

# The Detonation Properties of Explosive-Water Mixtures

B. Zygmunt

Technical Military Academy, Warsaw 00-908 (Poland)

## Detonationseigenschaften von Sprengstoff/Wasser-Mischungen

Mischungen von kristallinen Sprengstoffen mit Wasser haben üblicherweise andere Detonationseigenschaften als die trockenen Substanzen. Es wurde gezeigt, daß die Art der Veränderungen stark abhängig ist von der Gestalt der Teilchen (Kristalle, Granulate) der Sprengstoffe. Für eine Reihe von Sprengstoff/Wasser-Mischungen wurde der kritische Durchmesser und die Detonationsgeschwindigkeit bestimmt, die Ergebnisse wurden diskutiert in Anlehnung an die „Hot spot“-Theorie.

## Summary

Mixtures of crystalline explosive and water have as a rule detonation properties different from the dry material. It has been shown that the character of those changes is closely related to the structure of the particles (crystals, granules) of the explosives. The critical diameters and detonation velocities have been measured for a range of explosive-water mixtures, and the results are interpreted in terms of the hot-spot theory.

## 1. Introduction

A loose crystalline explosive changes its detonation properties when the air spaces are filled with non-explosive liquid. For such mixtures we observe a detonation velocity increased as compared with the dry material<sup>(1)</sup>, and – depending on the structure of the particles – an increase or decrease of the critical diameter<sup>(2)</sup>. With growing water content in the explosive we observe variations of the detonation velocity and of the critical diameter. The causes of that effect have not found a satisfactory explanation. In the present work we tested the susceptibility to detonation of crystal explosive-water mixtures.

## 2. Experimental

### 2.1. Measuring methods

The measurements of the critical diameter were carried out for cylindrical charges in thin polyethylene tubes. The length of the charges was 8 to 10 times that of the diameter. Measurement of the critical diameter consisted in determining such a minimal charge diameter at which the charge detonates fully and such a maximal diameter at which the explosive detonates incompletely. The critical diameter of the explosive was calculated as the arithmetic mean of the results obtained. The accuracy of determination of the critical diameter was up to 1 mm.

The detonation velocity was determined using a four-channel electronic counter, which measured time with an accuracy to  $10^{-8}$  s. The measurement consisted in determining the time of propagation of the detonation front through sections of the explosive charge. The lengths of the sections were determined

## Comportement à la détonation des mélanges explosif/eau

Normalement, un explosif cristallisé mélangé à de l'eau se comporte différemment lors de la détonation que la substance sèche. On montre que les modifications du comportement dépendent fortement de la structure des particules d'explosif (cristaux, granulats). Pour une série de mélanges explosif/eau on a déterminé le diamètre critique des particules d'explosif et la vitesse de détonation. Les résultats obtenus sont confrontés à la théorie des points chauds.

by the distance between the probes. The accuracy of determination of the detonation velocity was about 0.2 km/s.

### 2.2. Variation of the critical diameter of granulated cast TNT/RDX with the size of the granules

The granules were obtained by pouring a suspension of fine-crystalline RDX in molten TNT into cold water. The weight ratio of both explosives was 50:50. The granules after drying were subjected to screen fractioning. Particles of grain size below 1 mm were obtained by mechanical disintegration.

The variation of the critical diameter with the granule dimension is shown in Fig. 1 for the dry and water filled explosives. For the dry explosive the critical diameter increases with the size of the granules, whereas for the explosive-water mixture it is practically independent of the grain size.

### 2.3. Variation of the critical diameter of granulated cast TNT/RDX with the RDX content

Granules were obtained from a melt of different RDX content and the 1.0 mm–2.5 mm fraction was isolated. The critical

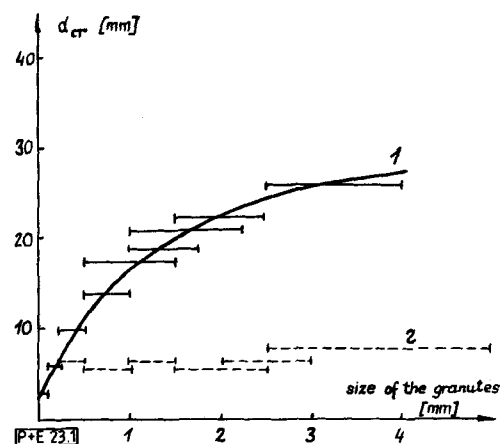
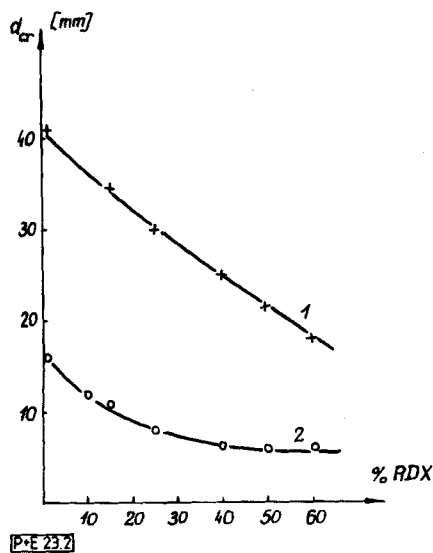
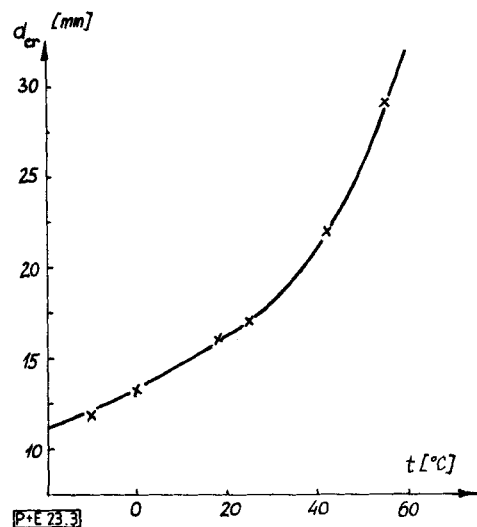


Figure 1. The relation between the critical diameter of granulated cast TNT/RDX and the size of the granules. 1 – dry granules, 2 – water filled.



**Figure 2.** The relation between the critical diameter of the granulated cast TNT/RDX and the RDX content. 1 - dry granules, 2 - water filled.

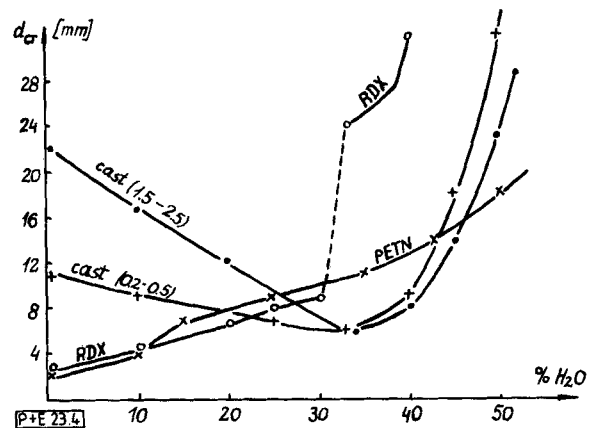


**Figure 3.** The relation between the critical diameter of water filled granulated TNT and the temperature of the granulation.

diameter was measured for dry and water filled granules (Fig. 2), and it was found that in the studied range of RDX contents that diameter decreases to about one third when the explosive is filled with water.

#### 2.4. Variation of the critical diameter of the TNT-Water mixture with granulation temperature

As it was already mentioned granulation consisted in pouring the melted TNT into water. The temperature of the water was a factor controlling the crystallization rate of TNT and affecting the structure of the polycrystalline granules. The variation of the critical diameter of TNT-water mixture with the temperature of water in the granulation process is shown in Fig. 3. The measurements were carried out for the 1.0 mm-2.5 mm TNT granule fraction.



**Figure 4.** The relation between the critical diameter of explosives and the water content.

#### 2.5. Variation of the critical diameter of explosives with water content

Measurements of variation of the critical diameter in function of water content were carried out for several explosives: granulated cast TNT/RDX 50:50 of grain size 0.2 mm-0.5 mm and 1.5 mm-2.5 mm, RDX of crystal grain size 0.1 mm-0.3 mm, and PETN of crystal grain size 0.2 mm-0.5 mm (Fig. 4). RDX and PETN were obtained by slow crystallization from acetone. The crystals were regular and revealed only minimal defects under a microscope. Mixtures with a water content exceeding 30% formed suspensions. To prevent sedimentation 1% of guar-gum was added to the water. As it is seen from the plots in Fig. 4 addition of water to the explosives can produce a decrease or increase of the critical diameter.

#### 2.6. Variation of the detonation velocity of explosives with water content

The effect of water content on the detonation velocity of explosives is presented in Fig. 5. For RDX of grain size 0.1 mm-0.3 mm the measurements were carried out using charges of 30 mm in diameter, for the granulated cast TNT/RDX 50:50 of grain size 0.5 mm-1.0 mm and for PETN of grain size 0.2 mm-0.5 mm in charges of 18 mm in diameter.

### 3. Discussion

The variation of the critical diameter of explosives after filling with water (Figs. 1 to 4) should be considered in terms of the structure of the individual grains. If the explosive crystals are homogeneous, then their filling with water produces a distinct increase of the critical diameter. However, if the explosive crystals are non-homogeneous (polycrystals), then the critical diameter of the explosive-water mixture decreases. In both cases the difference between the critical diameter of the dry and water filled explosives increases with the size of the crystals. The detonation velocity of water filled explosives is greater than that of the dry material, irrespective of the structure of the crystals.

These effects can be explained in terms of the hot-spot theory which identifies the hot spots with the non-homogenei-

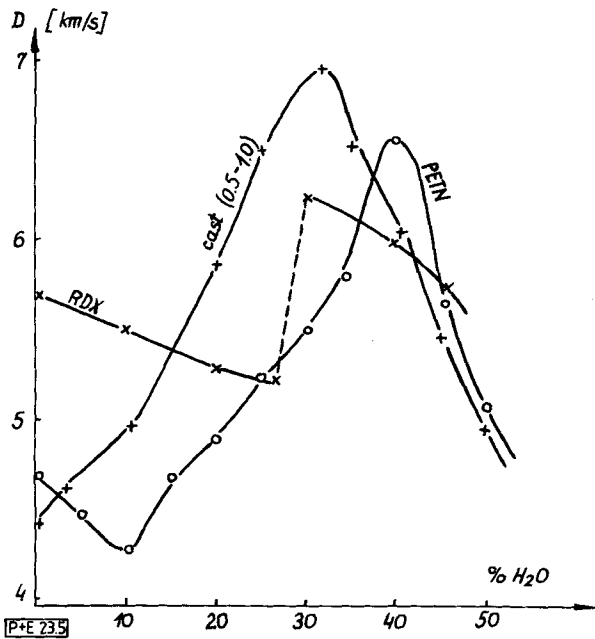


Figure 5. The relation of the detonation velocity of explosives and the water content.

ties of the explosives<sup>(3)</sup>. Let us classify the hot spots into external and internal ones depending on their location in the explosive particles (granules, crystals).

The external hot spots are located on the surface of particles. It can be supposed that, for instance, the sites of contact of the neighbouring particles can function as external hot spots. Reduction of the particle size of the explosive leads to the increased number of contact sites and hence to the corresponding growth of concentration of the external hot spots.

The internal hot spots are situated inside the explosive particles and therefore have practically no contact with the atmosphere. It can be supposed that the role of internal hot spots is played by macrodefects of the crystal lattice, inclusions of foreign solids or gases, etc. Disintegration of particles including those hot spots has a very limited effect on the lowering of their concentration.

The critical diameter is a parameter measured under conditions maximally unfavourable for the development of the detonation. Therefore the concentration and efficiency of the hot spots play a decisive role. Increased disintegration of the explosives, leading to increased concentration of the external hot spots, gives the well known phenomenon consisting in the reduction of the critical diameter (curve 1 in Fig. 1). As can be seen from the data in Ref. 2, an increase of concentration of the internal hot spots at constant grain size also produces a decrease of the critical diameter of the dry explosive, though much less pronounced.

Mixtures of explosives and water have as a rule detonation properties different from the dry material. The filling of the explosive with water causes the extinguishing of the external hot spots. If the explosive particles contain no internal hot spots, then the critical diameter will increase markedly on filling with water (Fig. 4), and the susceptibility to initiation by the shock wave will decrease distinctly<sup>(4)</sup>. However, such a

mixture reveals more advantageous properties as regards the propagation of the shock waves. This means that the energy losses on the shock wave front are smaller than in the case of the dry material and the pressure achieved are higher. Thus, if the explosive particles have internal hot spots, then filling the explosive with water will increase their activity. It can be believed (Figs. 1 and 2) that the increase of activity of the internal hot spots is sufficiently strong to compensate not only the effect of extinguishing the external hot spots but also to produce a significant lowering of the critical diameter. A decrease of concentration of the internal hot spots produces a distinct increase of the critical diameter of the water filled explosive (Fig. 3).

It can be concluded therefore that the critical diameter of dry explosives depends strongly on the concentration of the external hot spots, whereas the critical diameter of water filled explosives depends chiefly on the concentration of the internal hot spots.

Thus we can distinguish two factors contributing to the change of the properties of water filled explosives:

- improvement of the conditions of propagations of the shock wave owing to expelling air from the mixture,
- deterioration of the conditions of development of the detonation due to the extinguishing of external hot spots (desensitization effect).

The detonation velocity was measured in charges of diameter larger than the critical but smaller than the limiting one. In this range the detonation velocity is affected in a certain degree by, e. g., the charge confinement, size of the crystals and their structure. However, decisive here is the density of the explosive. The increase of the charge density as a result of pressing or filling with water is equivalent to the air content decrease which improves the conditions of shock waves propagation in the given medium. That factor is decisive for the increase of the detonation velocity in water filled crystalline explosive. A certain minor effect can be due to the concentration of hot spots, and a significant lowering of that concentration may decrease the detonation velocity. When the content of water in an explosive of high crystal homogeneity is low, both those opposing effects can be equal, or even the second one can prevail. This is how one can justify the minimum in the detonation velocity versus water content plots for PETN and RDX (Fig. 5).

To conclude, it should be admitted that the lack of physical interpretation of the mechanism of operation of the two kinds of hot spots is a deficiency of the present work. However, the suggested classification of the hot spots can be assumed purposeful if we consider the simple and reasonable interpretation of the described experiments.

#### 4. References

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