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EFFECT OF SHOCK PRECOMPRESSION ON THE CRITICAL DIAMETER OF LIQUID EXPLOSIVES

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Abstract. The critical diameter of both ambient and shock-precompressed liquid nitromethane confined in PVC tubing are measured experimentally. The experiment was conducted for both amine sensitized and neat NM. In the precompression experiments, the explosive is compressed by a strong shock wave generated by a donor explosive and reflected from a high impedance anvil prior to being detonated by a secondary event. The pressures reached in the test sections prior to detonation propagation was approximately 7 and 8 GPa for amine sensitized and neat NM respectively. The results demonstrated a 30% - 65% decrease in the critical diameter for the shock-compressed explosives. This critical diameter decrease is observed despite a significant decrease in the predicted Von Neumann temperature of the detonation in the precompressed explosive. The results are discussed in the context of theoretical predictions based on thermal ignition theory and previous critical diameter measurements.

Keywords: Critical diameter, nitromethane, superdetonation, shock precompression.
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INTRODUCTION

The critical diameter of an explosive has previously been shown to be highly dependant on the initial state of the explosive [1]. Small variations in initial temperature cause drastic changes in the critical diameter of nitromethane (NM) and other liquid explosives (NG, TNT) [1-3]. These changes in critical diameter have been attributed to the temperature sensitivity of the reaction kinetics in the detonation front.

In the present study, the explosive will be shock compressed and subsequently a detonation will propagate through the explosive at this shocked state. Past studies have focused on the effects of shock compression on the initiation of reaction in NM [4]. This study looks at the propagation of a detonation through a previously shocked explosive.

EXPERIMENTAL DETAILS

Two sets of experiments were conducted in this study. The first used sensitized NM (3% DETA by weight) and the second used neat NM. The experimental design was based on the experiments conducted by Petel et al. [5] and can be seen in Fig. 1. In all experiments, the donor and test explosive are the same explosive.

In the experiments involving sensitized NM, the donor explosive was 75 mm in diameter and 100 mm in height. The donor capsule was positioned on a PVC attenuator disk that was 165 mm diameter and 19 mm in height. In contact with the attenuating disk was a 152 mm internal diameter PVC test capsule, 25 mm in height. The test capsule had a transparent PVC tube running across its diameter, the diameter of which was varied in order to determine the critical diameter.

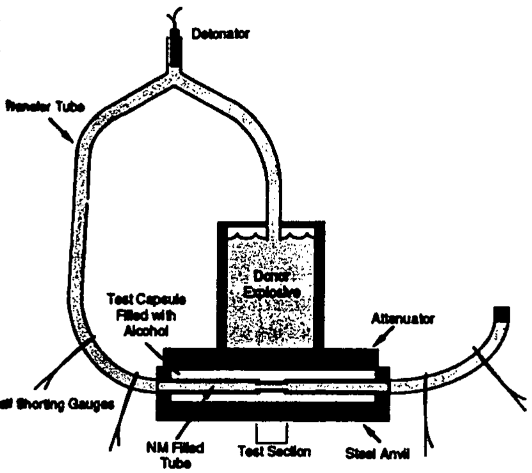

Figure 1. Cross-sectional schematic of the experimental setup used.

The section with the varied diameter was considered to be the test section. The test capsule surrounding the PVC tube was filled with denatured alcohol, which was used for its transparency under shock compression and acted as a hydrostatic bath on the time scale of the experiments. The test capsule was bounded on the bottom by a steel anvil. There was a 1.6 mm slit in the steel anvil, which was also filled with denatured alcohol and provided optical access to the experimental test section.

The setup of the experiments involving neat NM had the same components as the setup described above, only the scale was larger. For these experiments the donor explosive was 150 mm in diameter and 225 mm in height. The PVC attenuator disk had a 206 mm diameter and was 19 mm in height. The PVC test capsule was 32 mm in height, 203 mm in diameter and was filled with water instead of alcohol. Once again the diameter of the tube crossing the test section was varied to find the critical diameter. The steel anvil at the base of the test capsule was 50 mm thick. There was no slit in this steel anvil.

The experiments began with the initiation of a detonation in the tube filled with the explosive. The initial tube branched into two separate tubes. The first tube entered the donor capsule, initiating the donor explosive. The detonation in the donor explosive transmitted a shock wave into the attenuating disk which then entered the test capsule, compressing the PVC tube containing the test explosive. The shock wave then reflected from the high impedance steel anvil, further compressing the test section.

Meanwhile, the detonation in the transfer tube propagated the full length of the tube and entered the test section as the shock reflection from the steel anvil occurred. The detonation propagated into the test section which remained at the highly compressed state. The dimensions of the charges were determined by the requirement that rarefaction waves from the sides of the capsule or bottom of the anvil do not penetrate the test section on the timescale of the experiment.

For the sensitized NM experiments, data was collected with streak photography as well as self-shorting gauges to record the detonation as it enters and exits the test section. The experiments with the neat NM used only the self-shorting gauges to determine the results of the experiment. The results of the experiments were categorized as either a "Go" or "No Go". A "Go" consists of an experiment in which the detonation propagated through the entire test section and exits the test capsule. A "No Go" is considered to be the case in which the detonation failed to propagate through the entire test capsule.

Control tests were also performed to determine the critical diameter of NM in the same tubing under ambient conditions. The control tests were conducted at a temperature of 25 ± 1 °C

Experiments were also conducted with manganin strain gauges (Dynasen model MN4-50-EK) in order to estimate the post-shock pressure in the test explosive. In this set of experiments, the PVC test tube was removed and a manganin gauge was suspended on a Mylar bridge at the same height as the center of test section.

RESULTS

The results from these experiments are presented in Fig. 2, showing the Go/No Go results as a function of the tube diameter in the test section. In Fig. 2a, there is evidence of a decrease in the critical diameter of sensitized NM due to shock precompression. The critical diameter of the test explosive at ambient conditions is approximately 2.4 mm. The critical diameter of the same test explosive while being compressed to a final

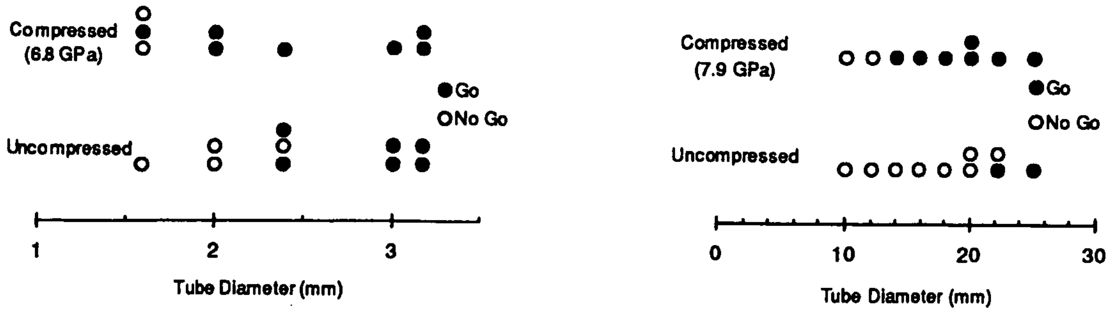

Figure 2. a) Results for NM + 3% DETA/wt experiments. b) Results for neat NM experiments.

pressure of approximately 6.8 GPa lies between 1.6 and 2 mm.

The results of the experiments with neat NM as the test explosive are shown in Fig. 2b. These results also show evidence of a decrease in critical diameter due to shock precompression of the test explosive. The control experiments conducted with the test explosive at ambient conditions found a critical diameter of roughly 22 mm, in good agreement with published values of d_c of NM in weak confinement [1]. The critical diameter of the same explosive under shock precompression was between 12 and 14 mm. The final pressure reached in these tests was 7.9 GPa.

It is important to note that all tube diameters given in Fig. 2 are the nominal sizes prior to compression. In fact, due to shock compression, the tube cross-section becomes elliptical, with the minor axis being approximately 35 % smaller than the original diameter. Thus the difference in critical diameter between compressed and uncompressed NM in these experiments is even greater than stated above.

DISCUSSION

To interpret these results, it is necessary to consider the effect of the shock precompression on the explosive. The passage of the shock through the test explosive raises the pressure, temperature and density of the explosive. Each of these state variables has a competing influence on the critical diameter of the explosive. Also, since the explosive is now confined at high pressure, the expansion of the confinement should be less severe, which would cause a decrease in the critical diameter. The fact that the density of the explosive is higher should also decrease the critical diameter from energy density considerations. Although all these factors play a role in determining the effect of precompression on the critical diameter of the explosive, we expect the dominant effect should be due to changes in the temperature of the reaction zone of the detonation according to Arrhenius kinetics.

To understand the influence of shock precompression on the reaction zone of the detonation, the von Neumann spike will be examined. This calculation will be performed using the NM EOS from Winey et al. [6] to approximate the post-shock temperatures. It is assumed that this EOS is valid for sensitized nitromethane as well. From the manganin gauge measurements, the first shock wave and the reflected shock bring the explosive to pressures of 2.8 GPa and 6.8 GPa respectively and temperatures of 604 K and 734 K respectively.

The detonation velocity of the sensitized NM is approximately 6 km/s, and the detonation velocity of the precompressed sensitized NM is approximately 7.5 km/s as measured by Petel et al. [5] for the same precompression conditions. Assuming that the U_s-u_p Hugoniot can be extrapolated linearly to these detonation velocities, the state at the von Neumann spike can be approximated using the NM EOS [6]. The calculations show that the von Neumann pressure and temperature are 17.8 GPa and 1740 K respectively for initially uncompressed NM. The calculation also shows that a 7.5 km/s detonation propagating in NM precompressed to 6.8 GPa and 734 K has a von Neumann pressure and temperature of 35.4 GPa and 1208 K respectively.

Since the reaction zone thickness is known to be extremely temperature dependent, such a large decrease in the von Neumann temperature (500°C) should result in a significantly longer reaction zone, in the precompressed case, thus increasing the critical diameter. From Arrhenius kinetics, assuming that the activation energy is the same for both detonations, the reaction zone of the precompressed detonation should be orders of magnitude longer than the uncompressed detonation. According to this estimate, the critical diameter should increase drasctically, however, just the opposite effect is seen. The reactions in the precompressed explosive are occuring at a much lower post-shock temperature than in the ambient explosive, but the precompressed explosives exhibit a smaller critical diameter. These results point to a more dominant role of pressure in the reaction zone at these extreme conditions. This result appears to contradict much of the literature which supports the thermal mechanism as being dominant in controlling detonation kinetics.

Recent molecular dynamics simulations have shown that at high pressures (compression factors between 2 and 3) it is possible to have proton transfer in nitromethane [7-9]. Engelke et al. [10] have shown that under high static pressure, nitromethane has an increased concentration of its aci ion form due to proton transfer. It has previously been shown that increased presence of the aci ion increases the reaction sensitivity of nitromethane [11] and could possibly explain the results obtained in this study. However, the role of pressure in the reaction mechanism of nitromethane has been widely discussed [4]. It was suggested that the reaction mechanism of nitromethane at high pressures could possibly involve a reaction precursor via an intermediate molecule [4, 12].

CONCLUSION

The critical diameter of both amine sensitized and neat NM is observed to decrease under shock precompression. This experimental result is in contrast to the prediction that a detonation in the precompressed explosive has a significantly lower von Neumann temperature than for a detonation in the ambient explosive. That the critical diameter decreased under these conditions points to the possibility of a strong pressure dependency of the activation energy for chemical reactions at high pressure. This study cannot single out one reaction mechanism over the other, but has shown that there is a definite pressure dependency in the reaction mechanism, whether it be through dissociation or through a reaction precursor.

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