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Research Article

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Coherency for the critical condition of DDT and SDT in energetic materials

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ABSTRACT

With safety issues playing a dominant role in present-day energetic materials technology, concern is increasing about the relative safety of solid high explosives shocked initiation(SDT) and deflagration to detonation transition (DDT). The critical conditions and parameters have been measured about SDT and DDT, the results indicate that existence coherency apparently between the critical initiation of SDT and DDT in this paper. Some of the results such as the increase velocity of combustion peak, the highest scope and the movement velocity in SDT indicated its existence.

Key words: shock wave; solid explosive; Lagrangian analysis; state equation

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INTRODUCTION

With the development of the rocket's boosting technology, propellant in the ratio of explosive is increased to enhance the boosting efficiency which makes the distinguish between the solid explosive and propellant disappearing. So they are called generally high energetically dense materials or energetic material. Deflagration and detonation are two important properties for energetic materials. Consideration for reliability, the energetic materials should detonate reliably when it is used for warhead and deflagrate reliably when it is used for propeller. Concern the relative safety of energetic materials, it should not detonate when production, transportation, shortage, or even ignition by accident. So the investigation of the properties, mechanism, critical condition and threshold value of the shock to detonation transition (SDT) [1-3]. and deflagration to detonation transition (DDT) [4],are important to design, production and application.

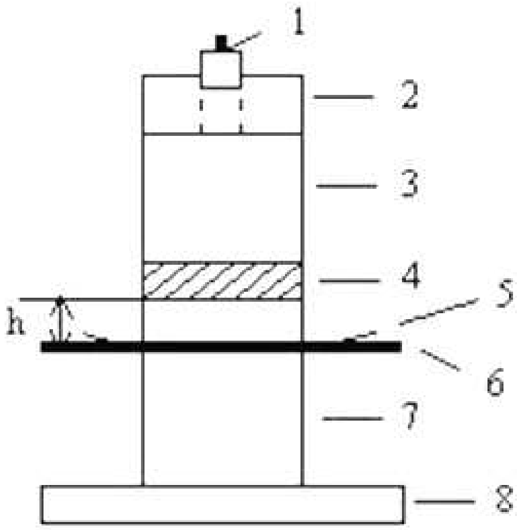
For the study of the safety of energetic materials, most of the past research methods are only for the problems of SDT of high explosives and DDT of the solid propellants. Since the increasing of the energy density in the solid propellant, the difference is decreasing between the explosive and solid propellant. So the study of SDT for the solid propellant is needed. Of interest here is determination whether existence the coherency between the critical conditions of SDT and DDT or not as far as the same kind of energetic materials are concerned. So the study of these problems are important to gain knowledge if existence the coherency or not for two types of explosives and two types of solid propellants. In this paper, two-dimensional SDT experiments [5-6]. and DDT experiments of thin wall copper have been carried out [7-8]. The critical conditions and parameters have been measured about SDT and DDT, the results indicate that existence coherency apparently between the critical initiation of SDT and DDT.

EXPERIMENTAL SECTION

In this experiments, the loading fashion of two-dimensional SDT experiments employed small scale gap test. 10g TNT as donor explosive charge is pressed to 20.1mm diameter and density is 1.60 g/cm3, and copper gap material is 20.0mm diameter. The properties of this loading fashion device can be sequentially adjusted by varying the thickness L of the copper to change the output pressure of the bottom-end face of copper gap. The measure of the pressure employed the manganin-constantan composite 2-D Lagrange sensors. Shock initiation experiments have been carried out for two solid explosives(Fig 1).

The particular gauge assembly was similar to that described previously in our last publication [8-10].

The DDT experiments employed two different diameters of thin wall copper pipes, one with outer and inner diameters are 30mm and 26mm, respectively. The other with outer and inner diameters are 24mm and 20mm, respectively. The thickness for both of the wall copper pipes is 2mm. The measure of the velocity employed the ionized probe. Since an impacting debulk area (so called no deflagration or detonation area) exists in the thin wall copper pipe DDT experiment, the pressure gauges were embedded in this region will not affect the DDT process apparently. Therefore, the formation of the shock wave and the circle detonation after the shock changes to detonation can be recorded. Shock initiation experiments have been carried out for Pressed TNT. Our goal is to investigated the shock wave extinguished in the pressed TNT . The schematic diagram of experimental is shown in Figure1.



1 Detonator 2 Detonator holder 3 Detonator explosive charge 4 Copper 5 Gauge 7 TNT 8 Witness plate
Fig 1. Experimental set-up for small scale gap test

RESULTS

The experiments of SDT measured the process of the critical initiating of that two solid explosives (E1, E2) and two solid propellants (P1, P2). For the two explosives (E1, E2) and solid propellants (P1, P2) applied in this paper, E1 is 95% RDX with ρ0=1.70±0.02g/cm3 , E2 is 95% HMX with ρ0=1.70±0.02g/cm3, P1 is 55% RDX with ρ0=1.68±0.02g/cm3, and P2 is 55% HMX with ρ0=1.70±0.02g/cm3. Both the E1 and E1 explosives are under press charge and both the P1 and P1 propellants are under cast charge. Specimen1. E1 (97%RDX, press ρ0=1.70±0.02g/cm3)

Specimen 2. E2 (94%HMX, press ρ0=1.70±0.02g/cm3)
Specimen 3. P1 (60%RDX, cast ρ0=1.68±0.02g/cm3)
Specimen 4. P2 (60%RDX, cast ρ0=1.70±0.02g/cm3)

Table 1. The results of shock initiation experiments

△unexploded ×exploded

L(mm) specimen	10.0	8.04	7.08	6.5	6.0	4.0	2.0	0
1.(E1)	△△	△	△	×	×××			
2. (E2)		△	△	△	△×			
3.(P1)					△	△	△	×
4.(P2)							△	△

Type of manganin-constantan composite 2-D Lagrange sensor is adopted in the experiment (Figure 2). Fabricate process of multilayer integrate circuit is adopted on the sensors, precision of superposition between cornwall foil and manganin foil is less than 0.005mm.

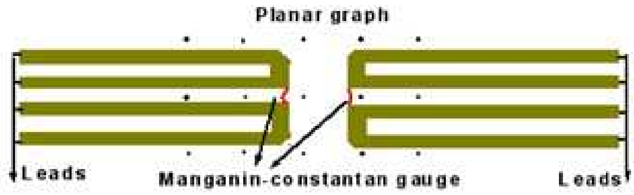


Figure 2 The Π type of manganin-constantan composite 2-D Lagrange sensors are used in the experiments

The signals can be obtained by the oscillograph which changed to the pressure by using the formula:

$$P = 0.27 + 34.4\frac{\Delta R}{R_0} + 1.07(\frac{\Delta R}{R_0})^2 \tag{1}$$

There are two mixture model for the SDT which can be used. Firstly, we can suppose the volume between the reacted explosive and the unreacted explosive are equal. The other is the single-temperature model which suppose the pressure between the reacted explosive and the unreacted explosive are equal. Here, The single-temperature models as mixture laws used in the shock initiation which assumed that the pressures and temperatures between the reacted explosives and un-reacted explosives are equal. The reaction rate . And the relative specific volumes are additive, i.e.

$$P_m = P_s = P_g \tag{2}$$

$$T_m = T_s = T_g \tag{3}$$

$$v_m = (1-F)v_s + Fv_g \tag{4}$$

$$e_m = (1-F)e_s + Fe_g \tag{5}$$

Where subscript m is the mixed state, subscript s is the un-reacted state, subscript g is the reacted state, *F* is the reaction rate.

The Ignition and Growth reactive flow of shock initiation and detonation of solid explosives has been incorporated into several hydro dynamic computer codes and used to solve many explosive and propellant safety and performance problems.

$$\frac{DF}{Dt} = I(1-F)^b(\frac{\rho}{\rho_0} - 1 - a)^x + G_1(1-F)^c F^d P^y + G_2(1-F)^e F^g P^z \tag{6}$$

Where F is the fraction reacted, t is time, ρ is the current density, ρ_0 is the initial density, and I, G1, G2, a, b, c, d, e, g, x, y, and z are constants. Similarly to our previous study of shock initiation [10].

For the experiments, we can easily compare the relative sensitivity of the four energetic materials which mentioned above to a more sensitive explosive E1 and insensitive high explosive P2 at their ambient conditions. The shock initiation thickness of explosive E1, E2, P1 and P2 are about 7mm, 6mm, 1mm and less than 1mm, respectively.The initial pressure of explosive E1, E2, P1 and P2 are about 2.8GPa, 2.9GPa, 5.4GPa and more than 5.4GPa, respectively.

With the experiment, we can see that
1、The average front shock velocity of shock initiation and extinction for the same initial pressure is illustrated in this paper, which shows the average front shock velocity of shock initiation higher than the average front shock velocity of extinction.
2、In the process of extinction, the average front shock velocity of explosive P1 and P2 are higher than the average front shock velocity of E1 and E2 for the same initial pressure.
3、The distance from combustion wave crest to the shock front of E1 is less than E2, the reason why the shock initiation sensitivity of E1 is higher than E2.
4、The pressure attenuation distance to , which occurs after the shock initiation of the four energetic materials, it is apparently longer than the attenuation distance of inert materials. It shows that there have part reaction take place in the extinction process.

DDT experiments measured the critical initiation process of two explosives and two propellants which mentioned above. Figure 3 shows the typical experiment results. For the DDT pipe experiments, we gain the length, which occurs just in the low velocity deflagration area; high velocity deflagration area and impacting debulk area, and the distance (Ld) of transition to detonation. For the unexploded experiments, the density distribution of energetic materials, which stay in the recycle pipe, is scanned by CT scanning.

Figure 3. The DDT pipe experiment results of specimen 3 (P1)

With the experiment, we can also see that
1、The measure effect for the process of DDT, which place the gauge in the impacting area, is minimum. The experiments indicate that the key point of DDT growth or extinction is the impacting area. The impacting area can prevent the deflagration wave from passing; only let the compressed wave and shock wave through, so the determination whether the downstream energetic materials detonate or not is a process of shock initiation.

2、The apparently property of energetic materials is performed by thin wall DDT pipes. The results of the DDT process are varied the ignition strength and charge density. For individual experiments, we can clearly perceive that the ignition area, low velocity deflagration area, high velocity deflagration area, impacting debulk area and the detonation transition area. For the rest experiments, it is hard to divide the ignition area, low velocity deflagration area, high velocity deflagration area. But the impacting debulk area is existence apparently, only some of them were destroyed by circle detonation.

3、For the DDT pipes experiments of detonation transition, it seems to be a characteristic length in the impacting debulk area. For the type of A, the characteristic is about 50mm, for B is about 70mm. we should make a step forward study to determination whether existence the characteristic length, which have something to do with energetic material, charge density, pipe diameter, inert package, etc.

4、For the DDT pipes experiments of unexploded transition, the impacting debulk is recycled, and some energetic materials which were measured is still conserved completely and pressed solid apparently which can be verified by CT scanning. So the front density is apparently bigger than the behind density.

5、It is very non-steady for the DDT process of critical condition. Though control the experimental condition strictly, the result is still very different. Some of them were smashed completely, and some of them were recycled for full. So the further study of this property is whether it is the inherent property of the DDT process or it is controlled by other unknown parameters.

CONCLUSION

1、In this paper, we employed the 2-D small scale gape test (Φ20mm) (for short: 2-D SDT experiment). It can determine the critical condition of shock initiation and sort of the SDT hazard of different energetic materials is varied the critical gap thickness, in addition to gain the flow feather, as critical initiating pressure, the shock velocity, the range and position of deflagration wave crest after the shock wave, growth or attenuation of shock velocity, etc, around the initiation thresholds. So the SDT hazard can be subdivided shock hazard and combustive hazard.

2、The DDT critical condition of energetic material is determined by thin wall copper pipe test ($\phi 20mm$), and sort of the DDT hazard of different energetic materials is varied the critical gap thickness, in addition to gain the length, as low velocity deflagration area, high velocity deflagration area, impacting debulk area and can measure the form process of pressure in the impacting debulk area. So the DDT hazard can be subdivided combustive hazard and shock hazard.

3、From the subdivide of SDT hazard and DDT hazard, we can clearly find the coherency for both, they all have the shock hazard. The last stage of DDT process will transfer the SDT process at last. Since the impacting debulk separate the combustion wave and the shock wave form, and set off the rear energetic materials.

4、The study of experiment indicate that the SDT sensitivity of E1 is the highest, E2, P1 and P2 in sequence. But they have the same sequence in the DDT sensitivity. Although such rules cannot be generalized to all high energetic materials, it is obvious that a relationship exists between SDT and DDT sensitivity.

5、The relationship between the deflagration hazard in SDT and the combustion hazard in DDT is critical in this study. Some of the results such as the increase velocity of combustion peak, the highest scope and the movement velocity in SDT indicated its existence.

The phenomenon indicate that there is certain counterpart relationship, then the growth velocity, the highest range and of combustion peak in the SDT.

6、The two-dimensional SDT experiments of the energetic materials are easy to operate, control, and repeat with enough information. Such method is suitable to measure the relative SDT and DDT sensitivity for different energetic materials.

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