparatus was used to study the sensitivity and impact-initiation characteristics of the reactive material samples. The tester has a drop mass of 5.0 kg which can be released ranging within 200 cm. The drop mass is controlled by an electromagnetic switch. The impact sensitivities of materials are characterized by the characteristic drop height obtained by “up-and-down” technique. The characteristic drop height of impact sensitivity ($H_{S0}$) can be calculated by the eq.1:

$$H_{S0} = H_0 + \Delta h \left[ \frac{\sum in_i}{N} - \frac{1}{2} \right]$$

(1)

Where $H_0$ is the lowest height in the test, $\Delta h$ is the increment of height, $N$ is the number of reaction events among the tests, $i$ is the order of the drop height starting from 0, $n_i$ is the number of reaction events under certain height.

Time sequences of all the impact events were recorded by a Phantom V710 high-speed camera (Vision Research, Inc., Wayne, NJ, USA), with the frame rate, resolution and exposure time were set as 8000 fps, 640×480 and 30 mics, respectively.
3. Results and discussions

3.1. Fabrication characters

The CIPed reactive materials have defects in the edges and are splintered with extruding manually for the molding pressure in pressing process is 3 MPa for the molding pressure in pressing process is 3 MPa. With the pressure increased to 5 MPa, the material materials are intact. When the increase of molding pressure to 50 MPa, the height of cold pressing molding material samples decreases gradually.

As the molding pressure continues to increase to 150 MPa, the material size remains stable comparatively. The densities of HTSed reactive materials change by comparison with CIPed samples. As for the low molding pressure from 5 MPa to 30 MPa, reactive material samples tend to be dense. For the high molding pressure from 38 MPa to 70 MPa, samples tend to be loose comparatively. The reduction of density between CIPed and HTSed samples remain 0.1 g/cm$^3$ stably.

![Figure 2. Schematic diagram of drop weight test apparatus.](image)

![Figure 3. The density distributions of reactive materials with TMD of 3.2 g/cm$^3$.](image)

Here the blue dotted line and red solid line are replicated to the density of CIPed and HTSed reactive material samples. The black line refers to the TMD of PTFE/Al/W reactive materials.

As shown in figure 3, the critical forming pressure and compaction pressure are approximately 5 MPa and 100 MPa, separately, and the reactive material density tends to be stable from 50 MPa For
solid materials fabricated by metal powders, size shrinkage occurs in sintering process. Sintered materials are formed toward dense when the sinter temperature of the material is lower than the material melting point. During the whole sintering process, the porosity of the material decreased from connection to isolation. Melting point of PTFE/Al/W reactive material can be considered as the temperature of the polymer matrix melting point approximatively. The density gradually increases with the increase of molding pressure in low molding pressure. High molding pressure induced porosity rearrangement of the CIPed and HTSed reactive material.

For pressed explosives, relations between density and molding pressure can be expressed as eq. 2. The density of CIPed and HTSed reactive materials were fitted through eq. (3-4) and are shown in figure 6.

\[
\rho_0 = a + b \ln P
\]

(2)

\[
\rho_{\text{CIPed}} = 1.925 + 0.3049 \ln P
\]

(3)

\[
\rho_{\text{HTSed}} = 2.435 + 0.1668 \ln P
\]

(4)

As the increasing of the molding pressure of the reactive material, the density of the material integrated gradually. The fitting density relations of CIPed material and HTSed materials intersected at 40 MPa area. That is, at the critical formation stage sintering process are benefit for dense which is similar to metal materials. Molding pressure would come to the intersection where achieves ideal material porosity. With the increasing of molding pressure internal particle shifted and reached and non-point contact with the Al/W particles caused internal stress such as force chain formation in CIPing process. In the HTSimg process the internal stress reduce and the porosity increased.

**Figure 4.** Fitting densities of CIPed and HTSed PTFE/Al/W reactive materials.

### 3.2. Impact initiation characters

Figure 5 shows the impact characteristics of PTFE/Al/W with different molding pressure. Figure 5 (a-d) presents the impact initiation behavior of reactive materials dropped from 110 cm height fabricated by decreasing molding density from 50 MPa to 15 MPa, 10 MPa and 7 MPa, respectively. Figure 5 (e-f) gives reactive material pressed by 5 MPa with 200 cm drop height.
Figure 5. Impact initiation behavior of reactive materials with TMD of 3.2 g/cm³.

With the molding pressure range from 7MPa to 50MPa, reactive materials of 3.2 g/cm³ preform sensitive and sustained the flame region formed by the reaction after the activation of impact.

Among them, 15 MPa and 10 MPa reactive material has a more intense reaction. As the molding pressure of the material increase to 50MPa, the impact initiation behavior decreased significantly, incomplete-reacted material fragments associated with sputtering activity images could be observed. As the molding pressure decreases, the internal porosity of materials decrease and homogenize gradually. During the compress process, the porosity of the material is appropriately increased to ideal situation. In addition, the internal porosity can be further reconciliation. The uneven density increase in energy-containing materials is beneficial to the initiation of materials to some extent. This shows hot spots will form easily for nonuniform density distribution reactive material.

Figure 5 (e-f) shows uncertain impact initiated characteristic for the same impact conditions and could be related to the “hot spot” formation mechanism of reactive material. Mechanical deformation formed among the particles could further evaluate the internal reaction of reactive material. The internal particles are randomly dispersed.

Under low-velocity impact, “hot spot” of the material form unsatisfactory and lead a decreasing trend to reaction intensity. reaction efficiency reduces and becomes unsustainable initiated. Generally,
the lower the material molding pressure is, the lower energies contained and the reaction finished rapidly, yet the more porosity spread in the reactive material and impact sensitivity improvement could be achieved, which would be easily explained by the hot-spot induced initiation mechanism.

Apart from the sensitivity increase stages, the then slowly decrease trend as the molding pressure increase suggest a stable impact sensitivity when the molding pressure further improves. Reactive materials show strain rate effect on impact characteristics, and the increase of molding pressure attributes to the transition from inertness to sensitivity of the material. With the increase of the molding pressure, the drop impact induced initiation flame transits from weak and unsustainable to intense and continuous and are shown in figure 6.

![Figure 6. Impact sensitivities (H50) of the 3.2 g/cm³ samples under different molding pressures.](image)

4. Conclusion
Fabrication and impact characteristics of PTFE/Al/W reactive materials reactive materials are studied experimentally and the main conclusions are as follows:

1) The sintering cycle could enhance the strength of the material pressed under the critical forming pressure.
2) The increase of molding pressure attributes to the transition from inertness to sensitivity of the material.
3) With the increase of the molding pressure, the drop impact induced initiation flame transits from weak and unsustainable to intense and continuous.

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