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Stream of Reaction Products behind the Detonation Wave Front

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Abstract: Embedded copper foils in a high explosive charge allow to see the stream of the reaction products behind the detonation front. With three individual firings in front of FXR it can be shown that the reaction products behind the detonation front are immediately going in the direction of the detonation front. But then the rarefaction fans are influencing strongly the further displacements.

Key words: ZNP model; reaction product; rarefaction

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1 Introduction

The detonation of detonable substances is often described by the physical model of ZND-Zeldovich[1]. The terminology and the schematic diagram of the pressure over the specific volume is presented in Fig. 1. This figure leads to the simplified general pressure distance diagram (Fig. 2).

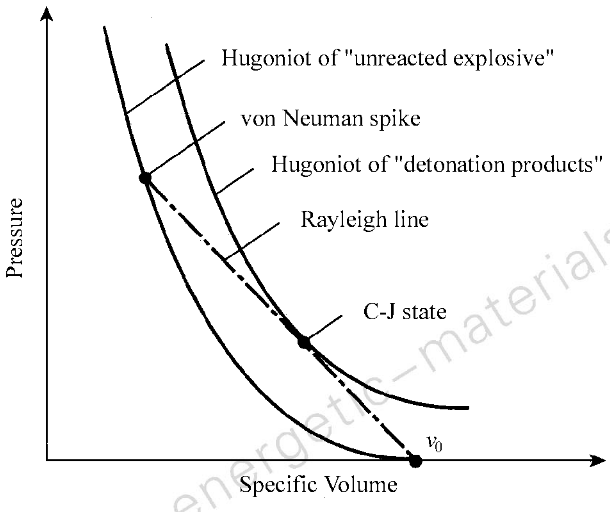

Fig. 1　Schematic diagram of the pressure over the specific volume

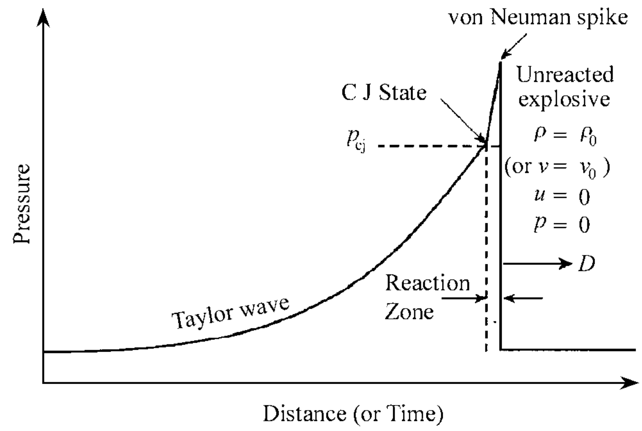

Fig. 2　Simplified general diagram of pressure-distance

No diagrams on the velocity vectors of the reaction products stream, in correlation to the pressure distance or pressure time profile can be found for, as an example, a one end initiated cylindrical charge. The author made once the following schematic diagram of the stream of the molecules or radicals after the extremely strong shock of the detonation front into the unreacted detonable material (Fig. 3)[2]. The free surface of the initiation plane allows a release wave which reduces the pressure of the highly compressed reaction products. These expanding, typically gaseous products, are pushing and compressing the air in the front and create the air shock wave. This blast wave has a relatively thin layer of highly compressed air and is followed by the expandingreaction products of the detonated high explosive charge .

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Biography: Dr. Manfred Held (1933 –), Professor of Military University of München, Germany. He is a world-famous expert in research, design, development and test of different advanced missile warheads and the related science and technology. He is also an internationally recognized authority in the field of dynamic response of materials as well as advanced armor and anti-armor.

The front of the rarefaction fan changes the sign of the velo-city vectors which are streaming first in the direction of the detonation direction and then in the opposite direction (see Fig. 3, below)

The stream of the reaction products going first behind the detonation front in the detonation direction is a requirement of the ZND theory before the direction is changed by the rarefaction fans, coming from the rear surface and from the side. The question was once arising: can the stream of the reaction products be easily observed. To measure the flow stream of the reaction products directly behind the detonation wave. Therefore the author has carried out the following tests.

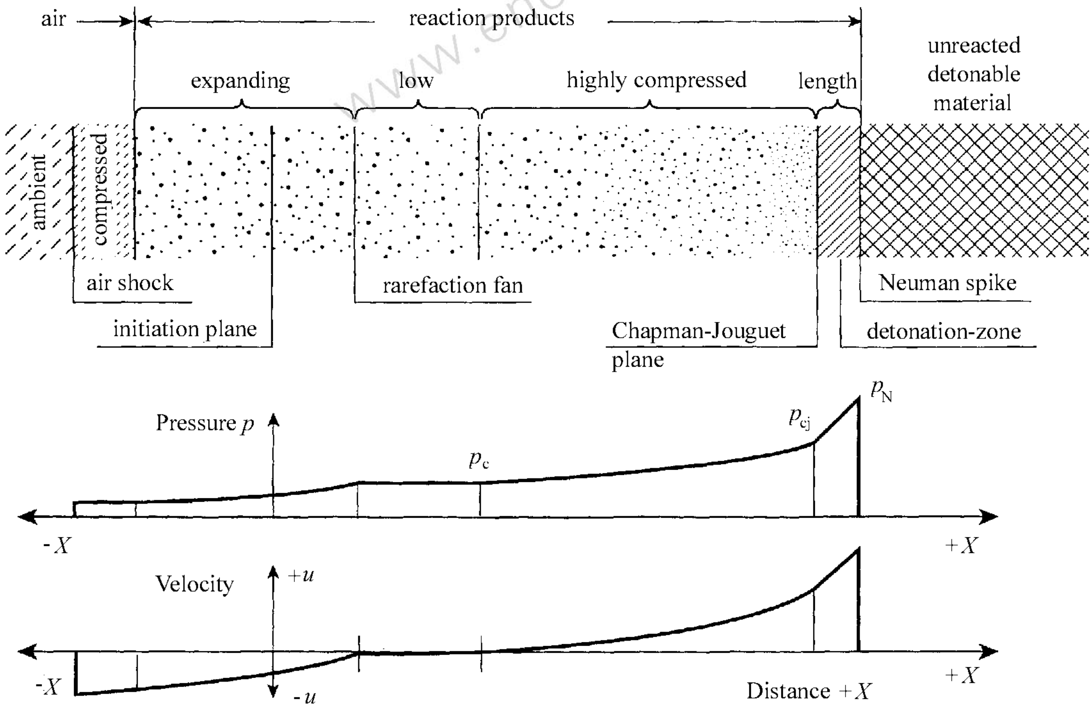

Fig. 3 Schematic diagram of the stream of the molecules or radicals after the extremely strong shock of the detonation front into the unreacted detonable material

2 Test setup

A 64 mm diameter and 100 mm long cylinder of normal cast TNT/RDX 35/65 composition, made up of 10 times 10 mm thick disks between which 0. 05 mm thick copper foils were inserted was fired in front of flash X-ray (Fig. 4). A double exposure was made on every firing, first a "static" picture of the arrangement and then the "dynamic" exposure during the detonation on the same film. Then the displacements of the copper foils by the detonation of the high explosive cylinder can be easily quantitatively analysed. The high explosive charge was initiated by a normal number 8 electric detonator and a 15 mm diameter RDX/Wax/Graphite 94. 5/5. 4/1 booster. Three firings were performed with a flash X-ray picture, each taken at a different time delay. One at minus 3 μs before the detonation front arrives at the right end surface of the charge, a second one at + 1 μs and a third one at + 7 μs after the arrival time of the detonation front on the right side (Fig. 5). The detonation wave is not at all plane because it was not used a plane wave generator. The displacements look very much linear, still a spherical detonation wave is pushing the individual copper foils. The displacements along the axis of the charge and the directions of the copper foils from the still pictures to the dynamic exposures are marked with arrows. In the printed copy the displacements are no more visible as well as in the original negatives which were used for the analysis.

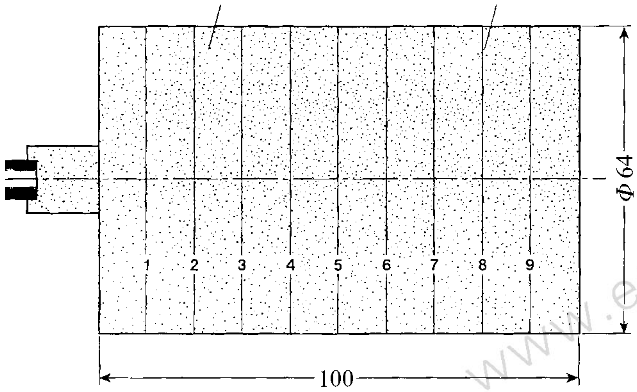

Fig. 4 Schematic diagram of the test setup

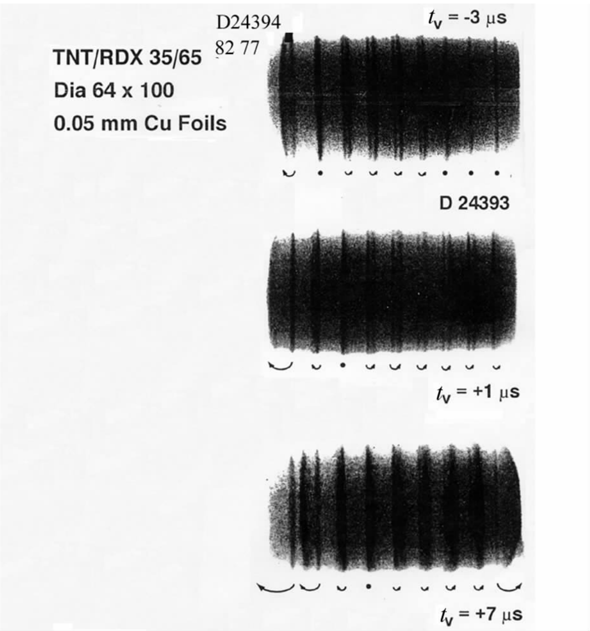

Fig. 5 Flash X-ray picture for three firings taken at a different time delay

3 Analysis

In a time-distance diagram (Fig. 6) the measured displacements of the 9 individual copper foils are drawn for the 3 FXR exposures. The copper foils are numbered from 1 to 9. Every foil has a fourth so-called zero or starting point in this diagram which corresponds to the original position and the arrival time of the detonation wave. This detonation line has a slope of 7.8 mm · μs^{-1}. The detonation time for the 100 mm long cylinders is 12.8 μs. Now the displacements of the individual copper foils can be discussed:

In this test setup with the time intervals copper foil No 1 has no visible movement in the detonation direction. The reason is simply that the rarefaction wave comes once very soon from the initiation plane and is pushing the foil fast in the opposite direction and the time interval between arrival time of detonation and FXR exposure is relatively long with 8.5 μs. The same happens to the copper foil No 2, but already with are duced velocity. In 30 mm distance from the initiation plane and about 6 μs after the passage of the detonation front copper foil No 3 shows a forward movement on the first dynamic flash X-ray picture at 9.8 μs and then a rearward movement pulled by the rearfaction fan coming from the initiation plane. Copper foil No 4 shows a forward movement of about 4 mm at the first flash X-ray (9.8 μs) and nearly remains at the same distance at the second FXR exposure (13.8 μs). At the third FXR exposure after 19.8 μs or at about 15 μs time difference again a negative movement. Copper foil No 5 shows a very similar trend, with a little less amplitude. Surely the time difference is generally 1.2 μs less. On copper foil No 6 the trend of copper foil No 4 to No 5 continues.

Copper foil No 7 had nearly no time to move in the de-tonation direction because the time difference between the arrival time of the detonation front and the FXR exposure is only about 1.0 μs. But the FXR exposure gained 4 μs later shows a displacemnnt of 4 mm. The detonation wave arrives at the right surface after 12.8 μs. Therefore the rarefaction fan from the right side is now pulling the copper foil to the right side what is already visible after additional 6 μs more time difference or 7 μs after arrival of the detonation wave at the right side. The same trend is given on copper foil No 8.

Copper foil No 9 shows again the strong movement in the detonation direction still it had only about 3 μs time difference. At 19.8 μs the foil is strongly pulled by the rarefaction fan from the right side.

Those firings with the copper foils in the charge in front of flash X-ray with different time intervals give the movement of copper foils embedded in the high explosive charge. They demonstrate the detonation feature and the flow of the reaction products.

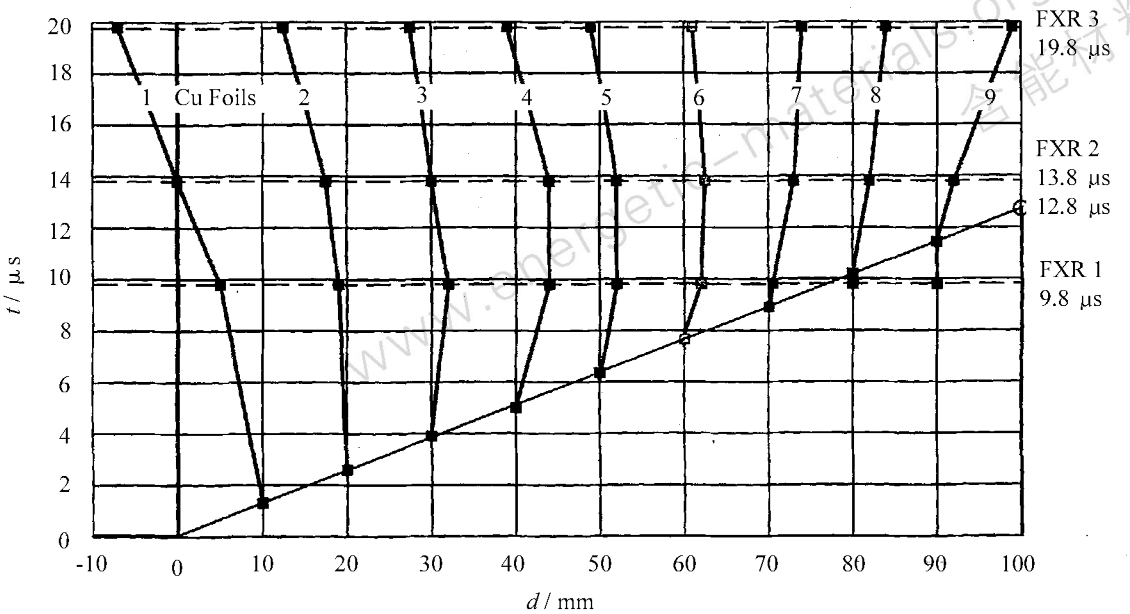

Fig. 6　Time-distance diagram of the measured displacements of the 9 individual copper foils darwn by the 3 FXR exposures

The detonation reaction products just behind the detonation wave are moving "in" the direction of the detonation front which can be confirmed by all contact foils which have displacements in the detonation directions shortly behind the detonation front and are not influenced by the rarefaction fans.

4　Conclusion

With thin contact foils in the high explosive charge the simple ZND theory can be confirmed with the statement that the products of high explosives are streaming in the detonation direction behind the detonation front.

The 0.05 mm thick copper foils are not a diagnostic tool to measure directly the velocity of the reaction products because they are too thick and give some shock impedance mismatch to the detonation front. But they give a simple indication of the direction of the stream. Further they indicate the influence and velocity of the rarefaction fan to the stream of the reaction products, either from the initiation plane or from the end surface.

It should not be forgotten that the rarefaction fan in the radial direction is diminishing the pressure durations and the profile of the streams, which is not measurable in the selected test setup.

REFERENCES:

[1]　Cooper P W. Explosives Engineering. Chapter 20. Detonations General Observations[M]. 1996, 253 - 257.

[2]　Held M. Struktur der Detonationsfront (Structure of the detonation front) [J]. Explosivstoffe, 1969, 17: 241 - 249.