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Desensitization in Multi-Dimensional Scenarios

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Abstract. Desensitization due to pre-shock is a characteristic of explosive behavior that is observable. Multi-dimensional scenarios can reveal information about desensitization, and in this study explosive filled channels are used to explore the nature of desensitization due to pre-shock for a PETN-based explosive. A series of experiments were performed with explosive-filled channels in varying arrangements. Neighboring channels imparted varying levels of preconditioning shocks to an acceptor channel, and the time for the explosive to detonate down the acceptor channel was recorded to determine if the neighboring channel imparted enough shock to desensitize or dead press the explosive. It is shown that dead pressing is possible for a small range of preconditioning shocks, and the viability of this methodology for probing desensitization is demonstrated. Modeling is performed using XHVRB in CTH to aid in designing experiments, and to evaluate the applicability of XHVRB for capturing desensitization in these types of scenarios.

Introduction

Desensitization due to pre-shock is a characteristic of explosive behavior that is well known in the literature [1]. Studies designed to measure the effects of desensitization due to pre-shock have been performed in one-dimensional scenarios which reveal quantitative information about the nature of desensitization [2]. Multi-dimensional scenarios can also reveal information about desensitization. Often times the multidimensional scenario is computationally prohibitive; however, by using the Adaptive Mesh Refinement (AMR) in CTH, models can be run efficiently in 3D to examine easy-to-design experiment that are 3D in nature. In this study channels are used to explore the nature of desensitization due to pre-shock for a PETN-based explosive. A series of experiments were performed with explosive-filled channels in varying arrangements, enabling independent variation of pre-shock amplitude and pre-shock arrival time.

It is hypothesized that at least three scenarios could be encountered through the experiments. The first is that the preconditioning shock is of sufficient amplitude to cause detonation in the acceptor material. This phenomenon would manifest in the detonation transmitting across the inert barrier between channels. The second scenario comprises desensitization sufficient to quench the detonation in the neighboring channel. Finally, it may be possible to affect the detonation velocity or explosive performance without fully quenching detonation. Some explosives may be less susceptible to desensitization than others, and different levels of pre-shock may desensitize to varying degrees ranging from little-to-no effect to complete dead pressing. The tests performed in this study suggest that this range of behaviors exists for

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the explosive studied here, and the range can be observed using this experimental methodology.

Pre-shock Parameter Study

The first experimental configuration designed to study desensitization is shown in Fig. 1. The substrate is a transparent polycarbonate with explosive-filled channels visible in white. The initiation point is moved to adjust the time delay of the pre-shock. Points P_1, P_2, and P_3 identify the location of piezoelectric pins which record arrival of the detonation and can be used to evaluate impact of desensitization on time of arrival. The localized region of pre-shock is highlighted in Fig. 2.

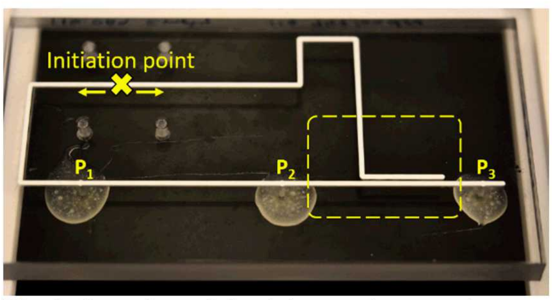

Fig. 1. Overview of shock interaction experiment.

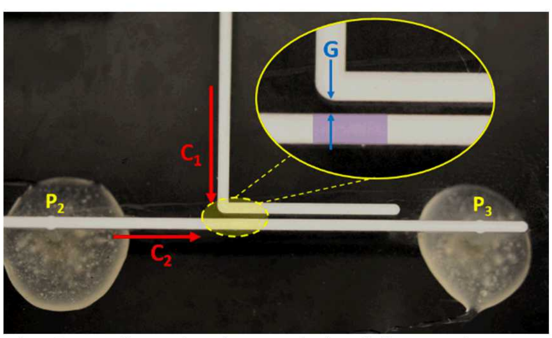

Fig. 2. Region of orthogonal shock interaction.

The detonation in channel C_1, as denoted in Fig. 2, arrives at the intersection at a prescribed time ahead of detonation in channel C_2. The region of greatest pre-shock is highlighted in the Fig.2 inset. As the pre-shock is orthogonal the channels were designed to be narrow (0.050" width) to minimize the pressure gradient within the unreacted material. By varying the distance between these channels (indicated as 'G' in Fig. 2) at the interaction point and the detonator placement, both the magnitude of pre-shock magnitude and the time between shocks can be varied, respectively, in a controlled manner.

The test configuration was used to evaluate delays of 0.5 and 1.0 μs over a range of gaps from 0.7-1.1 mm. The test matrix, along with a relative time recorded from the pins, is outlined in Table 1. The relative time is defined as the excess time for detonation to travel between P_2 and P_3 with respect to the undisturbed detonation time between P_1 and P_2.

Table 1. Test series for varying gap size and time delay of interaction.

Test	Gap (mm)	Delay (μs)	Relative Time (ns)
T-01	0.7	0.5	-1076
T-02	0.8	0.5	-40
T-03	0.9	0.5	-80
T-04	1.0	0.5	-54
T-05	0.7	1.0	-939
T-06	1.1	0.5	-63
T-07	0.8	1.0	No P_3 signal
T-08	0.9	1.0	9
T-09	1.0	1.0	-38
T-10	1.1	1.0	-23

The relative time for T-01 and T-05 shows the P_3-P_2 is much shorter than expected. This result is due to transmission of the detonation to C_2. T-07 recorded no signal on P_3 as the detonation in C_2 quenched due to the pre-shock. Of note is that the majority of other relative times are negative, suggesting that detonation in the pre-shocked region was faster than other areas. The exception is test T-08, which shows almost no effect, yet is the outlier in the group.

High-speed video was taken for a sub-set of the experiments at 10 Mfps using a Shimadzu HPV-X2 camera. The video was recorded from the backside through the polycarbonate resulting in the images horizontally flipped relative to Figs 1 and 2. Although the detonation saturated the video it is still possible to track the detonation front. The field of view included a section of C_2 with no pre-shock which was used as a baseline in post-test analysis.

Images extracted from T-05 in Fig. 3, which had a gap of 0.7 mm gap, show the initiation of the energetic transmitting across the gap. The area labeled as ‘A’ is likely reflected light from the neighboring detonation and not an indication of reaction in C_2. Not all explosive within C_2 was consumed, only the lower portion of the channel detonated, as the upper portion appears to be desensitized by transmission of the persistent shock in the adjacent channel. The post-test image of the C_2 in Fig. 4 confirms the region without detonation.

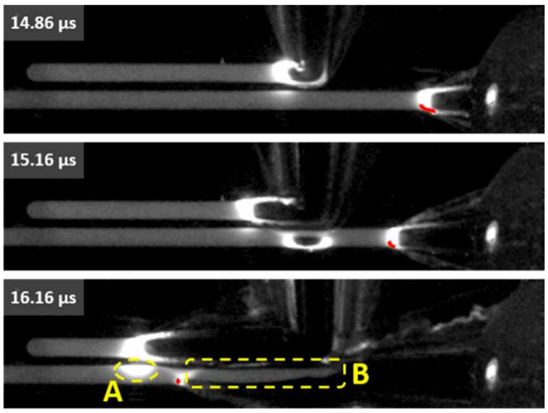

Fig. 3. Images of T-05, 0.7 mm gap, showing transmission of the detonation.

Fig. 4. Post-test image of T-05 block showing region of no detonation.

A slightly larger gap of 0.8 mm in T-07 was shown to fully desensitize the energetic and quench the reaction, as shown in extracted video frames in Fig. 5. In this experiment, the detonation did not propagate down C_2 beyond the localized region of pre-shock, and no arrival time was recoded at P_3.

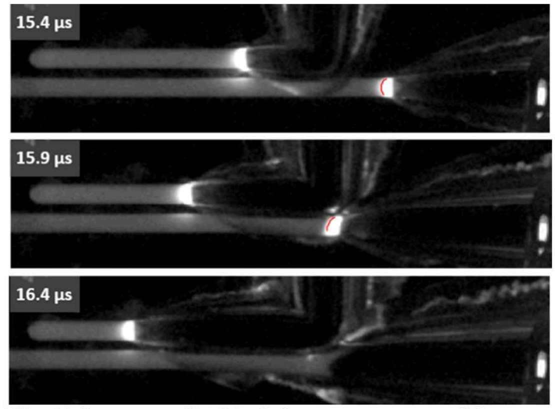

Fig. 5. Images of T-07, 0.8 mm gap, quenching.

In T-08, which had a 0.9 mm gap, the timing pin data did not reveal any impact from desensitization. However, the video shows the detonation in C_2 slowing after the pre-shock event. This is highlighted in Fig. 6, where sequential images show the advancement of the detonation in C_1 and C_2 with vertical bars indicating the detonation front progress in each channel. This highlights the propagation of detonation in C_1 being much larger than that in C_2 over the same time frame and demonstrates that the detonation slowed in the region of desensitization in this experiment.

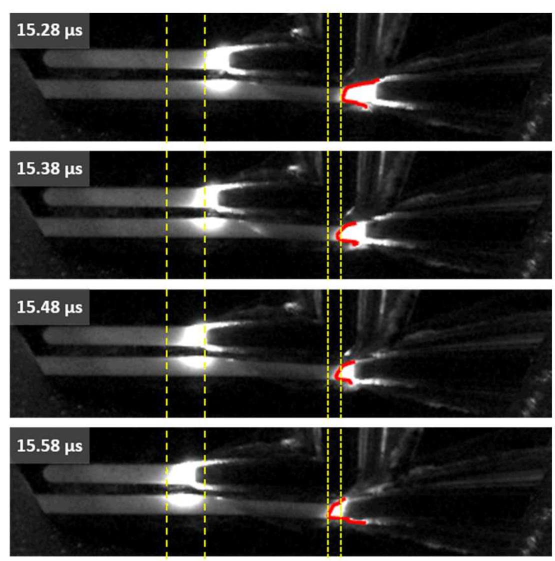

Fig. 6. High speed video images showing reaction slowing in the acceptor channel due to pre-shock in test T-08.

To help quantify the effect observed in experiment T-08, Fig. 7 shows a plot of detonation front position (in pixels) as a function of time (left axis, star symbols) and a plot of the deviation of the detonation front relative to a linear extrapolation of the steady state detonation (right axis, open circles). In this plot, two effects can be observed. Early in time, the deviation is approximately 0, but just as the detonation reaches the desensitized zone, there is a small increase in the detonation velocity and positive deviation. Then there is a sharp decrease in deviation such that the deviation becomes negative, showing a slowing of the arrival of the detonation relative to the steady-state detonation extrapolation.

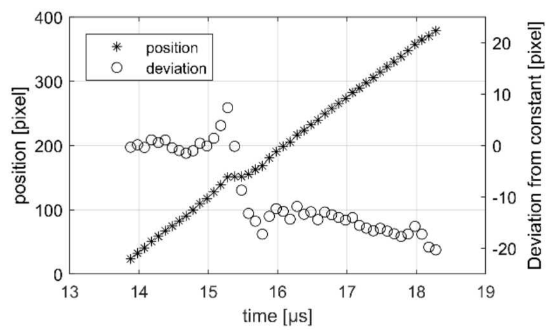

Fig. 7. Detonation front position for T-08.

Four regions are identified, shown overlaying the undetonated test article in Fig. 8, in which different behaviors associated with desensitization can be observed. Region R_1 is the unaffected portion of C_2. The behavior observed in this region is used to extrapolate the expected position of detonation. Region R_2 shows the detonation advancing faster than expected (detonation front accelerated). Region R_3 shows the detonation front lagging (slowing of detonation). Finally, R_4 is the detonation while continuing to be pre-shocked by the adjacent channel.

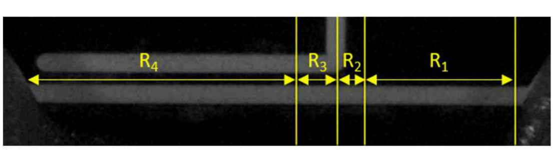

Fig. 8. Regions of experiment for analysis.

An explanation for the timing pins showing no slowing is the cancelling effects of the detonation, speeding up in R_2 and slowing in R_3. Further, the shorter timing from P_2 to P_3 can be shown by examination of the deviation from expected position. Fig. 9 shows the deviation for tests T-08, T-09, and T-10; which correspond to 0.9, 1.0, and 1.1 mm gaps, respectively. In both the experiments with larger gaps the apparent increase in velocity is observed in region R_2. However, for tests with gaps above 0.9 mm there is no subsequent slowing of the detonation.

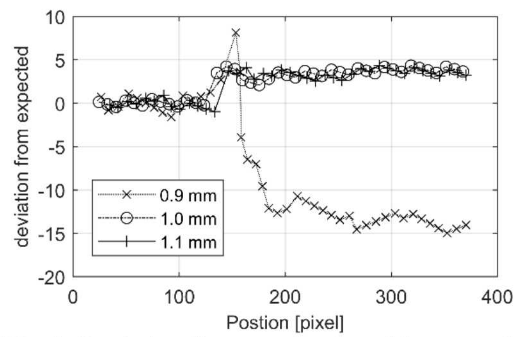

Fig. 9. Deviation from expected position over the distance image width.

The range of behaviors exhibited here can be described by the qualitative depiction in Fig. 10. For small gap sizes with higher magnitudes of pre-shock, the pre-shock is enough to initiate the detonation (region A). At some gap size, or pre-shock magnitude, the material in the acceptor channel is dead pressed, resulting in an infinite transit time (region B). As the gap size continues to increase and the pre-shock magnitude decreases due to attenuation across the gap, the explosive in the acceptor channel shows influence from the pre-shocking channel resulting in a slower than expected transit time (region C). At some distance this effect is compensated by a brief advancement of the detonation front through pre-shocked energetic resulting in the expected transit time (region D). Continued increase in gap removes the slowing behavior but maintains the brief advancement, resulting in shorter than expected transit time (region E). Finally, the gap is sufficiently large that there is no impact on the transit time (region F). Both the behaviors in regions B and C are desensitization effects. The gap size at which these effects can be observed will be

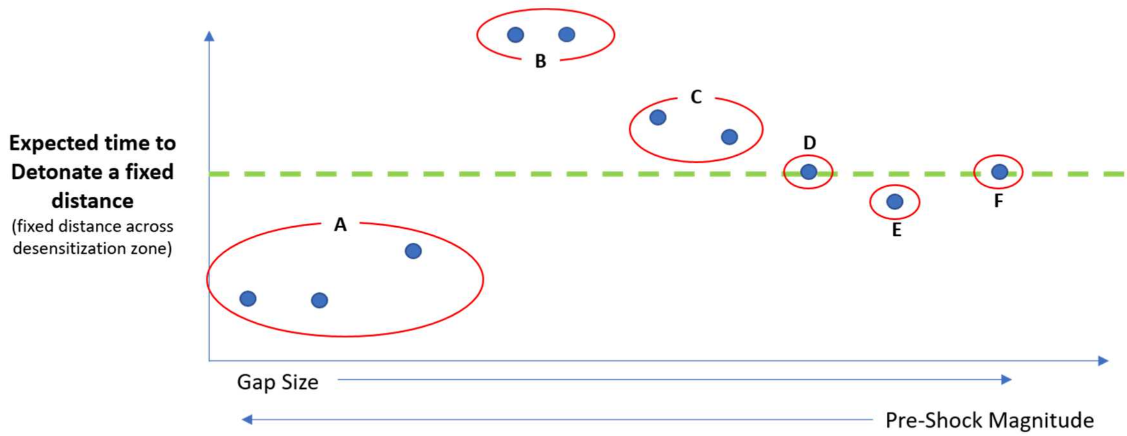

Fig. 10. Qualitative description of desensitization regimes.

dependent on both the explosive and substrate materials. While data recorded and analyzed here seem to demonstrate the proposed behaviors, additional experiments with more rigorous diagnostics are in progress to further evaluate the hypothesis.

Switchback Test Configuration and Results

Another channel arrangement for testing desensitization is to use a switchback configuration. This method also uses explosive in a channel, but employs increasing angles of switchback to impart varying pre-shock magnitudes and varying delays. Several angles can be tested on one fixture with just one detonator. Timing information is recorded before and after each switchback section, but the data are complicated by corner turning effects, making it difficult to de-couple those effects from desensitization effects. Cases in which the explosive is dead pressed are easily observed.

Six tests were performed on channels with switchback angles varying from 30 degrees to 70 degrees in both aluminum and polycarbonate substrates. The aluminum block post-test is shown in Fig. 11, and it is visibly observed that for all angles tested the detonation propagated to the end of the channel. This test was repeated twice, and the results were consistent in all three tests.

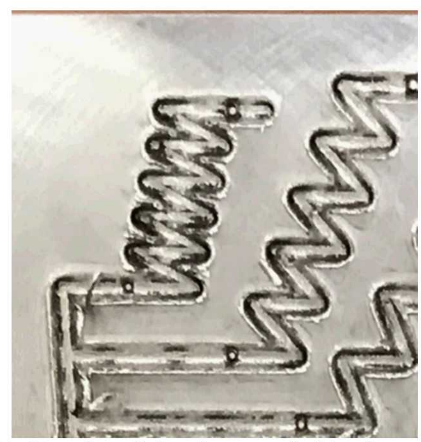

Fig. 11. Results of aluminum switchback test showing detonation in all angles tested.

The polycarbonate substrate tests showed dead pressing of the explosive in all three tests for the 30 degree angle, but propagation to the end of the channel for the 50 and 70 degree angles. One of the post-test test blocks is shown in Fig 12. In two of the three tests, the detonation failed to propagate past the first angle switchback, and in the third the detonation was quenched further down the channel, but in all three cases the quenching occurred just after a switchback.

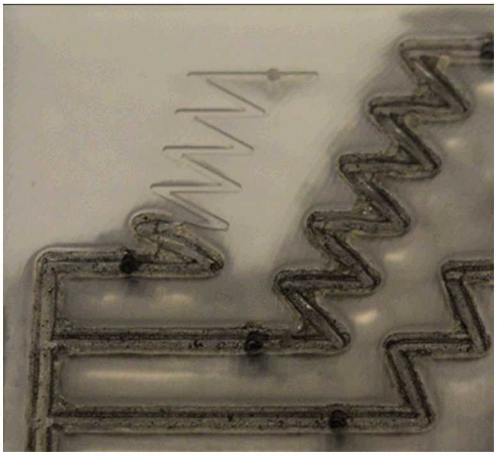

Fig. 12. Polycarbonate switchback test result, showing dead pressing due to desensitization in the 30 degree switchback channel.

The dead pressing of the explosive that is observed in these experiments is evidence of desensitization. Because the shocks will attenuate differently through aluminum and polycarbonate, we can use different substrates and angles to probe the desensitization space for this and other explosives.

Modeling

Both experimental methodologies above were modeled using CTH [3], a shock physics code from Sandia National Laboratories, and the reactive flow model XHVRB [4,5]. XHVRB is a reactive flow model that uses pseudo-entropy to calculate the extent of reaction, such that the explosive will behave differently after being pre-shocked. All calculations used AMR with a mesh resolution of approximately 0.1 mm inside the channel. The mesh was allowed to unrefine after the detonation had passed to increase computational efficiency. Simulations of the head-on interaction tests were conducted for all 10 experiments. The series of gap sizes with a 1 μs delay is shown in Fig. 13. The desensitization exponent used was 0.05, and the results of the simulations show many of the same trends identified in the experiments, though the quantitative comparison indicates a difference between model and experiment results. For a gap of 0.7 mm, the detonation transmits across the gap and causes detonation in the neighboring channel in both experiment and model. For a gap of 0.8 mm, the detonation is clearly quenched in the acceptor channel in the experiment, but in the model the quenching does not occur until the gap is increased to 1.1 mm. For larger gaps the detonation is affected but not quenched. Qualitatively the trends captured are the same. The model, however, did not accurately predict the exact gap across which the desensitization effects would be observable. Quantitative data are needed to fit the desensitization exponent so that its predictability in different scenarios can be tested, but the results shown here suggest that XHVRB can capture desensitization effects in multi-dimensional scenarios.

Simulations for the switchback configuration were run with varying levels of desensitization parameter for both substrate materials. The results for three different values of desensitization exponent value are shown in Fig. 14 for polycarbonate. For a low desensitization exponent value of 0.01, the detonation propagates to the end

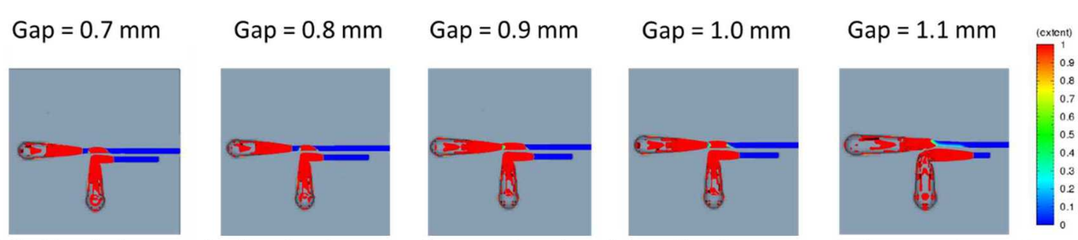

Fig. 13. Simulation results for shock across the gap showing detonation jump across the gap at gap sizes up to 1.0 mm, and dead pressing of the explosive in the acceptor channel at 1.1 mm.

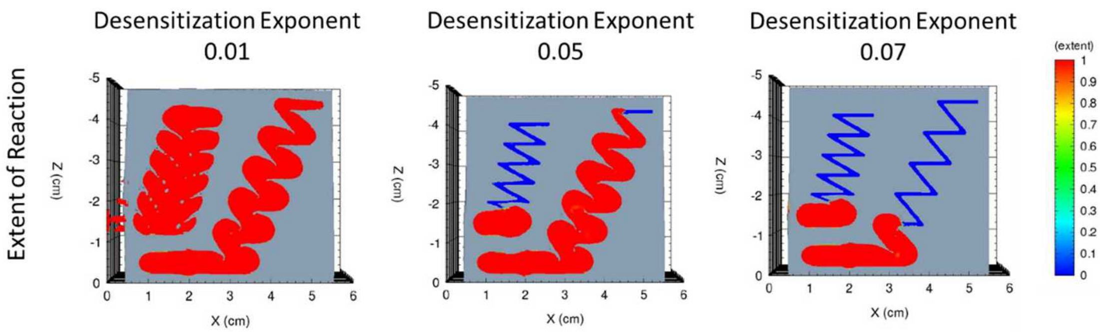

Fig. 14. Simulation results showing extent of reaction in switchback configurations. Results show detonation at both angles for the lowest desensitization exponent, dead pressing in the 30 dregree channel for a desensitization exponent of 0.05, and dead pressing in both channels at an exponent value of 0.07.

of the channel for all switchback angles. For a value of 0.05, the explosive in the channel with the 30 degree switchback dead presses just past the first switchback, as in the experiment. For a value of 0.07, the explosive in both the 30 and 50 degree switchback channels shows dead pressing.

The same set of simulations were run with the aluminum substrate with the desensitization exponent set at 0.05, and in all three channels the detonation propagates to the end of the channel, as was observed in the experiment.

Discussion

Desensitization is an explosive behavior that requires multi-shock experimental methods to characterize. Varying the levels of pre-shock into a channel in which a detonation is propagating is one method for examining the range of potential effects of pre-shock. Experimental results in two different arrangements showed that explosive can be dead pressed by pre-shock. These results also suggest that the explosive used here can be desensitized such that the explosive performance can be influenced without being dead pressed, but timing results are not conclusive.

The channel-based experiments necessitate full 3D modeling for comparison. The experiments were paired with CTH simulations using the AMR and the XHVRB reactive flow model. The simulations were shown to capture the observed phenomena with tuning of the desensitization exponent, which is specific to the energetic material.

Another feature of explosive desensitization that can be examined by these experimental methodologies is the importance of timing, or the ability of the explosive to recover due to release before a subsequent shock arrives. Results here show that a minimum time is required for desensitization to be realized – the 0.5 μs delay was not enough to apply the pre-shock to the acceptor channel fully. Larger delays could be introduced by moving the detonator location, and these results could help increase understanding of the role that shock and subsequent release play on desensitization.

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