# Experimental study on effect of large-sized granules in powdery explosives under drop-weight impact

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## 1 Abstract

Drop-weight impact experiments are performed on a thin layer of cyclotetramethylenete tranitramine(HMX) and cyclotrimethylene trinitramine(RDX) powdery explosives,which was mixed with a few large-sized crystals and NaCl salt granules. The drop-weight impact machine is equipped with the high-speed photographic systems for observing the experimental process.The influences of large granules on the low-velocity impact response of powder explosives were studied. Experimental results showed that the mixed explosives are more sensitive than pure powdery explosives Hard salt particles could greatly enhance burning probability of powdery explosives because friction between granules and powders, stress concentration and breakage of large granulesjointly contributed to heat accumulation at the junction of dissimilar materials.

**Keywords:** Drop-weight impact; powdery explosives; large-sized granules; salt particle

## 2 Introduction

Impact sensitivity is one of the most important safety concerns for energetic materials. Moore and Ray [1] described a statistical method in order to quantify the sensitivity of the explosives, and performance analysis of complex computer simulation experiments to calculate H50, which is“50% impact height” of the “GO” sound level of reaction, to characterize the explosives. However, Bruceton method described originally by Dixon and Mood [2], which is the most used method. The greatest advantages of the drop-weight test are flexibility, extended input energy range, simple operation, and the possibility of testing particle beds (Narayanan, 1986)[3]. Heavens and Field equipped the high-speed photography on drop-weight machine to observe the dynamic compression events of granular explosives in Cavendish laboratory[4].They used pressure-measuring techniques and high-speed photography to investigate the behavior of thin layers of pure explosives[5]. Using the technique of high-speed photography, Balzer et al. found that the conventional material pentaerythritolte tranitrate(PETN) is more sensitive to ignition than

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ultrafine pentaerythritolte tranitrate(PETN), which is resulting from the gas-space collapse under drop-weight impact[6]. Czerski et al. designed a set of test device, using second harmonic detection technology (SHG)and high speed photography to study the ignition behavior of HMX under the drop-impact. They found a little of delta-phase HMX before the ignition, which proved the drop-weight impact on HMX sample can cause HMX phase to change [7]. Drop weight impact testing shows that HMX bulk crystals are much more sensitive than HMX microcrystals of nanoscale size[8]. The impact sensitivity of HMX/nanometer-$Al_2O_3$ reduces obviously as increasing the nanometer-$Al_2O_3$ content in the composite explosive[9].

In the present study, a drop-weight impact apparatus equipped with high-speed photography is used to examine the powdery explosives mixed with a few large-sized granules, like salt or energetic crystals. The evolution of hot spot using optical images is difficult to obtain, but a burning site and its propagation may be directly observed. We are mainly concerned about effects of large-scale granules on the explosive sensitivity. The experimental results provided very useful data for ignition sensitivity and safety usage.

## 3 Experimental

A conventional drop-weight machine was modified in order to record the responses of impact explosives (Figure 1). The powdery explosive was placed between toughened glass anvil that was installed on the impact surfaces. The total mass of the drop-weight assembly is about 5.71kg and we employed the drop height 20cm in currentexperiments. A LED served as a light source, fixed at a bracket. The impact responses were photographed with an interframe time of 10 ms, using a low-light-level FASTCAM SA5 LOOOK C3 camera (Photron Corporation, San Diego, CA, USA).

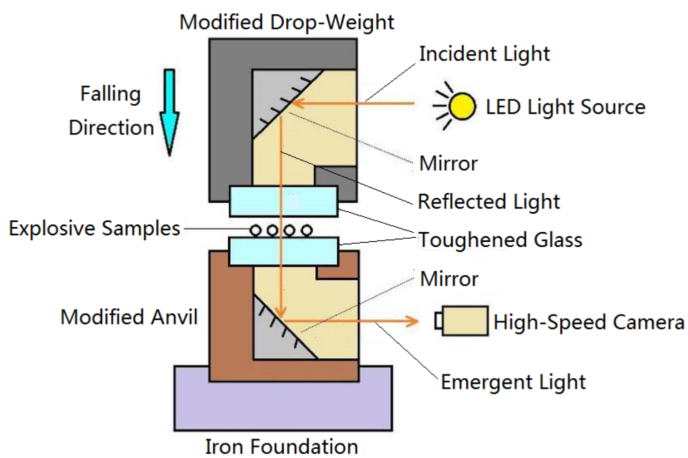



Figure 1 Schematic of the modified impact system

The powdery explosives and large-sized granules were provided by the China Academy of Engineering Physics.The grain size ranges of the materials used in current experiments are listed in Table 1.

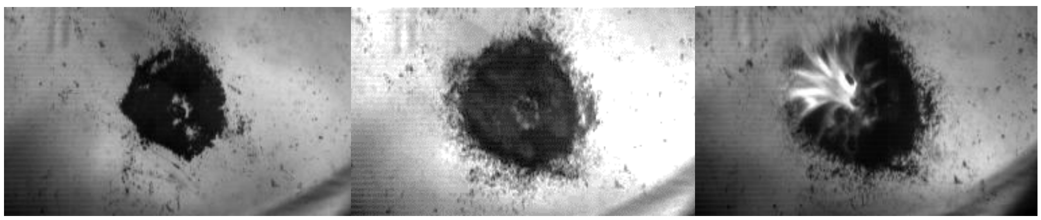
Table 1: Size range of the target materials

| Material | Range of grain size (μm) |
|---|---|
| RDX powder | 10~150 |
| RDX granules | 600~1200 |
| HMX powder | 10~50 |
| HMX granules | 300~500 |

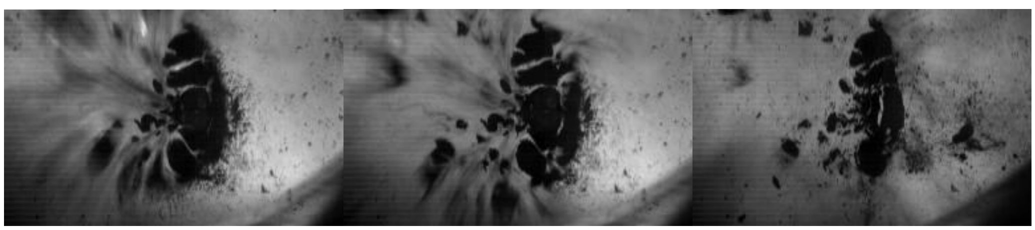
| | |
|---|---|
| Salt granules | 400~800 |

## 4 Results

Figure 2 gives the selected high-speed photographic frames of HMX powder with one HMX granule in response to an 20cm drop-heigh impact. The granule was placed in the middle of the powder layer. When impacted by the drop-weight, the granule in the mixture contacted with the hammer and underwent deformation and fracture much eariler than the powder. In the fast expansion process, for instance at 533.36μs, the boundary between powder and fragments of the granule was still distinguishable. Burning occurred at the junction of the two materials at 873.377μs. Afterwards, burning front propagate and consumed almost half of the sample.



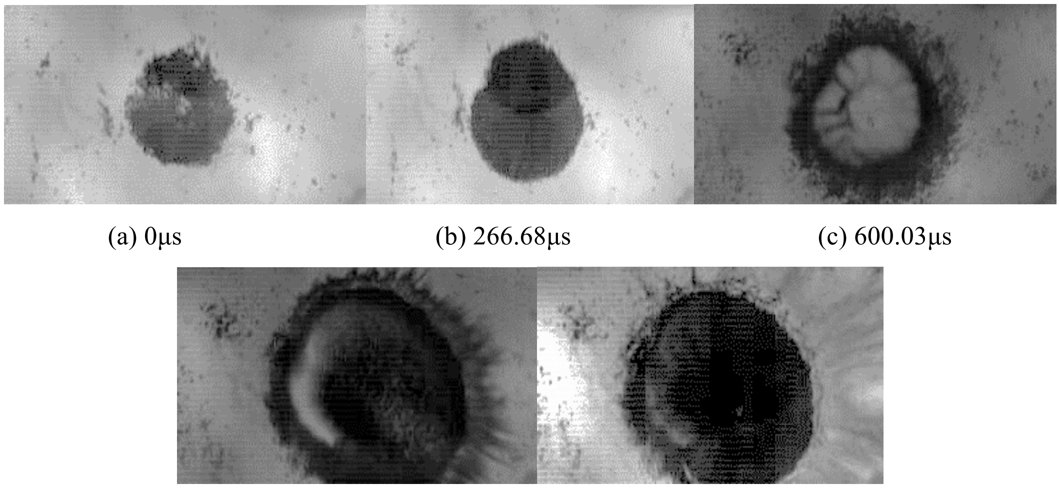
(a) 0μs (b) 533.36μs (c) 873.377μs



(d) 880.044μs (e) 886.711μs (f) 1133.39μs

Figure 2 Selected high-speed photographic frames of HMX powders with one large HMX granule at the center in response to an 20cm-drop height impact

Figure 3 shows the selected high-speed photographic frames of RDX powder with one RDX granule in response to an impact under 20cm drop height. Central color change appeared in the fast expansion process. Note that translucency or milky color can often be found in impacted RDX explosive. Hence, the milky-color regions of the large granule and ultra-fine powders connected mutually with each other at 600.03μs. In the end, the condensed area expands and flows rapidly and no burning spot was observed.

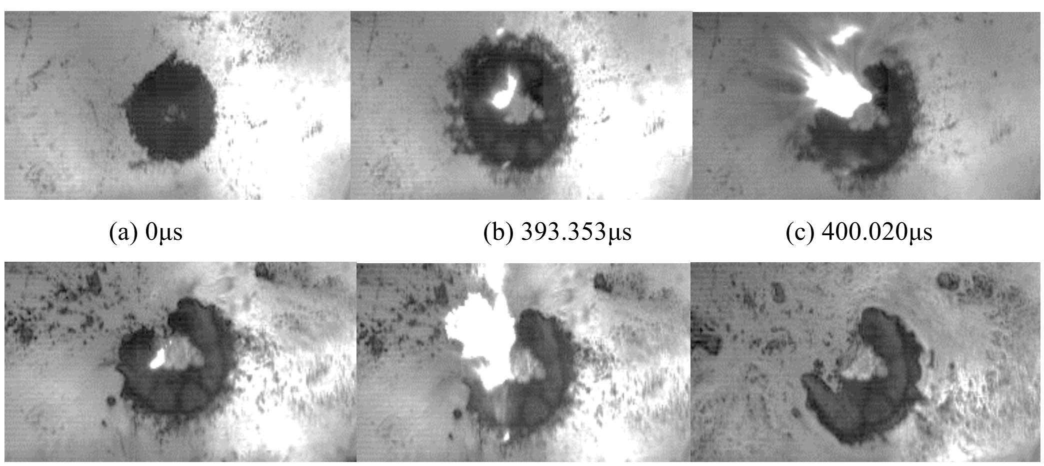


(a) 0μs (b) 266.68μs (c) 600.03μs

(d) 820.041μs (e) 900.045μs

Figure 3. Selected high-speed photographic frames of RDX powder and one RDX granule in response to an impact under 20cm drop height

Selected high-speed photographic frames of HMX powder with one salt granule in response to an 20cm drop-height impact are presented in Figure 4. Translucency arose in the region of salt granule, which is consistent with the result of previous research. The first burning spot occurred at the boundary between powder and granule at 393.353μs, and then quickly extinguished. The second burning spot adjacent to the former one then appeared at 440.022μs. Weak flame still existed after the second round of burning, and eventually disappeared until 620.031μs.

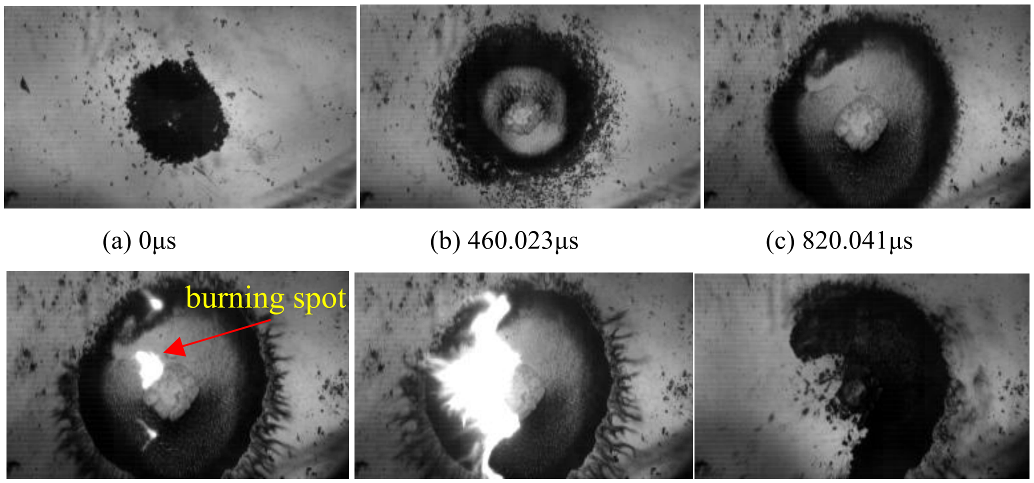


(a) 0μs (b) 393.353μs (c) 400.020μs

(d) 440.022μs (e) 446.689μs (f) 620.031μs

Figure 4. Selected high-speed photographic frames of HMX powder and one salt granule in response to an impact under 20cm drop height

Figure 5 shows the selected high-speed photographic frames of RDX powder and one salt granule in response to an 20cm drop height impact.Condensed region of the mixture experienced rapid flow at 820.041μs following central milky color occurrence. Stripe-like structure which was regarded as micro-shear bands can be observed near the surronding of milky-colored area. One large burning flame spot originated at the interface of broken fragments of large granule at 833.375μs. Burning front developed across the left half side of the sample at 840.042μs.




(a) 0μs (b) 460.023μs (c) 820.041μs

(d) 833.375μs (e) 840.042μs (f) 933.383μs

Figure 5. Selected high-speed photographic frames of RDX powder and one salt granule in response to an impact under 20cm drop height

Burning probability for mixture explosive sample under impact are summarized in Table 2. Ultra-fine HMX powders are more sensitive than ultra-fine RDX powders. It can be seen that no burning was observed by adding RDX granules into RDX powdery explosives, while the burning probability remarkably increased when salt granule was added. For both kinds of explosives, the sensitizing effects of large salt granules are higher than the large explosive granules. This is caused by several reasons: Firstly, NaCl salt is much harder than HMX (or RDX) granule. Stress concentration around the broken salt particle is higher that will lead to higher temperature rise. Secondly, NaCl salt has much higher melting point. Therefore, when localized temperature reaches melting point of the energetic material, salt still remain solid state. Fusing energetic material easily flows into the broken salt fragments. Heat generation due to rapid viscous flow contribute more to hot spots formation.

Table 2: Burning percentage summaries for impact experiments

| Mixture explosive sample | Burning percentage |
|---|---|
| Ultra-fine HMX powders | 2/11 |
| Ultra-fine HMX powders with one large HMX granule | 5/14 |
| Ultra-fine HMX powders with one large NaCl salt granule | 4/8 |
| Ultra-fine RDX powders | 0/11 |
| Ultra-fine RDX powder with one large RDX granule | 0/15 |
| Ultra-fine RDX powders with one large NaCl salt granule | 3/9 |

Interactions between granules and grains of powder is probably one of the most significant factors influencing burning probability. Micro-morphology observation reveals that large granules and powder grains are all irregular in shape, and it's rather rough on the surfaces of granules. When impacted by the drop-weight, granules experience deformation and fracture process leading to innegligible stress concentrations at the location of geometric defects. Meanwhile, tiny powder grains rub on the surface of large granule constantly. The temperature rises rapidly at the junction of powder and granule, which is inclined to induce hot-spots and trigger subsequent burning reaction.

Rapid compression of trapped gas near granules is another important reason for the initiation of burning. Once the ultra fine explosives powders react to produce gaseous products, gas phase is easy to enter into the solid phase gap. Since the salt is inert and has higher melting point than the explosive, the trapped gases adiabatic compression hot-spot mechanism is more prone to play important role around the crushed salt particles. A certain amount of gaps exist among powders and granule when they are mixed together. For the example in Figure 3, the space between powder and the granule was observable in the fast expansion at 533.36μs. Such trapped gas will be compressed rapidly as the loading continues and the temperature rise is dramatic, which enhances the possibility of hot-spots formation.

## 5 Conclusion

The drop-weight impact machine was modified for the high-speed photographic systems to investigate the mechanical and chemical processes. Effects of the large-scale granules for powdery explosives under drop-weight impact have been investigated. Experimental results showed that the mixed explosives are more sensitive than powdery explosives, especially when NaCl salt particles are added, in which case the burning possibility of explosives is greatly increased

Most of burning initiate at the junction of powder and granule. Adiabatic shear bands were frequently observed in the mixture of RDX powder and large granules. This mainly results from the softening effect due to temperature rise around the granules once the broken fragments experience deformation, friction to cause heat accumulation in a short time. .

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