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LOW PRESSURE SHOCK INITIATION OF POROUS HMX FOR TWO GRAIN SIZE DISTRIBUTIONS AND TWO DENSITIES[†]

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Shock initiation measurements have been made on granular HMX (octotetramethylene tetranitramine) for two particle size distributions and two densities. Samples were pressed to either 65% or 73% of crystal density from fine (≈ 10 μm grain size) and coarse (broad distribution of grain sizes peaking at ≈ 150 μm) powders. Planar shocks of 0.2 - 1 GPa were generated by impacting gas gun driven projectiles on plastic targets containing the HMX. Wave profiles were measured at the input and output of the ≈ 3.9 mm thick HMX layer using electromagnetic particle velocity gauges. The initiation behavior for the two particle size distributions was very different. The coarse HMX began initiating at input pressures as low as 0.5 GPa. Transmitted wave profiles showed relatively slow reaction with most of the buildup occurring at the shock front. In contrast, the fine particle HMX did not begin to initiate at pressures below 0.9 GPa. When the fine powder did react, however, it did so much faster than the coarse HMX. These observations are consistent with commonly held ideas about burn rates being correlated to surface area, and initiation thresholds being correlated with the size and temperature of the hot spots created by shock passage. For each grain size, the higher density pressings were less sensitive than the lower density pressings.

INTRODUCTION

The present work is a continuation of our efforts to develop an understanding of the low pressure shock compaction and initiation of highly porous HMX (1-3). References contained in our previous work (1,2) and others (4-7) indicate that the initiation sensitivity for porous explosives is a complex function of density (porosity), particle size, pulse duration, and input pressure. In an effort to determine how these parameters affect the initiation of HMX, we prepared samples with densities of 65% and 73% of TMD, grain sizes varying by more than an order of magnitude (from ≈ 10 μm to ≈ 150 μm) and used input pressures varying from 0.2 - 1 GPa. Sustained pulses were used and the response of the explosive was recorded using particle velocity gauges.

EXPERIMENTAL DETAILS

Description of HMX Powders

Two different lots of HMX powder with two different particle size distributions were used in this series of experiments. One powder was composed of "coarse" particles which had the appearance both to the naked eye and under a microscope of granulated sugar. This HMX was made by Holston (Lot HOL-920-32) and had a bulk or pour density of ≈ 1.16 g/cm^3 (8). The material was screened to eliminate agglomerates and a few of the largest particles. Sieve analysis of the powder done by Dick (8) is given in Table 1 and shows a broad particle size distribution with a peak near 150 μm. All the crystals have sharp corners and edges.

TABLE 1. Particle Size Distribution for "Coarse" HMX, Holston Lot 920-832.

Sieve Opening μm	500	350	250	177	125	88	62	44	Subsieve
Weight % Retained on Sieve	1.3	4.0	15.6	18.2	27.8	11.8	12.1	4.9	4.3

[†] Work performed under the auspices of the U.S. Dept. of Energy.

The second powder, whose size distribution is shown in Table 2, was composed of "fine" particles and had the appearance of powdered sugar. This HMX was also manufactured by Holston (Lot HOL-83F-300-023) and also had a bulk or pour density of ≈ 1.16 g/cm^3. The particle size at the peak of the distribution is about 10 μm. Particle sizes were determined by Microtrac analysis. The mean particle size of the coarse and fine HMX is different by a factor of more than 10. Photographs show that this powder also contains an occasional large particle with a diameter of ≈ 50 μm. The rounded appearance of the particles indicates that this material was probably prepared by milling.

Gas Gun Experimental Setup

The experimental setup for the initiation experiments is shown in Figure 1. Experiments used gas gun driven projectiles to obtain sustained-shock input conditions. HMX powder was confined in sample cells which had a polychlorotrifluoro-ethylene (Kel-F) front face and a poly 4-methyl-1-pentene (TPX) or polymethylmethacrylate (PMMA) cylindrical plug back. The front face was attached with screws to a Kel-F confining cylinder with an outside diameter of 68.6 mm and an inside diameter of 40.6 mm. The pressed HMX (between the Kel-F and TPX) was ≈ 3.9 mm thick. The back plug was pressed into the Kel-F confining cylinder and held in place with an interference fit. Projectiles faced with Kel-F impacted on the Kel-F target face.

Magnetic particle velocity gauges were located on the front and back surfaces of the HMX. These were constructed of a 5 μm thick aluminum "stirrup" shaped gauge on a 12 μm thick FEP Teflon sheet. The active region of the gauge was 10 mm long. Particle-velocity histories were measured at both the front and back of the HMX sample. The gauge at the interface of the Kel-F front disk and HMX gives the input or loading profile. The gauge at the interface of the back plug and HMX gives the transmitted wave profile. The transmitted wave profile is not equivalent to what would be observed if the gauge was suspended in the HMX powder because of the impedance mismatch between the HMX and the plastic back plug. However, it is representative of the transmitted wave profile and gives a reasonable

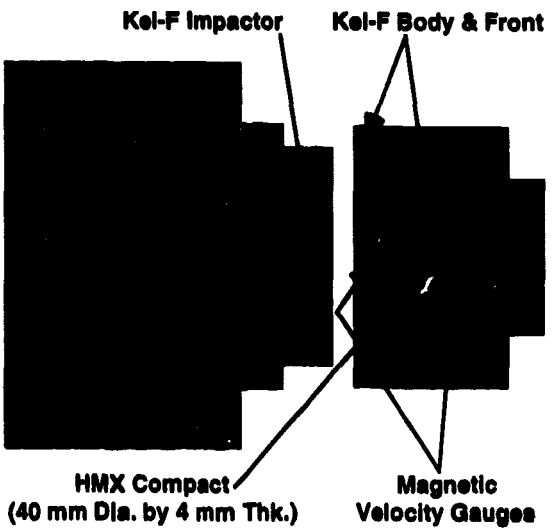

FIGURE 1. Cross section view of the projectile and target.

estimate of the rise time. Wave profiles were recorded on fast digitizing oscilloscopes.

RESULTS

A total of sixteen experiments were performed; four each for each of the two particle size distributions and for each of the two nominal densities. The nominal densities used were 1.24 g/cm^3 or 65% TMD (35 % porous) and 1.40 g/cm^3 or 73% TMD (27 % porous).

Figure 2 shows wave profiles for four experiments. The projectile velocities on these experiments were very close to the same at ≈ 0.6 mm/μs, resulting in an input to the HMX of ≈ 0.72 GPa. Complete results for the entire series of experiments will be presented elsewhere. With this input, the coarse HMX (Fig. 2a and 2c) begins to react as soon as the wave passes the front gauge and enters the powder. The front particle velocity decreases because the reacting HMX is decelerating the cell front where the gauge is located. Stress measurements show the stress at this interface increasing (1,2). The transmitted wave is growing and steepening up considerably. By the time the wave reaches the back of the HMX, the particle velocity has doubled. There appears to be a little

TABLE 2. Particle Size Distribution for "Fine" HMX, Holston Lot 83F-200-023

Particle Diameter μm	> 45	25.1	17.7	12.5	8.9	6.3	4.4	3.1	2.2	1.3	0.8	0.6
Weight % of Particles	6	8.3	10.3	11	15.8	12.5	11.3	9.5	5.8	5.0	3.0	1.5

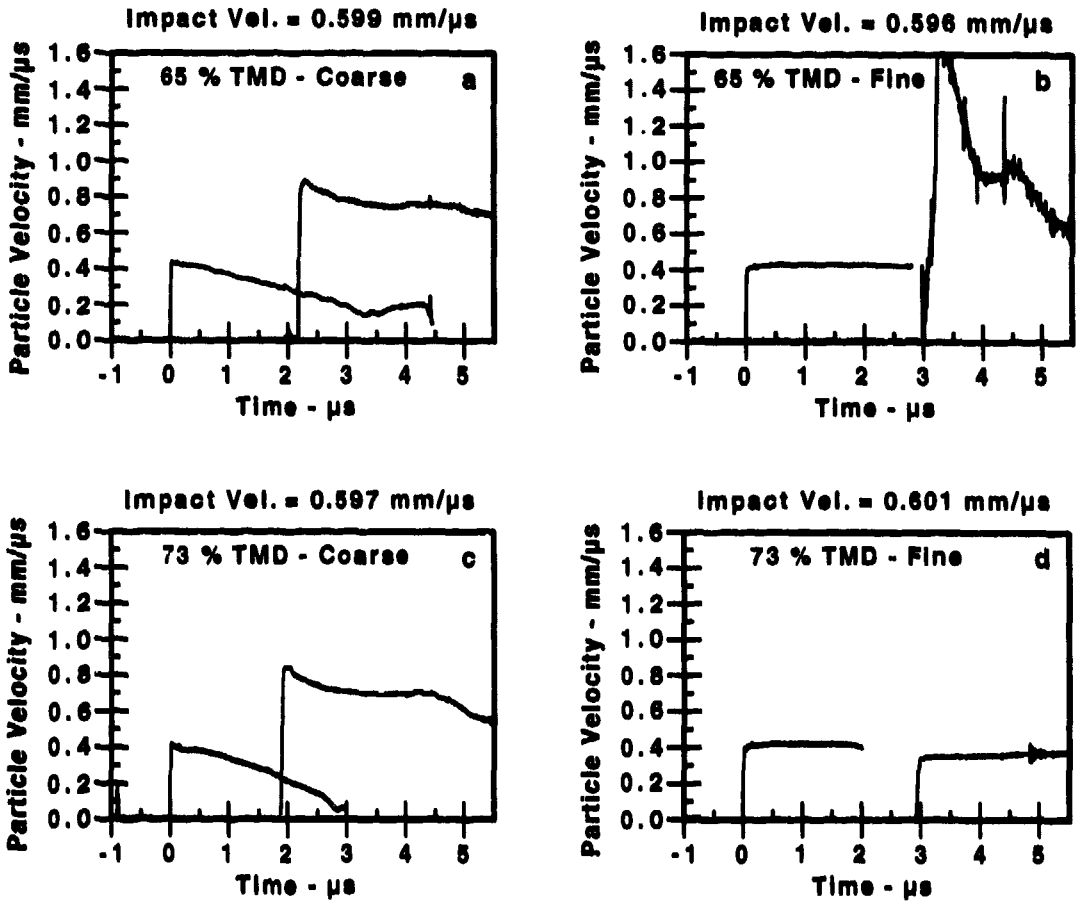

FIGURE 2. Input and transmitted particle velocities in porous HMX compacts. All the samples were about 3.9 mm thick. (a) 1.24 g/cm^3 (65% TMD), "coarse" particle powder. This experiment had a TPX back disk. (b) 1.24 g/cm^3 (65% TMD), "fine" particle powder. This and items c and d shown in this panel had a PMMA back disk. (c) 1.40 g/cm^3 (74% TMD), "coarse" particle powder. (d) 1.40 g/cm^3 (74% TMD), "fine" particle powder.

more reaction in the 1.24 g/cm^3 (Fig. 2a) than the 1.40 g/cm^3 (Fig. 2c) coarse material.

In this regime of 0.5-1 GPa, the reactivity of the fine particle HMX differs greatly from that of the coarse particle HMX. In these ≈ 0.72 GPa input experiments in particular, there is no reaction evident in the front gauge profile at either density for the fine HMX. (See Figs. 2b and 2d.) The transmitted wave profile in the 1.40 g/cm^3 fine powder (Fig. 2d) also shows no reaction.

The transmitted wave profile in the 1.24 g/cm^3 fine particle powder (Fig. 2b), however, shows a great deal of reaction. After the wave reflects off the back PMMA disk, the initial ≈ 0.72 GPa pressure in the HMX is approximately doubled. There is no reaction for several tens of nanoseconds. Then reaction begins and proceeds very rapidly. We have estimated this reaction to be more than 10 times more rapid than that shown by the input gauge in the coarse HMX.

DISCUSSION

From the four experiments shown in Figure 2 and others like it but at different inputs, we have drawn the following conclusions. Reaction (reactivity) depends slightly on density for both the fine and coarse particle HMX. In general the higher density HMX seems to be less sensitive. This is what might be expected from looking at the energy deposited during compaction. Less energy is

deposited in the higher density material for a given input pressure.

Reactivity depends a great deal on the initial particle size. For the coarse particle material, reaction occurs immediately when inputs are above 0.7 GPa. We have observed reaction begin at the front gauge with inputs as low as 0.5 GPa (after an induction time of several hundred ns). The fine particle HMX, by contrast, does not show any reaction at inputs less than ≈ 0.72 GPa at either the front gauges or in the higher pressure transmitted and reflected waves. With ≈ 0.72 GPa inputs and above, there is evidence of reaction, but only after the wave has reflected off the back PMMA disk and the pressure is approximately doubled. This reaction, which occurred only in the lower density powder, had a short induction time and was extremely rapid.

In addition to these features, the wave profile characteristics of initiating coarse and fine particle explosives are different. Jerry Dick's Manganin gauge measurements on coarse HMX (65 % TMD) for inputs of 0.81 GPa and thicknesses of 2, 3, and 4 mm, clearly show the wave growing in the front as the wave traverses the HMX compact (9). This is seen also in our more than doubled particle velocity at the back gauge (Figs. 2a and 2c). By contrast, run distance to detonation measurements in very fine particle HNS powders (nominal particle size 1-2 μm) showed strong velocity overshoots at the onset of detonation (4). These results suggested that a reactive wave developed well behind the shock front and caught up during the transition to detonation. This is similar to the mechanism by which a homogeneous explosive builds up to detonation (10). Thus, coarse particle explosives have a growing reactive wave at the shock front while fine particle explosives likely have a growing reactive wave behind and eventually overtaking the shock front.

These observations are generally explained in the following way. Most hot spot reaction theories indicate that the size of a hot spot is very nearly the size of a particle or of a void. Large particles thus lead to large hot spots. The initial temperature of the hot spot is scaled by the shock pressure. Large hot spots would cool slowly enough that they could begin reacting, even if the hot spot temperature was fairly low. The following reaction is relatively slow because the large particles don't have much surface area. By contrast, the small particles lead to small hot spots. These small hot spots cool more rapidly. Thus it takes higher pressures and higher hot spot temperatures to get the fine grained explosive to ignite before the hot spot cools. Once ignited, however, the reaction is relatively fast because the small particles have a large amount of surface area.

ACKNOWLEDGMENTS

Mr. J.G. Archuleta obtained the particle size distribution for the fine HMX shown in Table 2.

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