# Propagation of Detonation Initiated by Precursor Shock Wave in Explosive Lined Channels

V. Tanguay, J. Mamen and A.J. Higgins McGill University Montreal, Quebec, Canada e-mail: vince\_tanguay@yahoo.com

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# Introduction

When a detonation propagates in an explosive that only partially fills a channel, a precursor shock wave can be driven in the air gap between the explosive and the confinement. This is typically referred to as the *channel effect*. In the air gap, the rapidly expanding detonation products act as a piston, which drives the precursor shock wave ahead of the detonation. Since the precursor shock wave runs ahead of the detonation, it can precondition the explosive. In other words, the shock wave transmitted into the unreacted explosive can affect the detonation propagation. This can occur through various mechanisms. For example, the precursor shock will precompress the explosive to a higher initial density. This can result in an acceleration of the detonation velocity, which varies almost linearly with initial density. This phenomenon has been observed with porous explosives by various researchers [1].

Another mechanism by which the precursor shock can couple with the detonation is through initiation of the explosive. If the precursor shock wave is sufficiently strong and the explosive is sufficiently sensitive, then, the precursor shock wave could initiate a detonation. The detonation would drive a faster precursor, which would initiate the detonation at a faster rate. This positive feedback mechanism could lead to very high propagation velocities, possibly several times the CJ velocity of the explosive. This has been observed by Bakirov and Mitrofanov [2]. In their experiment, a shock wave was transmitted into a steel tube that was lined with lead azide and filled with helium. The shock wave initiated the lead azide and a combustion front was observed to accelerate up to 14 km/s (more than 3 times the CJ velocity of lead azide). Other studies have attempted to reproduce this result such as [3] and [4]. Even though some form of coupling was obtained in some of these studies, the mechanism was not demonstrated and it is doubtful that initiation occurred.

For these reasons, the goal of the present study is to reproduce and investigate this propagation mechanism. However, for safety reasons, primary explosives were not considered for this study. Therefore, the objective is to achieve the above coupling mechanism with a safer, secondary explosive.

A good candidate explosive is PETN powder because it is a very sensitive secondary explosive. Furthermore, previous studies have shown that PETN can be initiated from impact with a gaseous detonation. It was determined from these studies that the critical transmitted shock strength is 20-65 MPa (see [5] and [6]). This is comparable to the pressure generated by a precursor shock wave propagating at 5-7 km/s.

## **Experimental Setup**

The experiments were performed in rectangular PVC channels 8 mm wide, 6 mm high and 60 cm long. The bottom half of the channels were filled with PETN powder lightly pressed to 1 g/cc. The PETN was obtained from detonating cord (ICI "B-Line"); the loose powder had a density of approximately 0.5 g/cc.

The channels were instrumented with self-shorting twisted-wire pairs (SSTWP) to detect the time of arrival of the detonation, and contact gauges and shock pins to detect the time of arrival of the precursor shock wave. High-speed photography was also performed with a DiCam-PRO – an image intensified high-speed CCD camera.

#### **Experimental Results**

First, PETN was detonated both unconfined and completely confined with PVC. The velocity of detonation (VOD) was measured to be 5 km/s. This value shows relatively good agreement with the equilibrium code Cheetah 2.0, which predicts a VOD of 5.6 km/s.

When PETN was detonated in a channel with an air gap, the detonation was observed to accelerate from 5 km/s to 7.5 km/s. This is illustrated on the *V*-*x* diagram of Figure 1. This figure clearly shows that 7.5 km/s is a terminal velocity. Note also that it takes approximately 100 channel diameters for the detonation to reach a terminal velocity (steady state).

Experiments were also performed where the air in the gap was evacuated to less than 3 kPa. The air in the gap was also replaced by helium and argon. These results are also



Figure 1: VOD as a function of distance along the channel; experimental data and model prediction.



Figure 2: High-speed photograph of detonation and precursor shock moving left to right.

illustrated in Figure 1. In all cases, the VOD showed the same behavior (within experimental scatter).

In a few experiments, the sides of the channel were replaced with acrylic to permit visual access to the phenomenon. Figure 2 is a high-speed photograph of the detonation propagating from left to right. The bright rectangle is the shocked gas (its temperature is very high). The right edge of the rectangle is the precursor shock wave. The left edge is the interface between the detonation products (left) and the shocked gas (right). Below the interface is the detonation (bright line) propagating in the PETN layer. The upper part of the detonation is severely curved whereas the lower section is straight but oblique (it forms an angle of nearly 45° with the horizontal). Note that in this particular picture, the gas filling the gap is carbon dioxide. This gas was used because it is not as bright as air and results in a clearer picture. However, pictures taken with air show similar results.

## **Discussion of Results**

Although 7.5 km/s represents a significant acceleration of the detonation (150% of the CJ velocity), it corresponds to the VOD of PETN at approximately 85% of its theoretical maximum density (TMD). This suggests that the mechanism of acceleration is not by initiation of the explosive by the precursor shock wave but simply by precompression of the explosive to a higher initial density.

The precompression mechanism was therefore modeled with an unreacted shock Hugoniot for porous PETN. Note that this model also accounted for the effects of boundary layers on the channel walls (which turn out to be significant, see [7]). The model solution is plotted in Figure 1.

The agreement with experimental data is reasonable. Note that as well as predicting fairly well the terminal VOD (slightly above 7 km/s) the model successfully predicts the distance of propagation required by the detonation to reach a terminal velocity (steady-state).

The photograph in Figure 2 also supports the precompression mechanism. The upper section of the detonation propagates in the layer of shocked (denser) PETN at 7.5 km/s, whereas the lower section is oblique because it propagates at 5 km/s in PETN at the initial density of 1 g/cc.

## **Concluding Remarks**

The above results lead to the conclusion that the precursor shock does not initiate detonation in PETN. However, coupling was observed which lead to a significant acceleration of the detonation. It is believed that precompression of the PETN is responsible for the observed acceleration. Although initiation of the explosive by the precursor shock wave was not observed, it is expected that this could be achieved with a more sensitive explosive. Experiments with silver-acetylide and cyanuric-triazide will confirm this statement.

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