International Journal of Impact Engineering 95 (2016) 125–132

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Experimental study on penetration behavior of reactive material projectile impacting aluminum plate

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ARTICLE INFO

Article history:
Received 28 December 2015
Received in revised form 8 May 2016
Accepted 10 May 2016
Available online 13 May 2016

Keywords:
Reactive materials
Reactive projectile
Ballistic impact experiment
Penetration behavior
Ballistic limit velocity

ABSTRACT

Ballistic impact experiments were performed on the cold isostatically pressed and sintered PTFE/Al/W reactive material projectile with a density of 7.8 g/cm^3, in order to understand its penetration behavior of normally impacting 2024-T3 aluminum plates. The damage patterns of perforated and imperforated aluminum plates are observed and ballistic limit velocities are obtained by using experimental results. The penetration-induced deflagration behavior of reactive material projectile normally impacting aluminum plates with different thickness at approximate ballistic limit velocity is also analyzed. Combining the THOR penetration equation with experimental results, a semi-empirical relationship is developed to predict the ballistic limit velocity of reactive material projectile impacting aluminum plates. Moreover, the target thickness and the projectile mass effects on penetration performance of reactive material projectile relative to steel projectile impacting aluminum plates are analyzed and discussed. As the analyses show, when the reactive material projectile impacts aluminum plates at approximate ballistic limit velocity, an increasing target thickness always means that the delaying rarefaction wave effect, the dropping initial shock wave attenuation effect, and the decreasing time after impact for initiation. Hence more reactive materials are initiated to deflagrate in the penetration channel, enhancing the influence of chemical energy released on penetration-induced deflagration behavior and penetration performance.

1. Introduction

Reactive materials and its applications in high damage field are being intensively studied by various countries due to the combined efficiently damage of kinetic energy and chemical energy [1,2]. Different from a single mechanical perforation and kinetic energy damage of traditional inert metal projectile, the reactive material projectile is initiated to deflagrate/explode as soon as it impacts the target with enough velocity, resulting in dramatically more structural damage to lightly armored or unarmored targets and significantly enhancing the ignition/initiation capacities to combustible/explosive targets [3,4].

At present, much progress on reactive materials has been achieved, especially in their formulation, fabrication, mechanical properties, energy release characteristics and confirmatory experiments of its enhanced damage effect [5–16]. The formulation of reactive materials generally consists of thermite, intermetallic compound, metal/polymer mixture, semi-stable state intermolecular composite, composite materials, hydride, and etc. The metal/polymer reactive materials are most widely applied, which is fabricated through a mixture of metal powder and fluoropolymer, cold isostatically press and sinter hardening [5–7]. The influences of particle size, porosity and particles' morphology on the mechanical properties of the reactive materials are also studied by quasi-static compression, hammer dropping and split-Hopkinson pressure bar experiments [8–10]. Moreover, a vented test chamber is used to evaluate the energy release characteristic of reactive materials, and the results show impact velocity and reactive material formulation have markedly influence on energy release behavior [11,12]. Due to the high density and strength requirements for penetration, the Al/W/PTFE reactive materials have gradually received more and more attention [13,14]. The enhanced ignition effect to aviation kerosene and the initiation behavior to covered explosive are also investigated by ballistic impact experiments [15,16].

Due to the complicatedly coupled response of mechanics and chemistry during penetration, the penetration behavior and performance of reactive material projectile is difficult to be understood well, especially the influence of chemical response on penetration behavior and mechanism, which is less known. In this investigation, the ballistic impact experiments are conducted to understand the influences of impact velocity, target thickness and projectile mass on the penetration behavior of Al/W/PTFE reactive materials. Furthermore, for the coupled response of mechanics and chemistry consideration, the penetration-induced deflagration behavior, penetration performance and mechanism of reactive material projectile impacting aluminum plates are analyzed and discussed.

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http://dx.doi.org/10.1016/j.ijimpeng.2016.05.007
0734-743X/

2. Experimental arrangement

2.1. Preparation of reactive material projectiles

The PTFE/Al/W reactive materials are fabricated by cold uniaxial pressing at a pressure of 200 MPa and sintering at a temperature of 380 °C. In the sintering process, the pressed reactive material specimens are inserted into a vacuum sintering oven firstly. The oven temperature is then risen up to 380 °C at a rate of 50 °C/h and kept at 380 °C for 6 h. After that, the oven temperature is decreased to 310 °C at a rate of 50 °C/h and kept at 310 °C for 4 h. Lastly, in the cooling process, the oven temperature is decreased to ambient temperature at an average rate of about 50 °C/h. The mixture has the following weight content components: 11.3 wt% PTFE, 7.5 wt% Al, and 81.2 wt% W. And the initial powders have an approximate spherical shape with the following average sizes: 100 nm PTFE powder, 44 µm Al and 44 µm W. The density of pressed and sintered PTFE/Al/W reactive materials is approximately equal to 7.8 g/cm^3. In order to investigate the influence of projectile mass on penetration performance and behavior, the masses of cylindrical reactive material projectiles, with the same average diameter of 10 mm, are 2.01 g, 3.53 g, 5.10 g, and 6.12 g, respectively.

The typical photographs of powder mixture, pressed sample and sintered projectile are shown in Fig. 1. Compared with the sintered sample (Fig. 1c), some white spots are observed on the surface of the pressed sample (Fig. 1b). The phenomenon may be the result of that the PTFE powders, which is the white spots observed, melt gradually as the temperature increases and then recrystallize as the temperature decreases during the sintering process, resulting in better homogeneity of the Al/W/PTFE reactive materials.

2.2. Methods

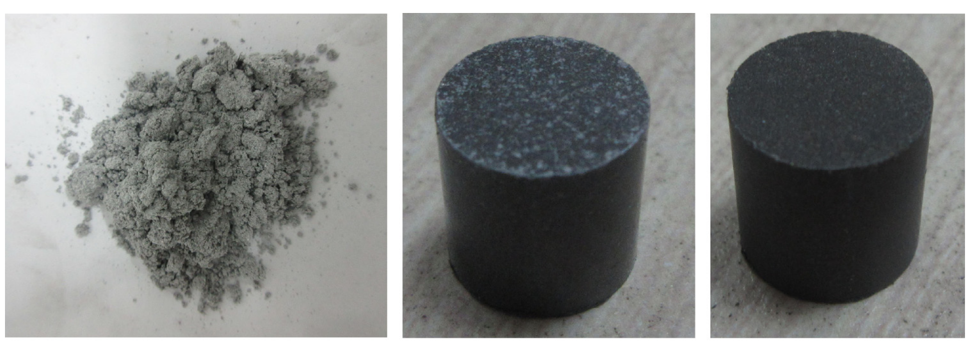
In order to investigate the influences of projectile mass and target thickness on penetration performance, both of the projectiles with masses of 2.01 g, 3.53 g, 5.10 g and 6.12 g, and the target aluminum plates with thicknesses of 3 mm, 6 mm, 9 mm and 12 mm, are used in the experiments. The powder mass is adjusted by Bruceton method according to whether the plate is perforated or not at the measured velocity. Particularly, if the reactive projectile launched at an estimated velocity perforates the aluminum plate, the powder mass for next shot decreases. Otherwise, it increases.

Fig. 2 shows the photograph of the bullet sample and the schematic diagram of the experimental setup. The reactive material projectile is encapsulated in a nylon sabot and is launched from the smooth bore powder gun barrel 12.7 mm in diameter. The distance between the muzzle and the aluminum plate is 8 m to ensure the separation of reactive projectile and sabot, and the distance between the aluminum plate and the velocity probes is 412 mm. Moreover, the impact velocity of reactive projectile is measured by the velocity probes. The process of reactive material projectile normally penetrating aluminum plate is recorded by high-speed video.

3. Experimental results

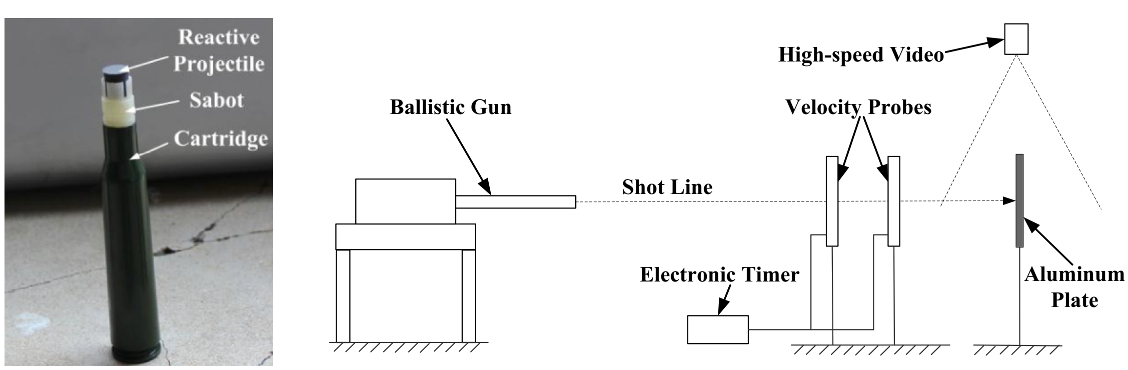
3.1. Ballistic limit velocity

Table 1 gives the experimental results of reactive material projectiles impacting 2024-T3 aluminum plates with different thicknesses, in which the '✓' means 'perforation' and '✗' means 'imperforation'. 'Perforation' means that the bottom of the projectile



(a) (b) (c)

Fig. 1. Photographs of reactive material projectiles at different fabricated stages: (a) the PTFE/Al/W granular mixture; (b) a pressed sample; and (c) a pressed and sintered sample.



(a) (b)

Fig. 2. Bullet sample and the schematic diagram of the experiment setup.