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TITLE: STRESS-TIME PROFILES, HUGONIOT, AND SHOCK SENSITIVITY DATA FOR 1-GPa SHOCKS IN LOW-DENSITY HMX (OCTOGEN) EXPLOSIVE

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Stress-Time Profiles, Hugoniot, and Shock Sensitivity Data for 1-GPa Shocks in Low-Density HMX (Octogen) Explosive

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ABSTRACT

Using manganin gauges, plane-wave stress-time profiles were obtained for HMX explosive with 35% voids. Profiles were taken at several sample thicknesses for input stresses near 1 GPa. The objective was to observe the effect of the porosity on the compacting and initiating wave. The character of the initiation build-up is different from that seen in full-density explosives. Profiles in PBX 9404 were taken for comparison. These profiles should provide a good test for 1-D modeling of the compaction and initiation processes. Hugoniot and Pop-plot data for the pour-density HMX will also be presented.

INTRODUCTION

This is a study on an explosive with high void content. This means that extensive void collapse and compaction processes will go on when stress waves travel through a bed of such material. It would be of interest to know how this compaction process affects the wave. One might expect that it would cause considerable wave dispersion. Furthermore, it would be of interest to know the nature of the process of initiation of detonation under these conditions. Does it differ from the behavior seen in high density materials? Based on these considerations it seemed worthwhile to make measurements with manganin gauges of plane shock waves propagating HMX with high void content.

EXPERIMENTAL WORK

The shock waves were generated in the samples by explosively driven systems. The samples were mounted on a 305-mm-diam explosive system consisting of a plane-wave lens, 25 mm baratol, 25 mm brass, 25 mm PMMA, 19 mm brass, and 13 mm PMMA. The stress wave emerging from the system has an amplitude of 1.18 GPa in PMMA. This driving system was characterized in previous work.[1] In that work on HMX with 35% voids the input stress into the HMX was 0.81 GPa and the estimated run distance to detonation was 5.2 mm. Particle size distribution is given in Table I. Hugoniot and Pop-plot parameters determined in that work are given in Table II. These data were obtained from transit time measurements (Ref. 1). The results in the shock velocity vs particle velocity plane is shown in Fig. 1. Results of a Gruneisen calculation of the Hugoniot are also shown. The results are shown in the P-V plane in Fig. 2. Note that compression to solid density is not achieved even at 2 GPa.

A schema of the sample and gauge measurement positions is shown in Fig. 3. The 2-lead, 50-Ω manganin foil gauges (Micromeasurements VM-SS-210AW-048) were placed in PMMA, either 0.75 mm in front of or to the rear of the sample. This is a conservative design to prevent extraneous resistance changes caused by compaction of the porous bed directly against the gauge. The manganin gauge data were obtained and analyzed in the manner described in Ref. 2.

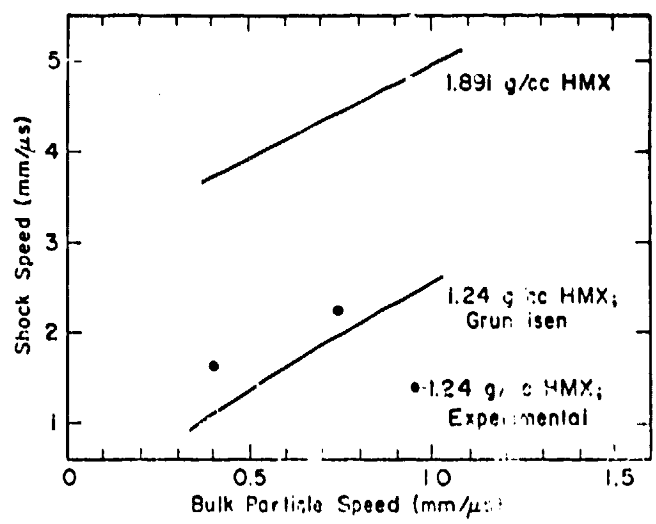

Fig. 1. Hugoniot data for HMX.

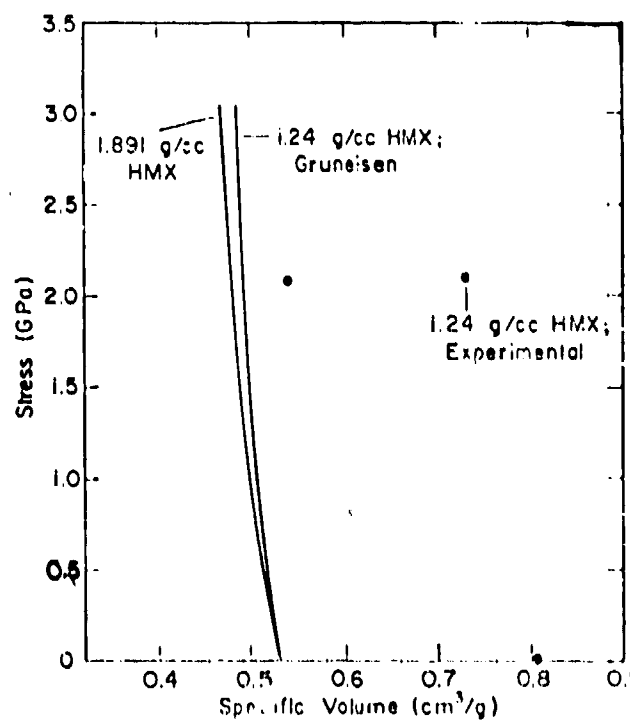

Fig. 2. P-V data for HMX.

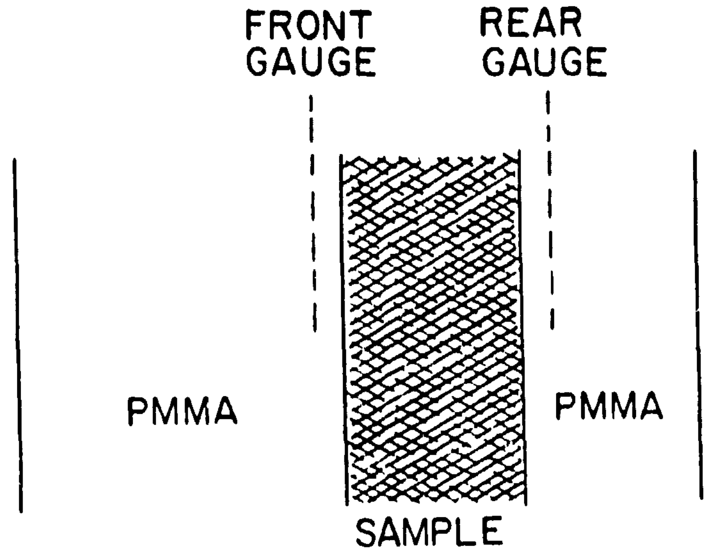

Fig. 3. Schema of the sample and gauge configuration. The manganin gauges are 0.75 mm from the sample. The shock moves from left to right.

Table I. Particle Size Distribution for Grade II Class A HMX[a]

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

[a]Specific surface area = 2260 cm^2/g.

Table II. Hugoniot and Pop-plot parameters[a] for HMX.

ρ_o g/cm^3	C mm/μs	S	a	b
1.24	0.88	1.82	4.5	-0.56
1.89	2.90	2.06	100	-1.69

[a]The parameters are defined by $U = C + S\,u$ and $x^* = aP^b$, where U is shock velocity, u is particle velocity, x^* is run distance to detonation and P is bulk input stress into the sample.

Figure 4 shows the results for a shot in HMX at a density of 1.24 g/cm^3 and a sample thickness of 2.1 mm. The profiles are for gauges in front of and to the rear of the sample. The front gauge registers the incident wave in PMMA for 0.47 μs. The measured peak amplitude is 1.14 GPa vs 1.18 GPa, calculated from known Hugoniots. The shock is not sharp in PMMA, because there is a yield point in this viscoplastic material at 0.75 GPa.[3] Appearing next is the rarefaction returning from the interface. This bulk interface stress appears as 0.68 GPa as compared to 0.81 GPa calculated from the Hugoniots obtained from previous transit-time measurements.[1] (If instead of using all the transit time data in Ref. 1, only the transit time through the thinnest sample is used in computing the shock velocity, a stress level of 0.73 GPa is calculated.) The stress level holds steady for over 1 μs, then rises, probably because of HMX decomposition. The transmitted wave front recorded on the rear gauge has some structure and a hump caused by heat release from decomposition in the following flow; measured wave amplitude is 1.1 GPa. An approximate impedance-match solution predicts 1.23 GPa for the state with no reaction, so initial and transmitted measured shock states are 10 to 16% lower than estimates. The true values may lie somewhere in between. From this shot we can conclude that extensive decomposition does not begin immediately in this HMX.

Figure 5 includes records for samples 3.1 and 4.0 mm thick. Wave front growth is strong, and a reactive peak is developing at the front; the stress is falling behind the shock front. From the shock-change equation we know that this means that wave growth is being driven by heat release due to decomposition at the wave front.[4] This wave growth with a reactive peak is not seen in initiation of full density propellants and explosives.[5-7] It is a result of the work done in compacting the porous material. This work is converted locally to heat and leads to prompt decomposition. An elementary mixture calculation implies about seven percent decomposition for both data points in Fig. 2. It must be noted that for previous manganin gauge measurement results in PETN with 21% voids the shock buildup was similar to that seen in full density explosives and propellants with no reactive peak at the shock front.[8] This may be understood in terms of the single-curve-buildup model.[9] The porous PETN Pop plot lines have slopes similar to full density PETN.[10] On the contrary, HMX with 35% voids has a much smaller slope magnitude than full density HMX (Table II). This smaller magnitude in turn implies earlier buildup of the shock strength within the context of the single curve buildup model (Fig. 6). The equation for common-curve buildup is

$$U = \frac{C}{2}[1 + (1 + \frac{4S}{\rho_o C^2}(\frac{X}{a})^{1/b})^{1/2}] \quad ,$$

where the parameters are specified in Table II and Fig. 6. Figure 6 shows the earlier buildup in the porous HMX. This shock strength buildup can also be seen in Fig. 5; two millimeters before detonation transition the shock stress is more than triple the input stress. The fact that the 1.24 g/cm^3 HMX does not compress to solid density is additional evidence for decomposition at the shock. One can interpret this as evidence that the void structure becomes filled with decomposition product gases which then resist the compaction process.

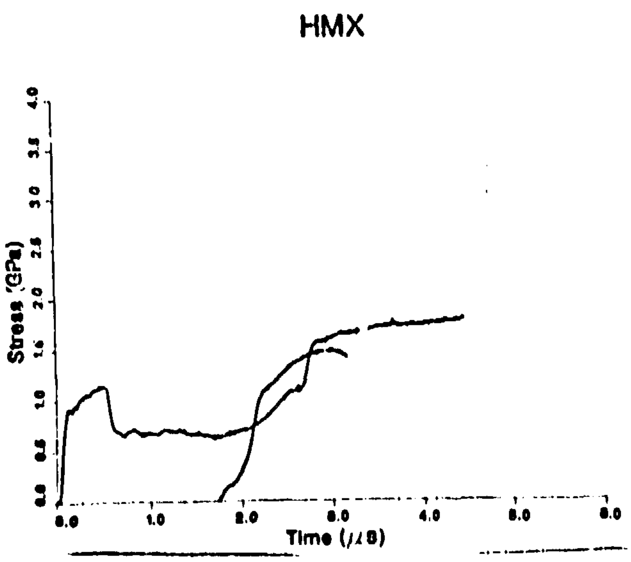

Fig. 4. Input and transmitted profiles for a 2.1-mm-thick sample of 1.24 g/cm^3 HMX.

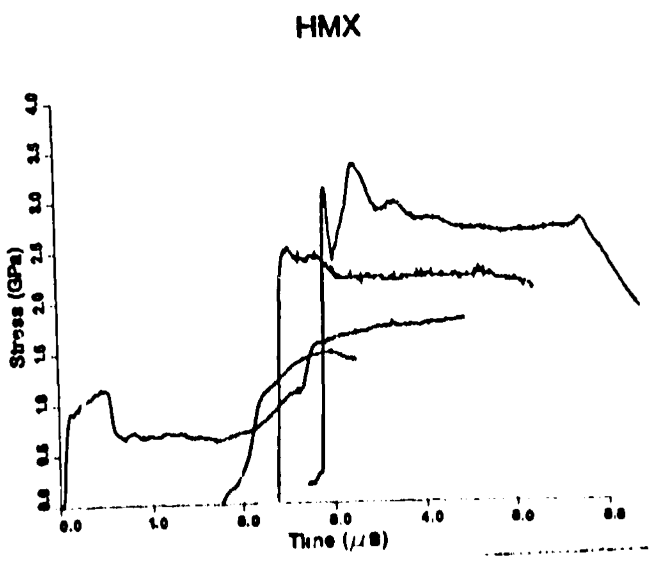

Fig. 5. In addition to profiles in Fig. 2, transmitted profiles for samples 3.1 and 4.0 mm thick are included. Run distance to detonation is 5.2 mm.

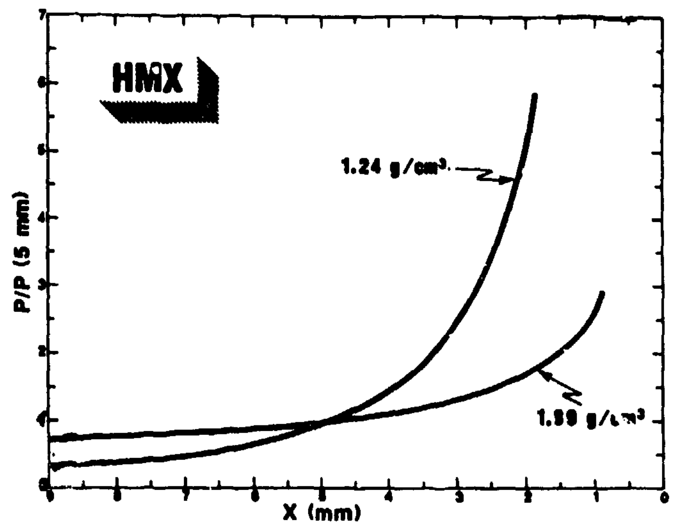

Fig. 6. Common-curve buildup for two densities of HMX.

PBX 9404

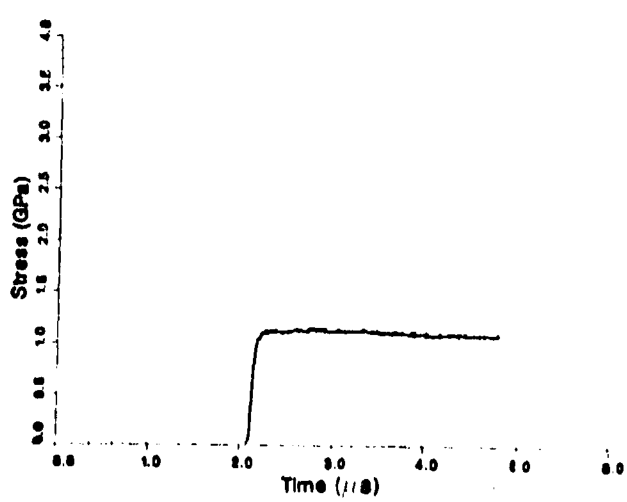

Fig. 7. Transmitted profile for a PBX 9404 sample 6.4 mm thick.

For comparison, Fig. 7 shows a record for a PBX 9404 sample 6.4 mm thick. Peak stress for the transmitted wave is 1.11 GPa, comparing very well with 1.12 GPa computed for the shot. The front is fairly sharp with little residual effect of the shape of the PMMA input wave dispersion. There is no evidence of decomposition.

CONCLUSION

In full density explosives (Fig. 8) the shock growth is due to the rising stress behind the front. From the shock change equation we know that the shock strength can grow either from the stress gradient or from heat release at the shock front. In the porous energetic materials studied here, this latter mechanism is observed in the later stages of shock initiation. The extra work of compression of the porous material is converted into localized heat, leading to partial decomposition at the shock.

ACKNOWLEDGMENTS

A critical reading of the manuscript and helpful suggestions by J. D. Wackerle are greatly appreciated.

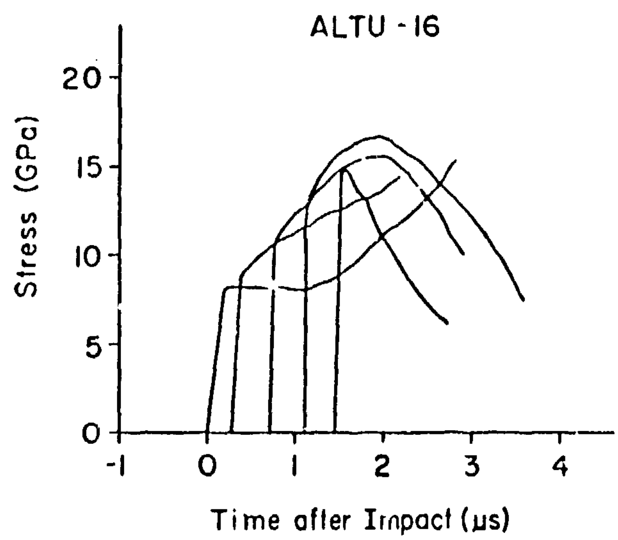

Fig. 8. Manganin gauge records in ALTU-16 propellant. First gauge is on interface between copper flyer and ALTU-16. Subsequent gauges were embedded at 2, 4, 6, and 8 mm. Run to detonation is 10 mm. (From Ref. 4)

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