EFFECT OF SHELL'S DYNAMIC RIGIDITY ON DETONATION PROPAGATION IN FLAT CHARGES OF INSENSITIVE TATB-BASED EXPLOSIVES

S.M. Dolgikh, M.A. Sokolov, V.N. Smirnov, E.B. Smirnov
sokolovm1982@mail.ru

Russian Federal Nuclear Center – Zababakhin All-Russia Research Institute of Technical Physics, Snezhinsk, Russia

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Detonation front propagating in the finite-transverse-size charges is bent. The angle of detonation front with the adjacent plate depends on the rigidity, i.e. acoustic impedance, of this plate's material. Well-known beryllium properties such as high Young's modulus, low Poisson ratio, etc., are due to the increased velocity of sound in Be. The presence of a high-rigidity Be wall adjacent to charge should lead to detonation front unbending. However, high sound velocity of ≈8.1 km/s causes the shock wave to propagate in Be faster than a detonation wave. It goes ahead of detonation front and slightly compresses the thin HE layer adjacent to Be. As a result, the thin HE layer located near the insensitive HE charge boundary can fail to detonate.

In the experiments described, the sliding mode of HE detonation propagation was attained. Two compression waves developed in Be therein. The first one is an elastic wave with the velocity 1.8 times higher than that of HE detonation. This wave always gets ahead of detonation front which means that this is a detached wave. It is responsible for slight side-contact pre-compression of nonreacting HE, which determines the detonation character. The second wave is plastic. It can be either a shock wave or a simple compression wave. So, different scenarios of this wave propagation are possible. For example, it can be an attached wave or it can go ahead of detonation front but at a smaller distance than the elastic wave does [1]. Attached wave causes no preliminary HE compression. The plastic wave front observed in experiments was slightly convex in the direction of its travel or even plane and not completely perpendicular to the side surface (Figure 1).

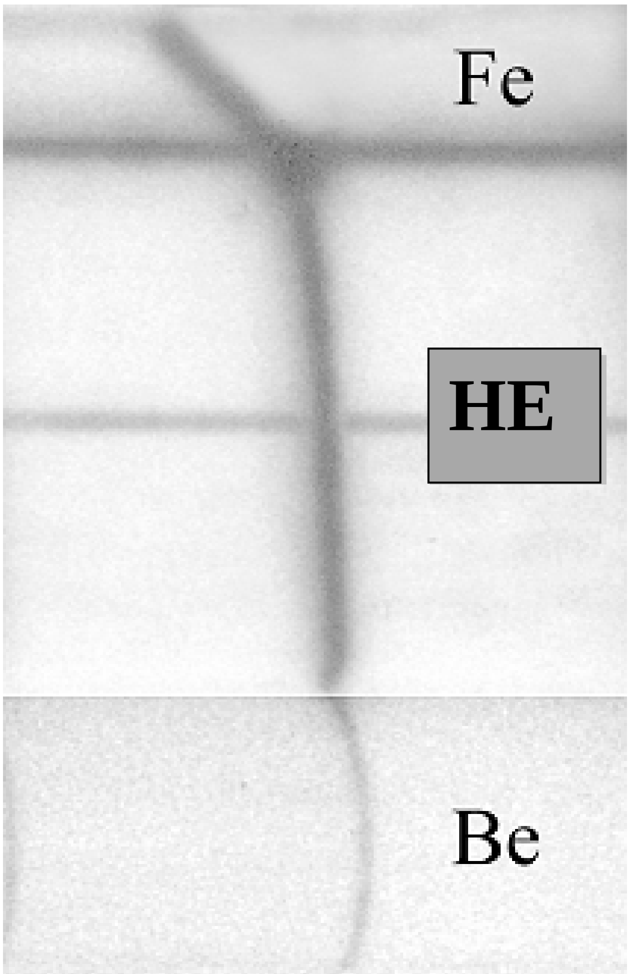


Figure 1. Streak-camera record revealing detonation front shape in HE charge and shock wave shape in Be (time from right to left, V_{sweep}=3 mm/μs)

The paper discusses results of experiments aimed to study the interaction between the shock wave and the detonation wave using a flat charge made of insensitive HE enclosed in steel and beryllium on lateral sides (Figure 2).

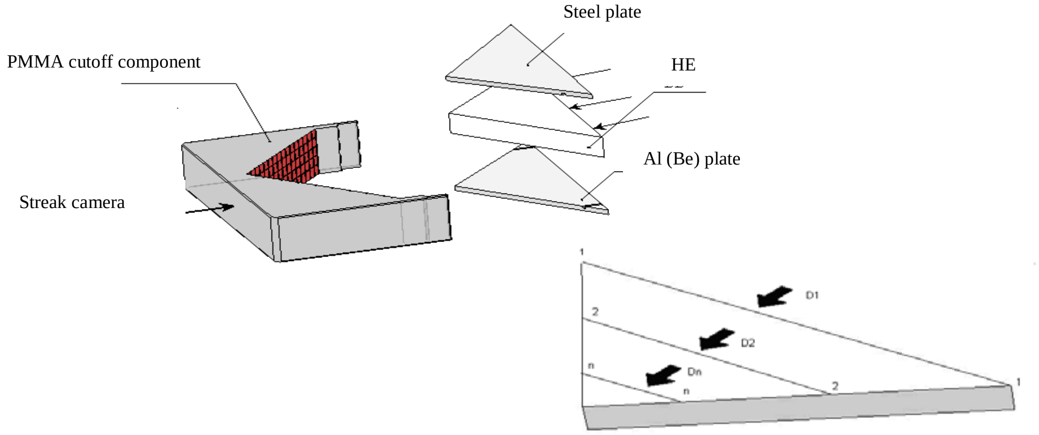


Figure 2. Experimental assembly without a casing

Experimental setup that uses streak-camera photorecording, or scanning analysis, and wedge-shaped samples has an advantage of simultaneous observation of the detonation front in HE, the plastic wave in Be, and the shock wave in steel, as well as of the shock pulse transfer from HE to steel through the layer of isentropically compressed beryllium. At that, the whole range of waves was studied over time. We acquired the data on how beryllium effects the detonation front flattening and unbending. It is shown that the $D_{Be}>D_{HE}$ and $V_{Be}>D_{HE}$ inequalities establish conditions for the development of overtaking perturbations in detonating HE. Unlike the lagging ones, the overtaking perturbations are very distinct and have diverse effects on detonation front, which include acceleration of front, extinction of detonation in the adjacent layer, formation of transverse wave sources, and detonation front unbending. Such a variety of effects is not observed when insensitive HE is placed adjacent to conventional materials.

Experiment is an effective method to study the direct and indirect reactions when using the “insensitive HE – Be” scheme. It should be emphasized that plastic wave velocity in Be is only 4% higher than that of HE detonation. In fact, we can assume that $D_{HE}\approx V_{Be}$. From the perspective of weak perturbations propagating in Be, the situation when perturbation source, namely the detonation wave observed in the insensitive TATB-based explosive, moves at the sound velocity should be treated as a special case. At any given time, the early and late perturbations in Be have a common point of contact, which coincide with the moving detonation-wave point of contact (Figure 3). Similar results are given in paper [2].

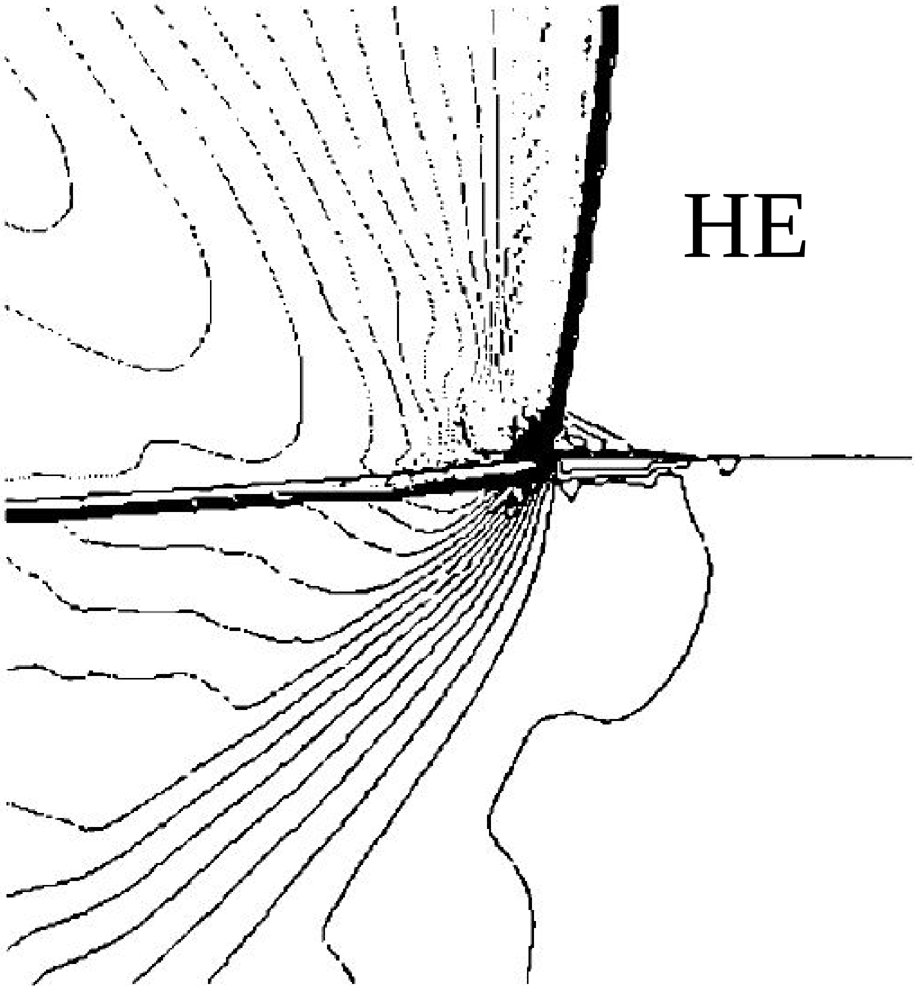
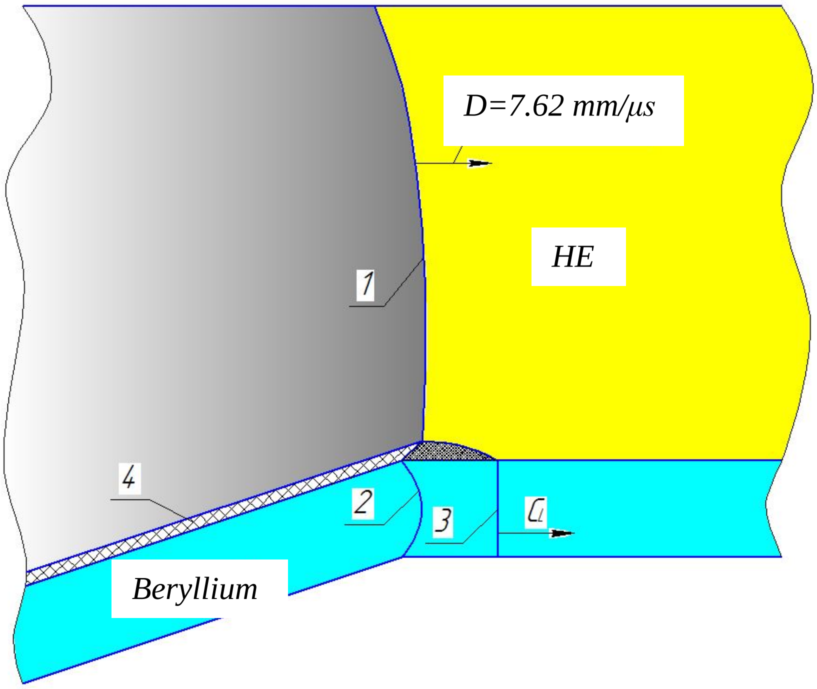


Figure 3. Flow fields and constant- pressure lines in the insensitive TATB-based explosive and the Be shell

Let us discuss the detonation extinction experimentally observed in the thin HE layer at the beryllium boundary. All experts share one view on the nature of preliminary HE compression in the experiments with Be and ceramic wall. It is believed that pre-compression is due to an oblique shock wave observed in the near-wall layer. The difference is in the treatment of reasons why this oblique shock wave is developed. According to paper [3], detached plastic wave in Be is deemed to be responsible for this phenomenon. In our experiments, the reason is an elastic precursor observed in Be since the plastic wave appeared to be attached to the detonation front. In the experiments with ceramics [4], the treatment is similar to ours (Figure 4).



1 – detonation wave front in insensitive HE, 2 – compression wave in beryllium, 3 – elastic precursor, 4 – nondetonating layer.

Figure 4. Detonation front shape observed when insensitive HE contacts with Be

Methodically, it is a challenging task to register inert thin layer against a thick Be wall. Attention should be paid to a phenomenon observed in the experiments, i.e. the local detonation front lagging near Be boundary (Figure 2). Suppose that this is a local detonation extinction response. Let bend layer thickness be the thickness of an inert HE layer. Experimental measurements taken after the detonation wave travelled the distance of 90.64 mm are given in Table 1.

Table 1. Inert HE layer thickness

Porosity, %	2.2	1.5	1.2
Inert layer thickness, mm	0.97±0.13	0.95±0.24	1.14±0.23

Variation of insensitive HE porosity causes practically no changes in the inert layer thickness.

When beryllium is loaded by the detonation front which is perpendicular to contact boundary, the wave propagating in parallel to this boundary and having a low curvature front is registered in Be. The overtaking wave front point is observed in the middle of Be layer and has a lead of ~0.2 μs when compared to detonation wave front. Such wave behavior differs markedly from that of conventional oblique wave typical for materials with moderate sound velocity. The registered wave velocity of ~7.9 mm/µs is close to volumetric sound velocity for Be, V_{Be}=7.9÷8.1 mm/µs [5, 6]. Hence, mass matter velocity behind the front of this wave is close to zero, which means that it is very weak. In paper [2], they also registered a weak shock wave, D_{Be}=8.2 mm/µs. In such a wave, compression is as low as ~2 %.

Therefore, one could conclude that for the case of sliding detonation, Be loading by the explosion products is almost shock-free, i.e. isentropic.

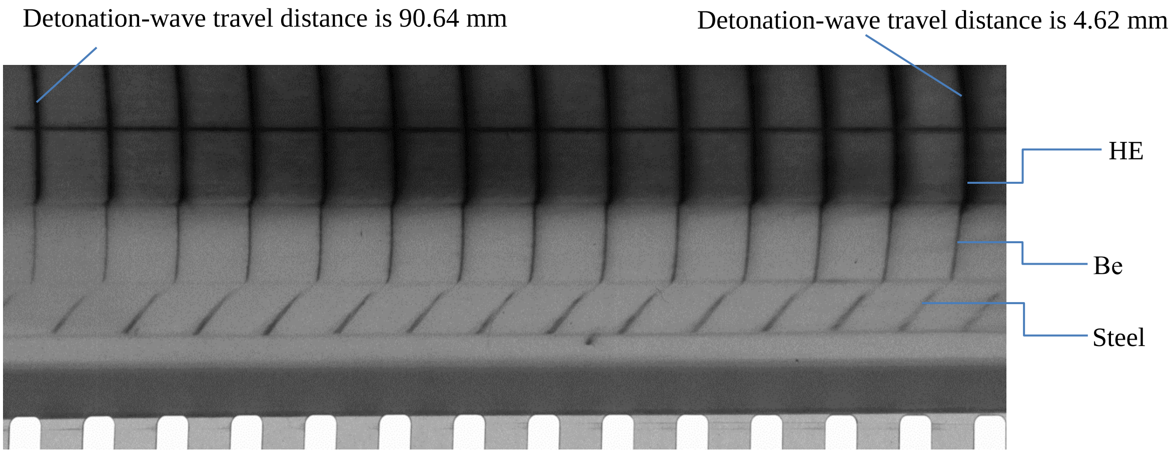
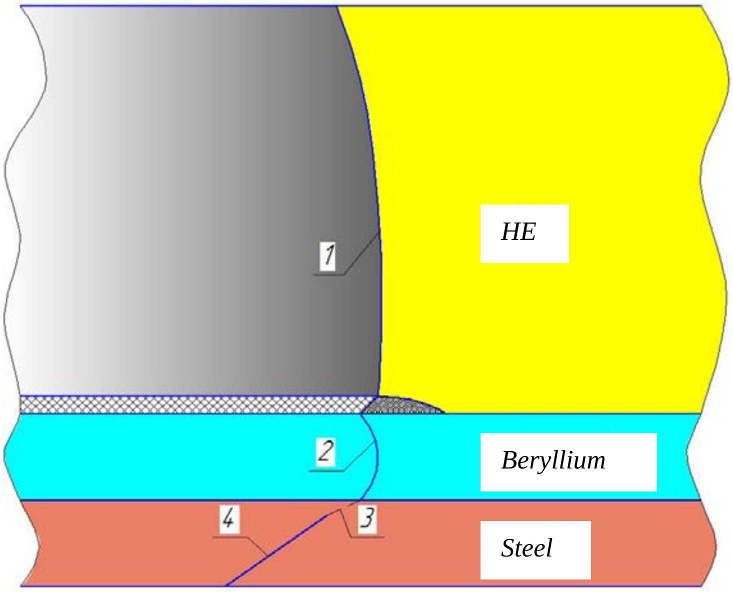


Figure 5. Streak-camera record from the experiment (time from right to left, V_{sweep}=2.25 mm/µs)

Turn attention to the process of shock-wave formation in the Be-adjacent steel (Figure 5). In the steel barrier, we can see two light traces, one following the other, having different intensity and angle of slope. For details, refer to the legend in Figure 6. Compared to the second one, the first trace is less intensive and has a smaller angle of slope. The same pattern is realized in other experiments with beryllium for both convex and plane plastic-wave front.



1 – detonation wave front in insensitive HE, 2 – compression wave in beryllium, 3 – acoustic wave in steal, 4 – shock wave in steel.

Figure 6. Detonation front shape and shock wave shape under sliding detonation of insensitive HE enclosed in beryllium and steel

Compared to the second one, the first trace is less intensive and has a smaller angle of slope (24° and 35°, respectively). The first trace is estimated to be an acoustic wave and the second trace – to be a shock wave with the pressure of 16.3 GPa at the shock front. This pressure is attained when the compression wave amplitude in Be equals 12 GPa. Thickness of the “acoustic” layer in steel is ~1.8 mm. It is interesting that the wave slope angle is estimated (acoustic approximation) to be 29° and this is in a fairly good agreement with the experimental data. So, acoustic effects are observed to be involved when the detonation pulse is transferred through the thick beryllium layer.

Another very important characteristic of an explosive material is its critical thickness of detonation as it determines HE detonability. The critical detonation thickness is a non-constant value that depends on different factors attributed not only to the manufacturing process, but also to conditions of HE practical application.

The "cross" wedge method was used for our investigation wherein the interruption of light in the PMMA cutoff component indicated the detonation extinction location. A series of experiments was performed with wedges made from explosives with the ≈1.5% porosity when these HE wedges were adjacent to PMMA (organic glass), fluoroplastic, magnesium, aluminum, beryllium, and copper plates.

Our experimental assembly (Figure 7) comprised the wedge-shaped TATB-based HE sample placed on the 10-mm thick plate of the test material. The vertex angle of the HE wedge was α=3°, the wedge width was equal to 245 mm, and the wedge length equaled 30 mm.

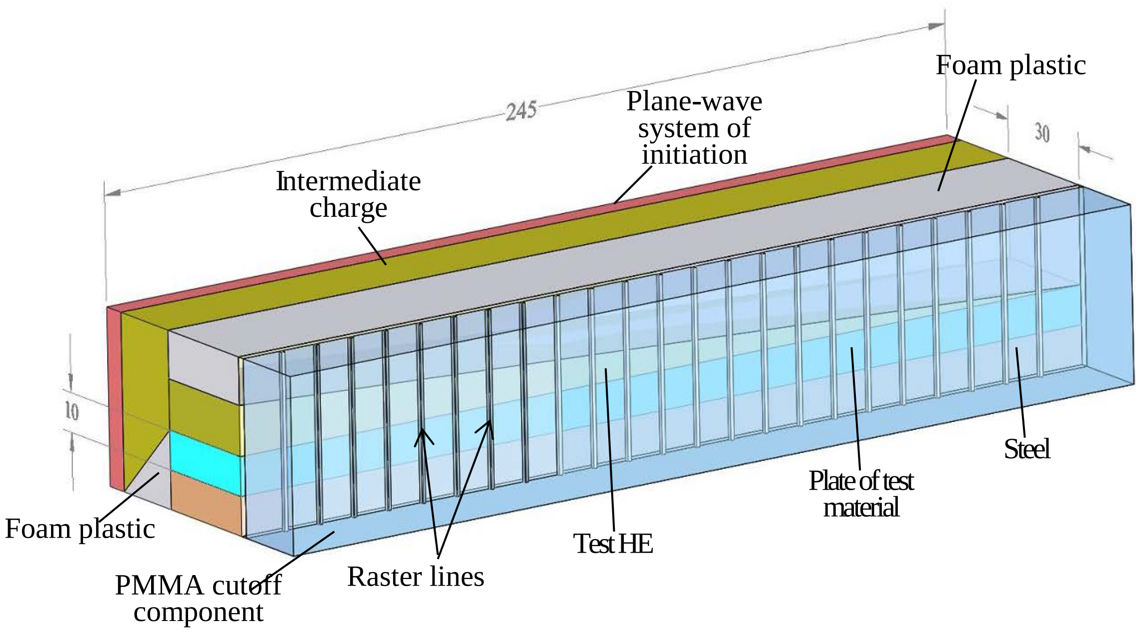


Figure 7. Schematic experimental assembly

In experiments, streak-camera with the sweep velocity of V_{sweep}=2.25 mm/μs served to record, through raster lines, light from the shock and detonation waves when they arrived at the surface adjacent to PMMA cutoff component. This made it possible to determine the detonation front shape in the HE charge, the shock wave shape in the plate of the test material, as well as the location of detonation attenuation.

Figures 8÷13 show typical streak-camera records. These records give a good view of the HE wedge section without explosive transformation (no light in raster lines) and with the detonation propagation (light is observed in raster lines), as well as a good view of shock waves in plates under the wedge and in the foam plastic over the wedge.

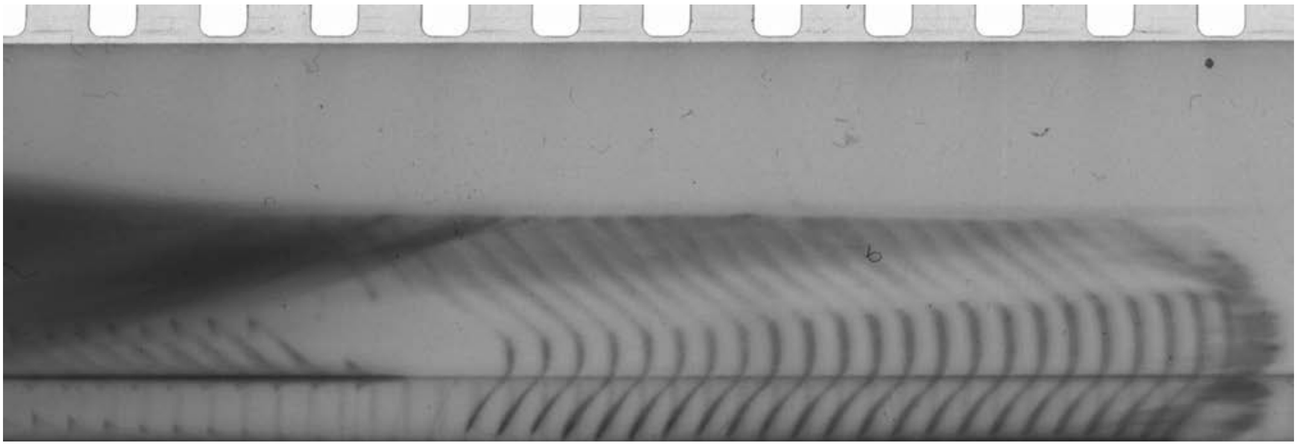


Figure 8. Streak-camera record from the experiment with the PMMA plate

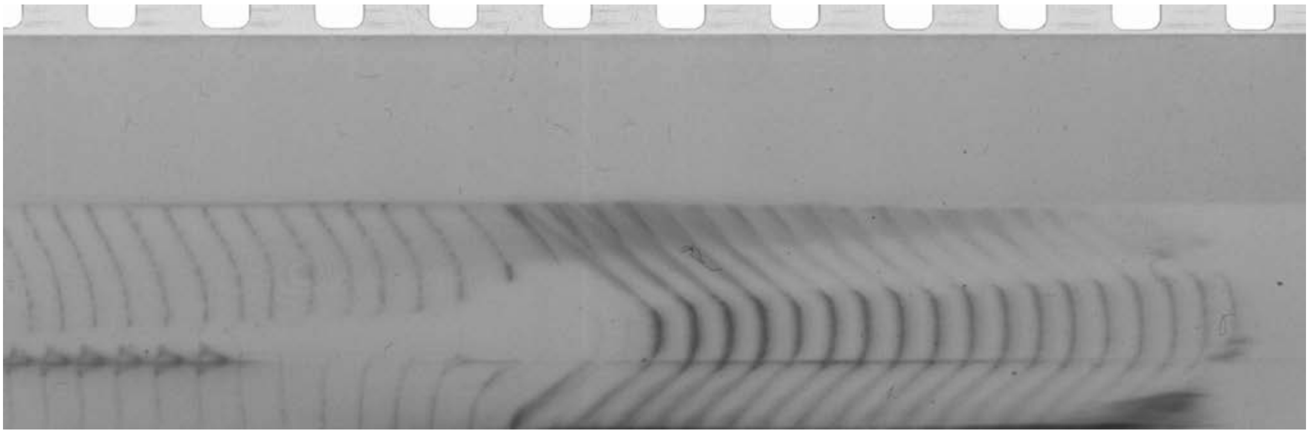


Figure 9. Streak-camera record of the experiment with the fluoroplastic plate

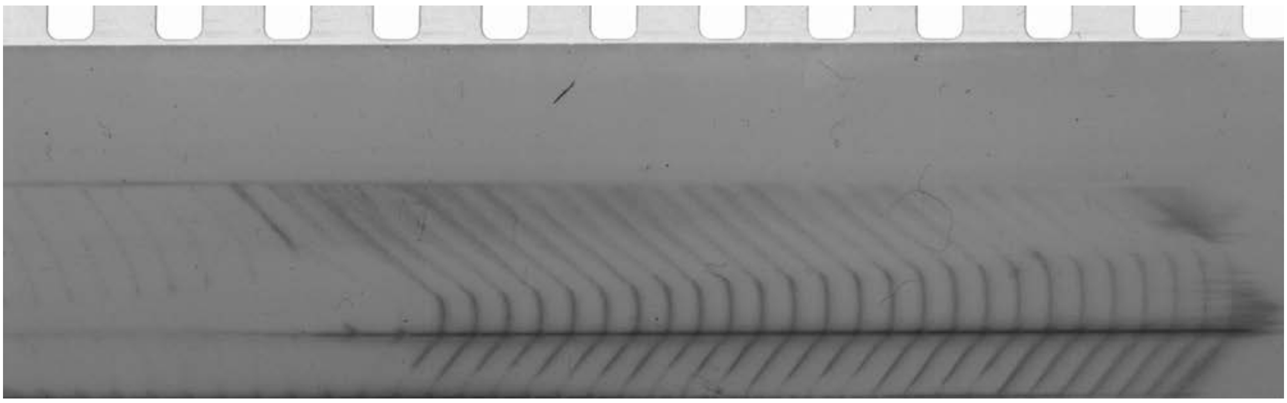


Figure 10. Streak-camera record from the experiment with the magnesium plate

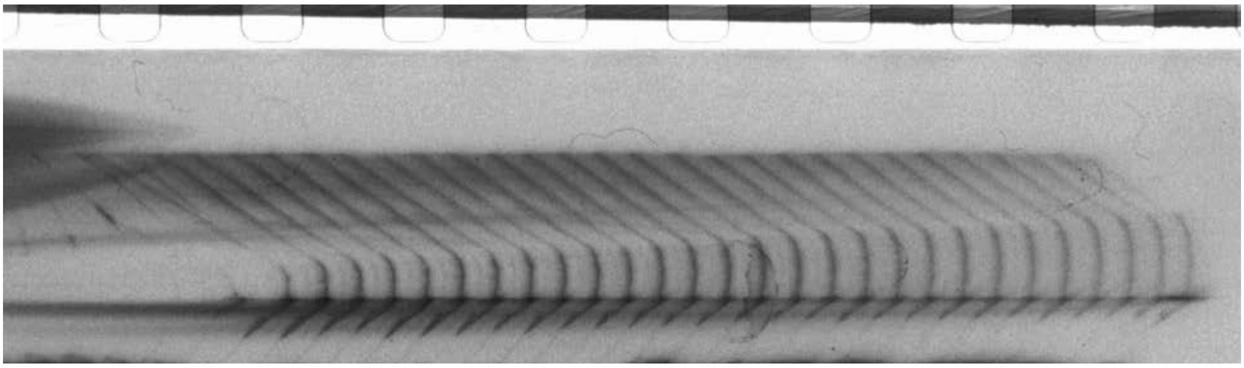


Figure 11. Streak-camera record from the experiment with the aluminum plate

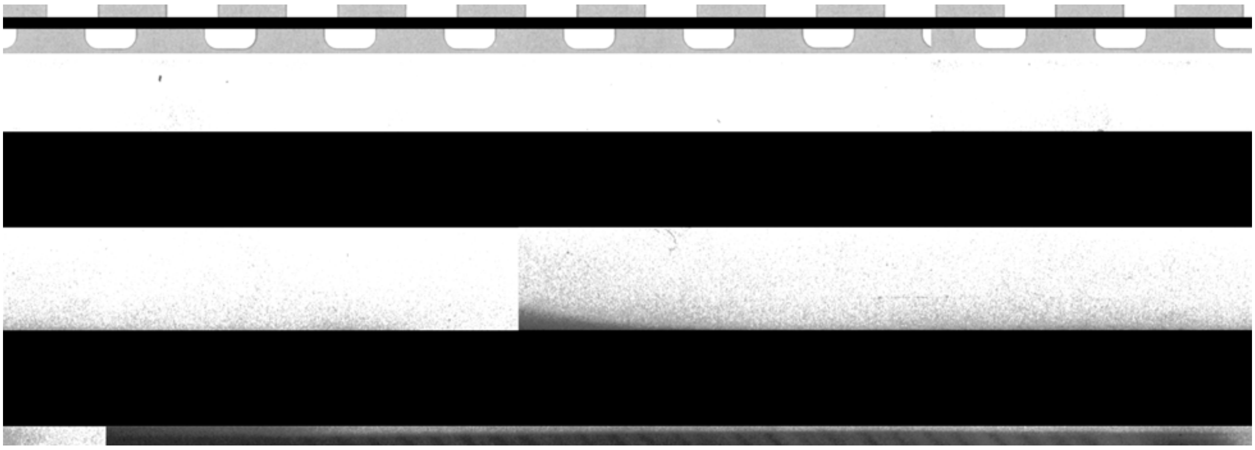


Figure 12. Streak-camera record from the experiment with the beryllium plate (raster lines opposite to the beryllium plate have 10-mm spacing)

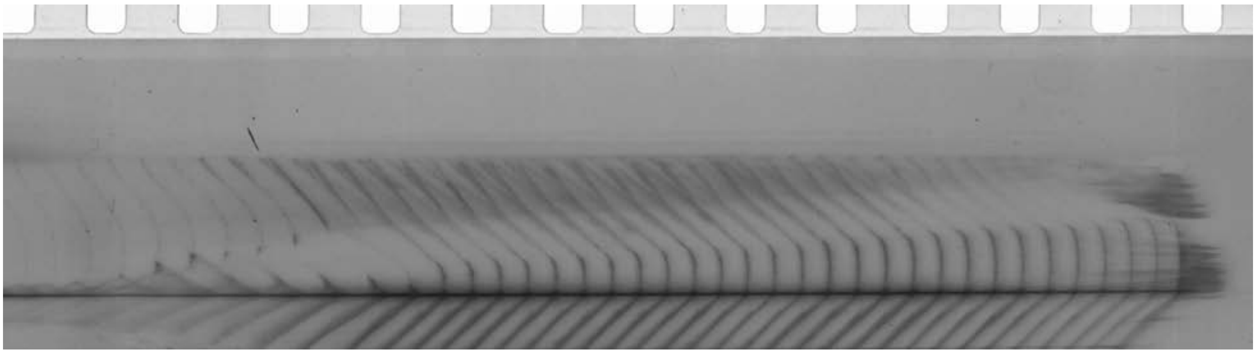


Figure 13. Streak-camera record from the experiment with the copper plate

Results given by the series of experiments are plotted in Figure 14 as the critical thickness, h_{cr}, of HE detonation versus rigidity of the contacting plate material, $\rho{\cdot}V_{mater}$.

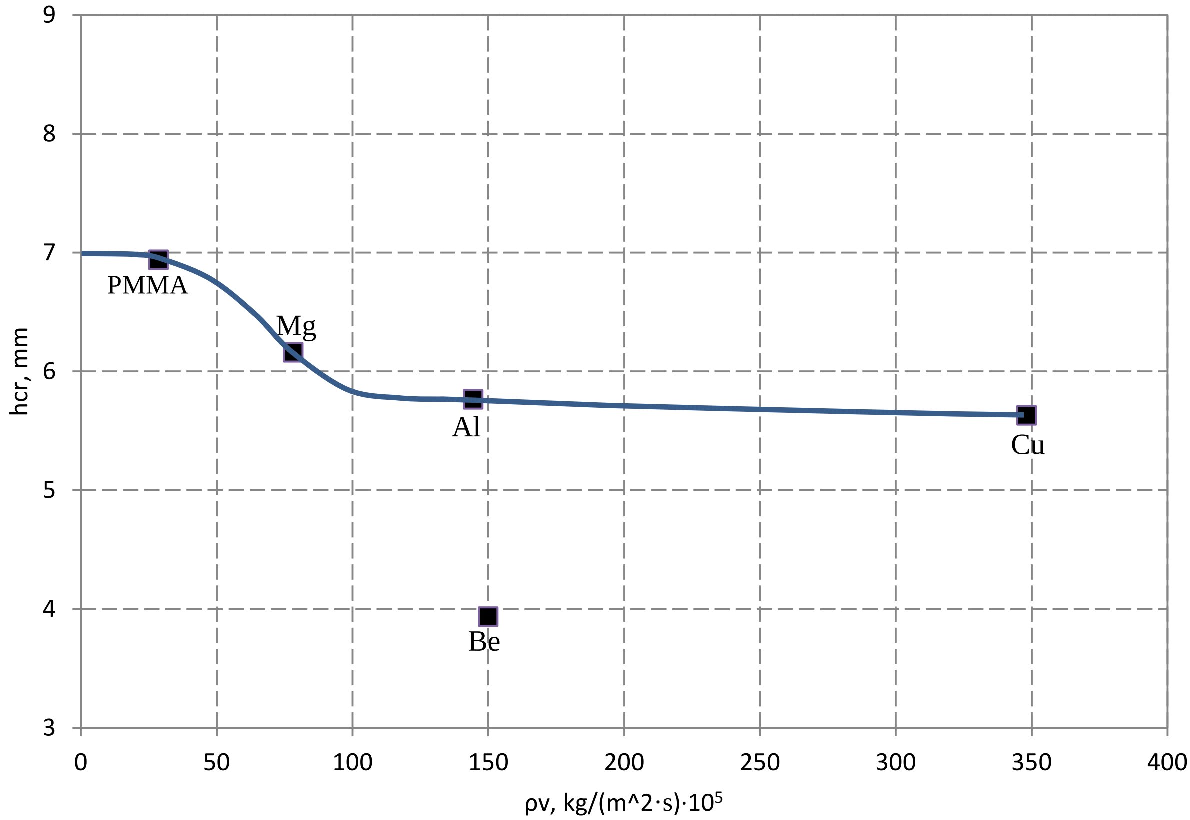


Figure 14. Critical thickness of detonation versus rigidity of HE-adjacent material

From Figure 14, it is obvious that compressibility of the contacting plate material influences the critical thickness of TATB-based HE detonation and this relationship agrees with the previous one from [9]. Our results confirm the conclusion from [10] that presence of a material with greater compressibility compared to that of the HE charge causes no changes in the front shape along the contact boundary and, thus, no decrease in the critical thickness of detonation.

Measurement results shown in Figure 14 demonstrate that the critical thickness of detonation in the experiment with the beryllium plate “falls out” of the general relationship. Compressibility of beryllium is close to that of aluminum and two times less compared to copper though critical thickness of the detonating HE adjacent to beryllium is by ≈30% less than in the case of contact with two other materials.

A smaller critical thickness of HE detonation in the experiment with beryllium can be explained by certain features existing in the detonation front propagation along a particular material and these features are due to the “HE detonation velocity – sound velocity” ratio in beryllium.

Experimental results demonstrate that the critical thickness of detonation depends both on compressibility of the contacting material when D>V, and on the sound velocity in the contacting material when D<V. Similar conclusions are made in paper [10].

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