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POROUS HMX INITIATION STUDIES – SUGAR AS AN INERT SIMULANT†

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For several years we have been using magnetic particle velocity gauges to study the shock loading of porous HMX (65 and 73% TMD) of different particle sizes to determine their compaction and initiation characteristics. Because it has been difficult to separate the effects of compaction and reaction, an inert simulant was needed with properties similar to HMX. Sugar was selected as the simulant for several reasons: 1) the particle size distribution of C & H granulated sugar is similar to the coarse HMX we have been using (120 μm average size), 2) the particle size of C & H confectioners (powdered) sugar is similar to the fine HMX in the studies (10 μm average size), 3) it is an organic material, and 4) sugar was readily available. Because the densities of HMX and sugar are somewhat different, we chose to do the experiments on sugar compacts at 65 and 73% TMD. As expected, no reaction was observed in the sugar experiments. Compaction wave profiles were similar to those measured earlier for the HMX, i.e., the compaction waves in the coarse sugar were quite disperse while those in the fine sugar were much sharper. This indicates that the compaction wave profiles are controlled by particle size and not reaction. Also, the coarse sugar gauge signals exhibited a great deal of noise, thought to be the result of fracto-emission.

INTRODUCTION

We have been studying porous cyclotetramethylene tetranitramine, HMX, at two densities (65 and 73% theoretical maximum density [TMD]) to determine the low level shock response (less than 1 GPa) of this material to help calibrate computational models being developed in the deflagration-to-detonation transition (DDT) area. Experiments have been carried out in which particle velocity and stress on both sides of an HMX compact were measured so that the stress-particle velocity mapping could be made directly(1,2). From this diagram, it was possible to make estimates of the reaction rate at various input levels. An equation of state was developed for porous HMX that allowed calculation of the Hugoniot at various densities.

Later work involved studies on two different batches of HMX with different particle sizes,(3) one which was called "coarse" HMX, with a mean particle size of about 120 μm, and the other called "fine" HMX, with a mean particle size of about 10 μm. The behavior of these two batches of HMX was quite different, with the coarse material having more disperse transmitted waves and more reaction at lower shock input levels than the fine material. Because reaction and wave dispersion were both occurring at the same levels of input, it was important to find an inert substitute for the HMX so the effects of these two things could be independently determined.

While considering several possible materials, it was determined that granulated sugar had a particle size distribution similar to the coarse HMX and confectioners (powdered) sugar was quite similar to

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the fine HMX. Based on this, sugar was chosen as the inert simulant without really worrying about the crystal strength and breakage characteristics.

This paper reports measurements of the shock response of porous sugar compacts (at 65 and 73% TMD) to low level shock inputs (less than 1 GPa).

EXPERIMENTAL DESIGN

C & H brand sugar was selected as the HMX simulant for several reasons: 1) the particle size distribution of C & H granulated sugar was found to be similar to the coarse HMX we used in previous studies (120 μm average particle size) (see Fig. 1), 2) the particle size of C & H confectioners (powdered) sugar was found to be similar to the fine HMX in the studies (10 μm average particle size), 3) sugar is an organic material, and 4) C & H brand sugars were available and some particle size data were available from the company. The crystal density of sugar (1.59 g/cm^3) is less than that of HMX (1.90 g/cm^3) so the material was loaded at the same percentage of TMD as the HMX, namely 65% (1.03 g/cm^3) and 73% (1.15 g/cm^3) TMD. Although pictures of the fine materials are not shown, they were also similar. Information relating to the crystal strength of the two materials was not compared. However, as will be discussed later, some of the crushing properties appear to be similar.

The experimental design for this study was the same as in the earlier studies(1-3). Magnetic "stirrup" particle velocity gauges were attached to the plastic cell front and cell back in contact with the sugar compact so both the input particle velocity and the wave interacting with the cell back were measured. Using this technique, the input to the sugar was accurately determined and the tendency of the wave to spread out was also measured.

It should be noted that confectioners sugar has 3% corn starch added to it to keep the sugar particles from agglomerating. The effect of this on these experiments is unknown at this time.

Gas-gun-driven experiments were conducted; i.e., a projectile faced with polychlorotrifluoroethylene (Kel-F) impacted a Kel-F cell containing the sugar. This is shown schematically in Fig. 2.

Sugar powder was pressed and confined between the Kel-F front face and a polymethylmethacrylate (PMMA) cylindrical plug back. Nylon

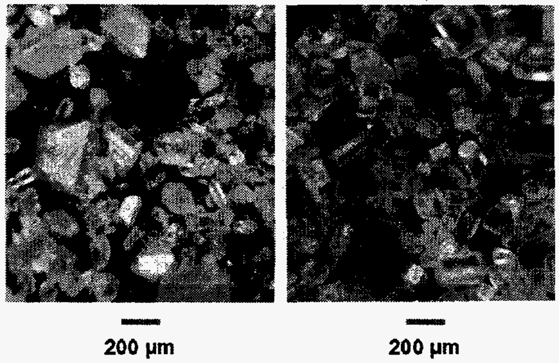

FIGURE 1. Pictures of the HMX (left side) and granulated sugar (right side) showing that the particle size of the two batches are similar. The HMX particles are typically diamond shaped while those of the granulated sugar particles are typically cubic.

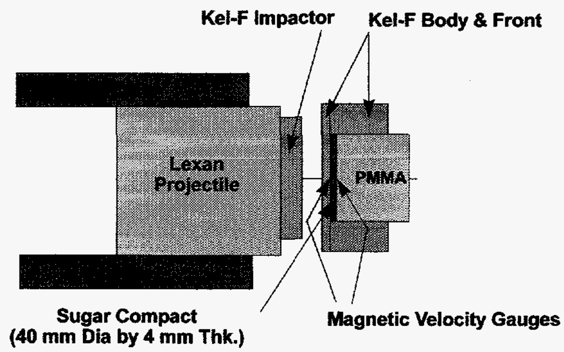

FIGURE 2. Schematic of the sugar experiments. Kel-F cell was impacted by a Kel-F faced projectile. Stirrup magnetic gauges were located on both sides of the sugar compact. Stirrup gauges are single element gauges with a 10-mm long active end that is situated perpendicular to the magnetic field lines.

screws were used to attach the cell front to a Kel-F confining cylinder body (O.D. 68.6 mm and I.D. 40.6 mm). The back PMMA plug was pressed into the Kel-F confining cylinder and held in place with an interference fit. The pressed sugar compact was ≈ 4-mm thick. The magnetic "stirrup" gauges on both sides of the sugar compact were each composed of a 5-μm-thick aluminum stirrup-shaped gauge on a 12-μm-thick FEP Teflon sheet which was glued to the front and back cell pieces.

Magnetic gauging work was started at Los Alamos by Vorthman and Wackerle in about 1980 (4), setting the stage for the magnetic gauge work done at Los Alamos since then.

RESULTS AND DISCUSSION

Eleven experiments were completed in this study; six on coarse sugar and five on fine sugar.

The nominal densities were either 1.03 g/cm^3 (65% TMD) or 1.14 g/cm^3 (73% TMD). Data obtained from these experiments were surprisingly similar to that obtained for HMX in the earlier studies; the only difference was that no evidence of reaction was observed. In the case of the granulated (coarse particle) sugar, the transmitted waves were disperse in the same way that the coarse HMX waveforms were disperse. This is shown in Fig. 3 for the lower density (65% TMD) HMX and sugar experiments.

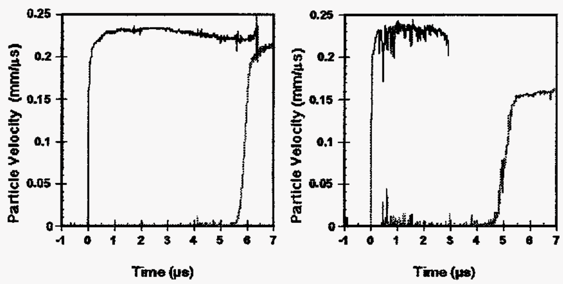

FIGURE 3. Particle velocity waveforms for coarse HMX (left side) and C & H granulated (coarse) sugar (right side). The shock transmission times through the compacts are quite close with the sugar being slightly faster. The transmitted waves are disperse, each with risetimes > 0.5 μs. Impact velocities were 0.288 mm/μs (HMX Shot 912) and 0.295 mm/μs (sugar Shot 1015).

The fine particle (confectioners) sugar experimental waveforms were similar to those obtained in the fine particle HMX experiments. The transmitted wave had a risetime of ≈ 100 ns, indicating that similar phenomena occur both in HMX and sugar. Comparable HMX and sugar waveforms are shown in Fig. 4 for the lower density (64% TMD).

Since the waves move through the sugar faster than through the HMX for both particle sizes, the sound speed in the sugar may be higher than in the HMX. This remains to be experimentally verified.

The sugar waveforms at low input stresses for the two different particle sizes are quite similar to the corresponding HMX waveforms. This indicates that sugar is a good inert simulant for the HMX in that similar processes are obviously occurring in other materials. At the higher input stresses (above about 0.6 GPa) there is reaction in the HMX. One of the input conditions that resulted in considerable reaction in coarse HMX at the lower density (65% TMD) is shown on the left side in Fig. 5. The HMX waveforms are affected a great deal by reaction. Shown on the right side are

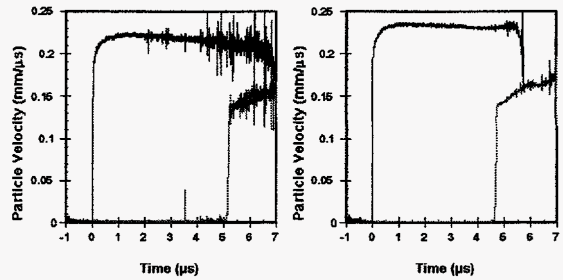

FIGURE 4. Particle velocity waveforms for fine HMX (left side) and C & H confectioners (fine) sugar (right side). The shock transmission times through the compacts are quite close with the sugar being slightly faster, the same as in the coarse materials. The transmitted waves have risetimes of ≈ 100 ns. Impact velocities were 0.279 mm/μs (HMX Shot 982) and 0.299 mm/μs (sugar Shot 1020).

corresponding coarse sugar waveforms showing no reaction at all, i.e., this what the HMX waveforms would have looked like with no reaction present. It is now easy to see that the reaction in the HMX is causing the input particle velocity waveform to decrease as a function of time (due to reaction products pushing back on the cell front) and the transmitted wave has grown a great deal as a result of reaction occurring at or near the wave front. Input to the HMX in this experiment was ≈0.8 GPa.

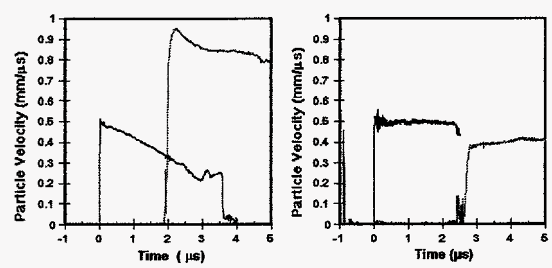

FIGURE 5. Particle velocity waveforms for coarse HMX (left side) and C & H granulated (coarse) sugar (right side). The shock transmission time through the HMX is faster because of the reaction and the wave front buildup. Obviously the HMX waveforms result from reaction occurring in the HMX compact. Impact velocities were 0.696 mm/μs (HMX Shot 913) and 0.700 mm/μs (sugar Shot 1017).

The disperse nature of the transmitted waves measured in the sugar experiments was similar to that previously measured in HMX. This is best illustrated by plotting risetime data as shown in Fig. 6. The risetime of the transmitted wave in each experiment is plotted vs. the projectile impact velocity for that experiment. Risetimes for the sugar are slightly longer than those of HMX and they appear to decrease at slightly higher input velocities. This is probably suggesting there are differences in the crystal strength or crushing characteristics of the sugar and HMX crystals. However, the fact that the behavior was very nearly the same was encouraging. It indicates that in both the sugar and HMX, the particle size controls the wave dispersion, presumably due to the crystal crushing/breakage processes involved in the transmitted wave.

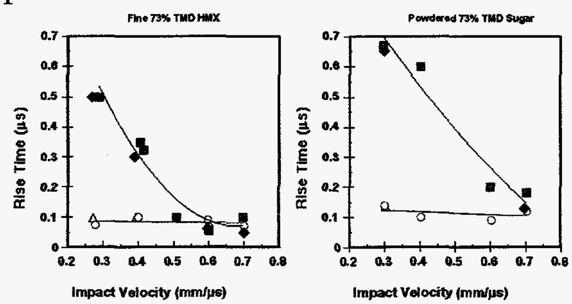

FIGURE 6. Transmitted wave risetime data for the HMX (left side) and sugar (right side) experiments. Data from experiments at both densities ant both particle sizes are shown on each side. Shaded squares are 65% TMD "coarse" materials, shaded diamonds are 73% TMD "coarse" materials, open circles are 65% TMD "fine" materials, and open triangles are 73% TMD "fine" materials.

It is clear that the risetime is not closely associated with density but is directly associated with particle size for both materials.

A difference between the two materials that was substantial was the amount of electrical noise associated with the crystal crushing/breakage process occurring as the wave moved through the compact. Noisy records were not a problem in the HMX experiments. However, all the coarse sugar wave profiles had to be smoothed in order to obtain the average particle velocity waveform. This is shown in Fig. 7 for an experiment on coarse sugar (65% TMD) in which the input to the sugar was ≈ 0.28 GPa. The original data are shown (noisy), along with the smoothed waveform.

This noise indicates that the crushing/breakage process in sugar includes "fracto-emission" to a greater extent than does HMX. This phenomena has been studied in sugar and explosive crystals by Dickinson and coworkers at Washington State Univ. during the 1980s (5-7). They believe the noise is related to photons, electrons, positive ions, etc., being emitted as part of the crystal fracture process. We observed this noise in the coarse sugar but not the fine sugar. This could be because the electrical signals were too small to measure or that compaction in the fine material proceeds by a mechanism other than crystal fracture.

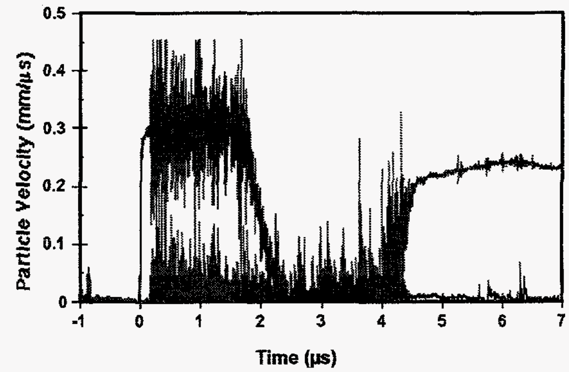

FIGURE 7. Particle velocity waveforms from coarse sugar Shot 1014 with an impact velocity of 0.4 mm/µs. Both the original record and the smoothed record are shown. Notice that the noise stops as soon as all the crushing is complete, i.e., the transmitted wave reaches near the maximum particle velocity in the back gauge.

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