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Initiation and Correction of the Detonation Wave in the Shaped Charge Peripheral Zone

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Regular and centric initiation and further axis-symmetric propagation of the detonation wave have a significant role in shaped charge functioning. The generated form of the detonation wave also represents a very important parameter of metallic liner collapsing and the whole shaped charge effect. The choice of a more acceptable profile of the detonation wave enables the increase of this charge penetrability. From this point of view, some aspects of explosive charge initiation and the possibilities to shape the detonation wave in the shaped charge were considered. In an attempt to generate a detonation wave of a required form in the peripheral zone of the charge, a two-part explosive charge made of explosives with different detonation velocities was analyzed. Some results related to the numerical simulation and experimental testing of the detonation wave in 60 mm caliber shaped charge models are given

Key words: **physics of explosion, shaped charge, initiation, detonation wave, numerical simulation, 60mm caliber.**

Introduction

ASSUMING that an explosive-driven system consists of an explosive charge and an inert (metallic) liner, then, for a given form and mechanical characteristics of the metallic liner, the initial conditions of its collapsing depend only on the detonation wave parameters - the detonation velocity, the detonation pressure, and the profile of the detonation wave determining the local collision angle of the detonation wave and the metallic liner, i.e. the detonation wave attack angle. In the case of a shaped charge, a detonation wave of required parameters must be generated in order to obtain the required exit collapsing parameters of the metallic liner (final liner collapse angle and liner collapse velocity) and thus reach the maximum velocity of the jet and the highest jet penetrability.

Theoretical and experimental research of the initiation, propagation and detonation wave optimization in shaped charges has been largely performed [1, 2]. The research results showed that the optimization of detonation wave parameters in the *central zone* of a shaped charge could be performed and in the same time accepted in real designs of shaped charges [3, 4]. However, the optimization of detonation wave parameters in the *peripheral zone* of these charges cannot be realized easily.

The basic goals of theoretical and experimental research of this work include the activities as follows:

- brief retrospective of shaped charge initiation and clarification of the processes occurring during the interaction of the detonation wave and the inert body (waveshaper),
- consideration of the possibilities of detonation wave profile optimization in the shaped charge,
- numerical simulation of detonation wave propagation and testing of a real profile of the detonation wave in the shaped charge experimental model, and
- comparing the results of the numerical simulation and the experimental testing.

The theoretical determination of the detonation wave profile was carried out using the software for numerical simulations based on the finite element method.

The experimental research was performed with the help of:

- the IMACON 790 high speed camera and methods of the high speed recording in streak and framing techniques, and
- the SCANDIFLASH 600 kV Roentgen equipment and the method of impulse radiography.

Shaped charge initiation and detonation wave propagation

References related to the analysis of shaped charge functioning that consider the initiation of booster charges, so-called primary initiation, are not largely available. The reason is their indirect but not negligible influence on shaped charge effects. On the other hand, the initiation of the main explosive charge, linked with the booster charge over the contact ring surface, occurs over the mentioned surface. This initiation, so-called secondary initiation, has significant influence on the profile and further propagation of the detonation wave through the explosive charge affecting the process of charge functioning.

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Primary initiation

Regular initiation of the detonation of the explosive component in the shaped charge is carried out through a special assembly called initiating and detonating device[1]. Its important component is a detonating cap that initiates the explosive process in the detonator. A classical detonating cap has a cylindrical form and relatively small dimensions (4 to 8 mm in diameter). It provides point initiation and, more or less, eccentric initiation of the detonator that causes a negative effect on the shaped charge functioning and its penetrability.

The dependence of the axis-symmetry of the detonation wave on the eccentric point initiation was tested [1] using a cylindrical detonator of 40 mm in diameter and a detonating cap of 7 mm in diameter, illustrated in Fig.1.

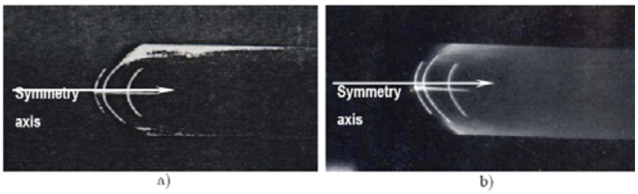


Figure 1. Streak recordings of an emerging detonation wave: a) centric initiation; b) eccentric initiation (4 mm eccentricity)

Modern shaped charges use self-centering initiating devices (Fig.2) which eliminate the eccentricity of initiation owing to their special design and provide the centric initiation of detonator charges [1, 5].

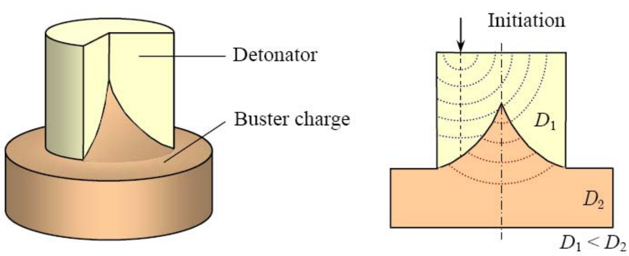


Figure 2. Self-centering initiating device with a schematic sketch of its functioning

The initiation of detonation and further axis-symmetric detonation of the whole explosive charge is obtained by an appropriate choice of:

- Shape of the contact surfaces between the detonator (or transducer) charge and the explosive charge in the booster, and
- Ratio of the detonation velocities of the explosives in the detonating cap and in the detonator. There we have to satisfy the condition that the detonation velocity of the explosive in the detonator D_2 must be more intensive than the detonation velocity in the detonating cap (about 20%).

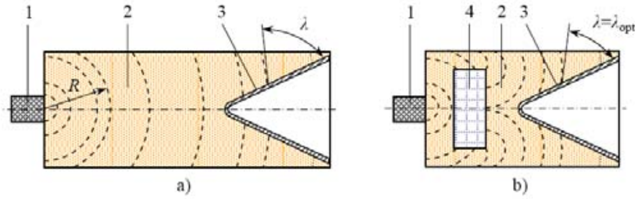
By an appropriate choice of the shape and detonation velocities of the explosive charges in the detonating cap and the detonator (or the booster charge), we will successfully initiate the axis-symmetric initiation and further detonation wave propagation independently of the eccentricity of initiation.

[1] Initiating and detonating device consists of a detonating cap – it is often a part of fuzes, detonators, boosters and waveshapers. This device is intended to accept and reinforce the initiating impulse generated by the fuze and then to initiate the regular and total detonation of the explosive charge.

Secondary initiation

As mentioned above, the secondary initiation is very important for detonation wave shaping. Namely, the conditions of energy transfer from the detonation products to the metallic liner depend on the profile, i.e. on the attack angle λ of the detonation wave (Fig.3a).

So the most favorable conditions of energy transfer and, at same time, the maximum kinetic energy of the collapse liner will be achieved for $\lambda = \lambda_{opt}$[2] [1] (Fig.3b).



1 – Initiating and detonating device; 2 – Explosive charge; 3 – Metallic liner; 4 – Waveshaper

Figure 3. Optimization of the detonation wave shape in the shaped charge: a) without waveshaper; b) with waveshaper

In the shaped charge without the waveshaper (Fig.3a), considering that the detonation process is initiated by point due to very small dimensions of initiators, the stabilization and correction of the detonation wave are carried out increasing the length of the explosive charge. In other words, according to the Huygens' Principle of wave propagation, as the distance from the initiation point increases, the radius R of the detonation wave profile increases and its curvature $\rho=1/R$ decreases optimizing the shape of the detonation wave for a certain value. Meanwhile, for the distances over 3 or 4 calibers [6, 7] the radius of the detonation wave curve becomes stable, so the profile of the detonation wave stays constant independently of the length of the shaped charge.

The number of possibilities of shaping the detonation wave into a desired form significantly increases by introducing the waveshaper into the shaped charge (Fig.3b). Owing to the waveshaper, generating a detonation wave with a shape closest to its optimum profile is more effective than in the previous case. The full efficiency of the waveshaper requires a significantly smaller length of the shaped charge keeping its total mass as small as possible.

The inert materials usually used for waveshaper manufacturing are rubber, metal, glass, ceramics and, most frequently, plastic masses like Teflon, Polyetilene, etc. The primary role of the waveshaper is to optimize a shaped charge design giving the required efficiency with the minimum mass of explosive charge in a provided shaped charge caliber.

Interaction of the detonation wave and the waveshaper

The waveshaper causes some different transient detonation processes in the shaped charge that are illustrated in Fig.4 [8]. They are classified into three typical groups:

- Transfer of the detonation wave from one explosive charge to another one which has different physical and chemical characteristics; it appears on the contact surface

[2] λ_{opt} assumes the value of the attack angle of the detonation wave that provides the best transfer energy of detonation products to the metallic liner and reaches its maximum velocity and kinetic energy.

between the detonator (booster charge) and the main explosive charge (Fig.4a).
- Interaction of the detonation wave and an inert obstacle; this is the case of the detonation wave propagating around the waveshaper (Fig.4b).
- Interaction of two detonation waves; this process begins at the end side of the waveshaper along the symmetry axis of the explosive charge and sometime generates the appearance of the Mach wave (Fig. 4c).

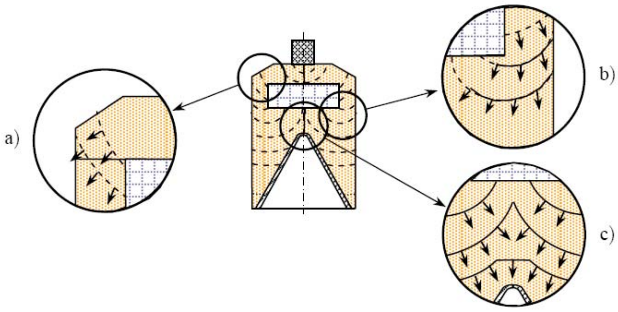


Figure 4. Typical appearances of the transient processes in shaped charges: a) Detonation wave transfer: b) Interaction of the detonation wave and the inert obstacle; c) Interaction of detonation waves behind the obstacle

In order to clarify the above mentioned processes, comprehensive theoretical and experimental research was carried out [9]. The research results were used to determine an optimum waveshaper design satisfying more at same time contradictory requirements such as its functioning and total mass, as well as technological, economical and other aspects.

The transfer of the detonation wave from the explosive of one type (active charge, donator or detonator) to the explosive charge of other type (passive charge or acceptor) was analyzed considering the flat contact and contour surfaces. Theoretical analyses have been considered for each of three cases of detonation propagating through contact surfaces depending on the colliding angle between the detonation wave and the contact surface as follows [1, 9]:
- Detonation transferring in the case of the lateral propagation of the detonation wave.
- Detonation transferring in the case of the detonation wave arriving onto the contact surface under some colliding angle.
- Detonation transferring in the case of the frontal arrival of the detonation wave onto the contact surface.

When we consider non-stationary detonation processes appearing during the interaction of the detonation wave and the waveshaper, we can conclude that there are two important and very different cases:
- Divergent propagation of the detonation wave that appears during its travel around the end side of the waveshaper. A test model for testing the propagation of the divergent detonation wave contains the cylindrical explosive charge and the passive hemispherical charge of a significantly larger diameter (Fig.5.). The experiments have shown that in the passive explosive charge there is a zone with the reduced parameters of detonation (subdetonation zone). Even a zone without detonation (nondetonation zone) appears as well (Fig.6.).
- Convergent propagation of the detonation wave that appears after its travel around the end side of the waveshaper. It includes the process of the detonation wave propagation after the peripheral initiation of the explosive charge, considering its arrival on the symmetry axis and self-interaction behind the waveshaper (Fig.7.).

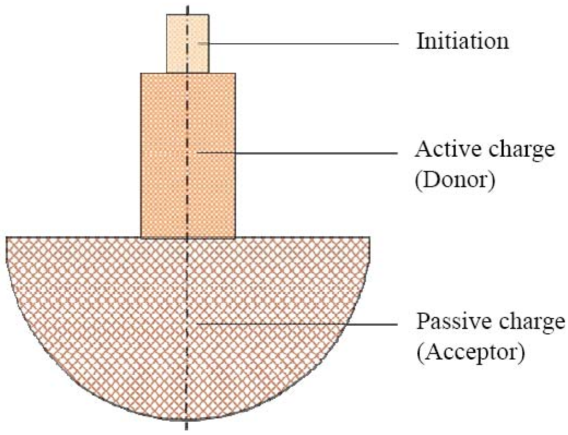


Figure 5. Test model for testing the divergent detonation wave propagation

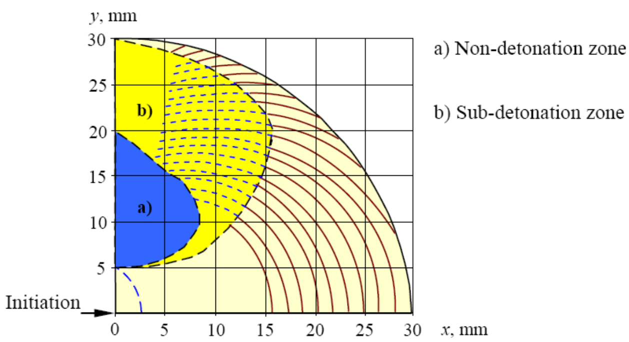


Figure 6. Detonation wave profiles $y = f(x)$ depending on time in the axial cross-section of the hemispherical explosive charge

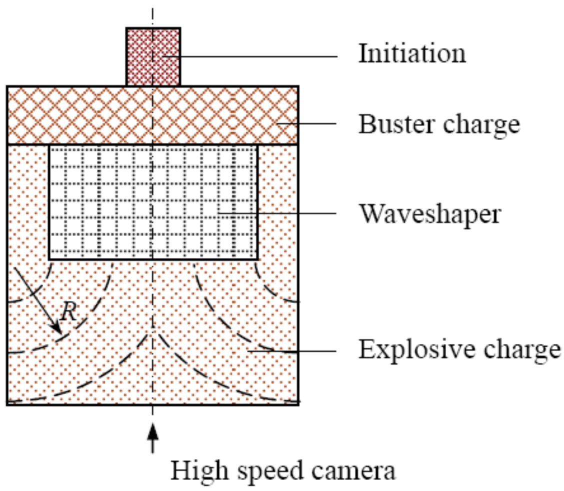


Figure 7. Test model for testing the convergent detonation wave propagation

The interaction of two detonation waves was analyzed assuming an ideal theoretical case. Namely, the contact surfaces as well as the detonation waves that come into interaction are considered to be absolutely flat. This appearance is very interesting from the point of view of the multi-initial systems used in some explosive propulsive systems for civilian and military purposes. In this way, the extensive experimental research into the interaction of two oblique waves was performed.

The interaction of two detonation waves, analogically to the interaction of shock waves, depends on their intensity and collision angle. There can be three typical groups of interactions illustrated in Fig 8.

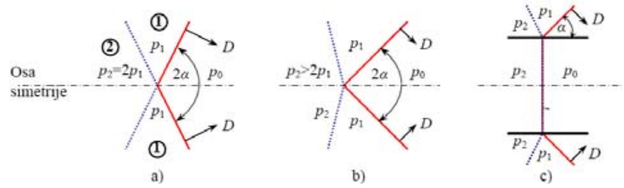


Figure 8. Interaction of two detonation waves: a) low intensity; b) medium intensity; c) high intensity

Fig.8 illustrates the ideal cases of interactions of oblique detonation waves of low, medium and high intensity. In comparison with the interaction of low detonation waves (Fig.8a), during the interaction of medium detonation waves (Fig.8b) the pressure p_2 in zone 2 grows up to the value higher than $2p_1$. At same time, relating to the symmetry axis the slope of the contour surfaces between zone 1 and zone 2 becomes steeper. In the case of the interaction of very intensive detonation waves (Fig.8c), a flat Mach wave appears in the zone of the symmetry axis.

Optimization of the detonation wave profile

The optimization of the detonation wave profile on the peripheral zone will be considered [10]. Supposing that the values of the design parameters of the shaped charge with the conical copper liner are constant and assuming only variations of the type and density of explosive charge while trying to generate a detonation wave with the parameters as desirable as possible, we carried out the research in two ways:

- Analysis of the possibilities of technological interventions for the correction i.e. the control of density distribution of the explosive charge to support continual increasing of the detonation pressure along the height of charge. This is possible owing to special procedures of casting and pressing technologies and relevant tools developed for the given purposes. In that way the initial density on the peripheral zone of the explosive charge ρ_1 changes more or less linearly to the value ρ_2 (Fig.9) and causes the increase of the detonation velocity and detonation pressure simultaneously decreasing the detonation wave attack angle.
- Analysis of the possibilities of design corrections of the explosive charge to generate a desired detonation wave profile. The principle of two-part explosive charge made of explosives with different detonation velocities was used here (Fig.10).

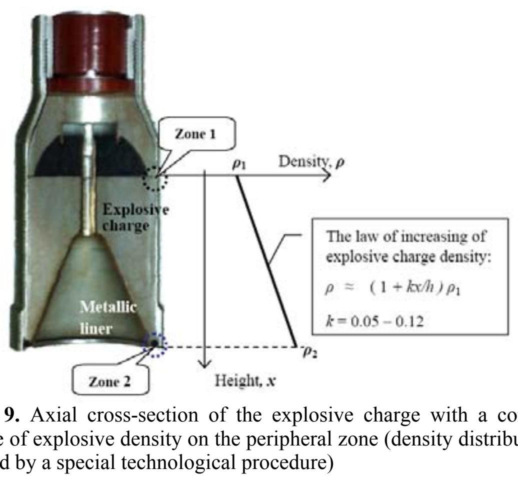


Figure 9. Axial cross-section of the explosive charge with a continual increase of explosive density on the peripheral zone (density distribution is provided by a special technological procedure)

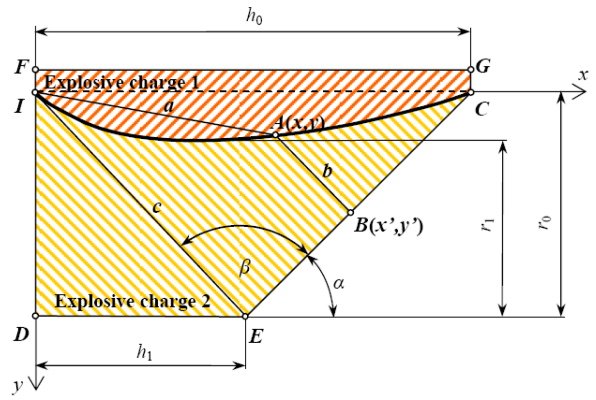


Figure 10. Axial cross-section of the two-part explosive charge with a calculation scheme for the determination of the contact line between explosive charges

One of simpler types of two-part explosive charges consists of the combination of the peripheral explosive part in the form of a hollow cylinder and the central explosive part. The peripheral explosive charge, with a wall thickness from 0.1 to 0.15 caliber, is of very high density and detonation velocity.

Theory

The theoretical analysis of the possibility to produce the required profile of the detonation wave was carried out supposing a 2-D model of the explosive charge and its ideal mechanical and detonation characteristics [11, 12]. The axial cross-section of the charge with a calculation scheme used to determine the form of the contact line between two explosive charges is shown in Fig.10. The form of $\overline{IAC}$ contact line was calculated supposing the simultaneous emerging of detonation wave (initiated in the peripheral point I) on the free surface of the hollow cone (line $\overline{CE}$).

In other words, in order to generate the conical form of the detonation wave at the moment of the arrival on the free surface of the hollow charge, the simultaneous emerging of the detonation wave on the line $\overline{CE}$ must be satisfied. This condition is described by the equation:

$$\frac{\overline{IA}}{D_1}+\frac{\overline{AB}}{D_2}=\frac{\sqrt{x^2+y^2}}{D_1}+\frac{\sqrt{x'^2+y'^2}-\sqrt{x^2+y^2}}{D_2}= =\frac{h_0}{D_1}=Const. \tag{1}$$

The detonation wave attack half-angle α depends directly on the selected types of explosives in the explosive charges 1 and 2, i.e. on their detonation velocities:

$$\alpha = f\left(\frac{D_1}{D_2}\right) \tag{2}$$

For the chosen detonation velocities D_1=8700 m/s and D_2=6200 m/s the half-angle α has the value $\alpha = 45°$.

Besides the abovementioned, for the regular generation of the conical detonation wave (with the assumed values of half-angle $\alpha = 45°$), the geometrical limitations of the used explosive charge require an additional condition concerning the value of the angle β (Fig.10):

$$\beta \geq 90^{\circ} \tag{3}$$

The algebraic curve of the second order with two independent variables in Eq. (1) represents the hyperbola that was approximated with two technological radii (Fig. 11). In that way, the geometry of the explosive charges was adapted for the pressing procedure in special tools.

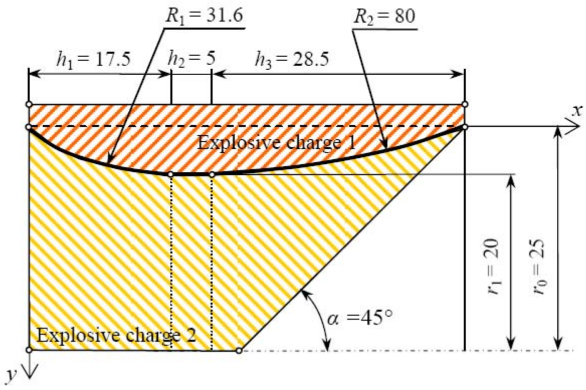


Figure 11. Approximated geometry of the contact line in the two-part explosive charge

Experiment and numerical simulation

Results of the experimental testing

A model of 60 mm explosive charge was used in the experiment (Fig.12). The basic geometrical and physical parameters of the shaped charge are as follows: two-part explosive charge (HMX and TNT), detonator (pentryte, density 1.61 g/cm^3), booster (hexogen, density 1.71 g/cm^3), inserted part (teflon, density 2.15 g/cm^3), angle of the metallic liner cone (inner 50º, outer 51º), metallic liner apex radius 8.5 mm, thickness of the metallic liner (progressive, min. thickness 1.0 mm), metallic body (duralumin, density 2.75 g/cm^3), thickness of the metallic body (1.5 mm) and waveshaper (teflon, density 2.15 g/cm^3). The initiation was provided punctually with an electrical fuze.

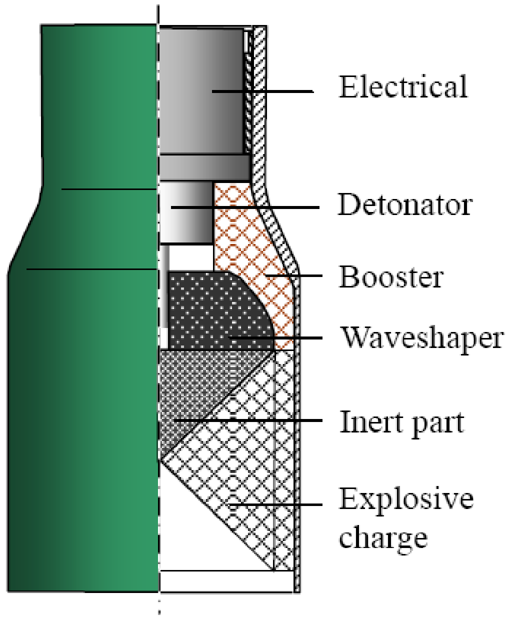


Figure 12. Axial cross-section of the experimental 60 mm shaped charge model

The two-part explosive charge was made of HMX and TNT with the detonation velocities of D_1=8700 m/s and D_2=6200 m/s, respectively. In order to obtain all required results for a comparative analysis of real detonation profiles, a standard mono-block explosive charge and a two-part explosive charge (with the inert inserted part) were tested. The initiating and detonating device (Fig. 13) activates the two-part explosive charge over the peripheral ring contact surface of 4 mm in width (*IF* zone in Fig. 10).

A conical Plexiglas mask with engraved slots (Fig. 14) served for streak recording of the emerging detonation wave. The conical surface of the mask that is in contact with the external face of the explosive was colored in black before engraving.

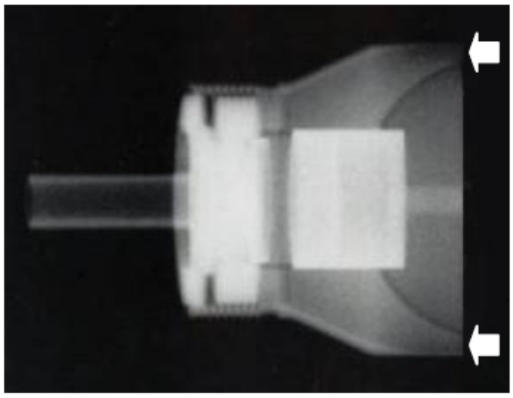


Figure 13. Radiograph of the initiating and detonating device (arrows indicate the position of the initiating surface)

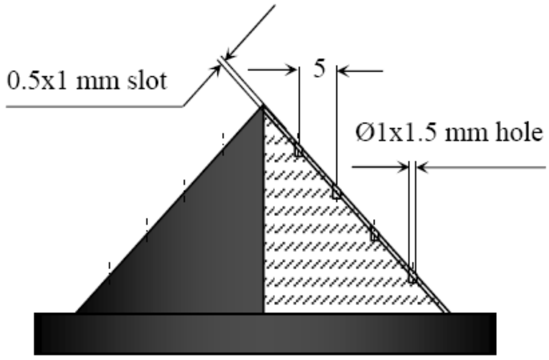


Figure 14. Conical Plexiglas streak mask

The control of the prepared experimental models before the testing was carried out using the method of impulse radiography (Fig.15).

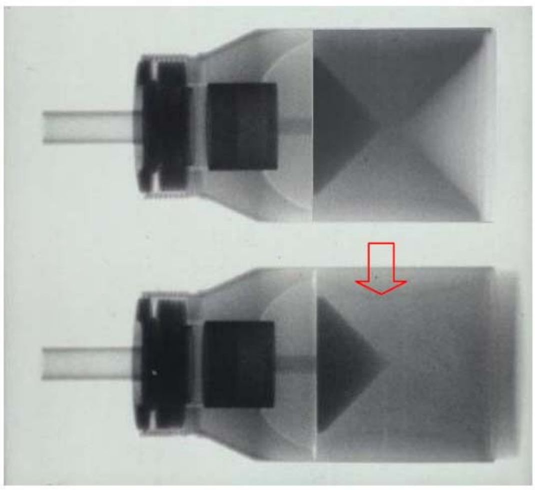


Figure 15. Radiographs of 60 mm experimental models of the two-part explosive charge (the arrow indicates the position of the contact line in the two-part explosive charge)

In the static radiographs (Fig.15), neither a deviation of the contact line between two explosive charges nor any defect of the explosive charges can be seen.

The bright trace of the detonation wave emerging on the free conical surface of the two-part explosive charge (Fig.15) was recorded using the streak technique at 10 mm/μs of streak recording speed (Fig.16).

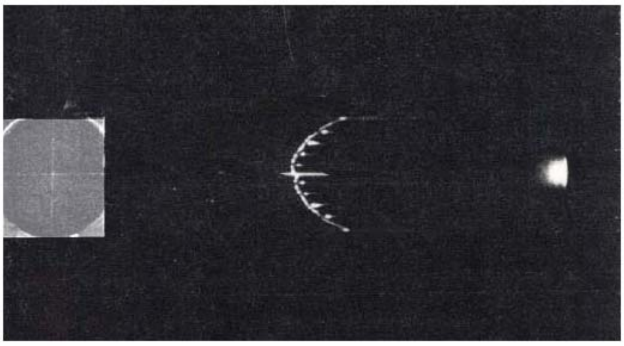


Figure 16. Streak recording of an emerging detonation wave on the free conical surface of the two-part explosive charge

The experimental research was also used for recording an emerging detonation wave on the free surface of a standard mono-block explosive charge. The experimental models (Fig.17) with different and known heights of explosive charge are prepared and then controlled using the method of impulse radiography.

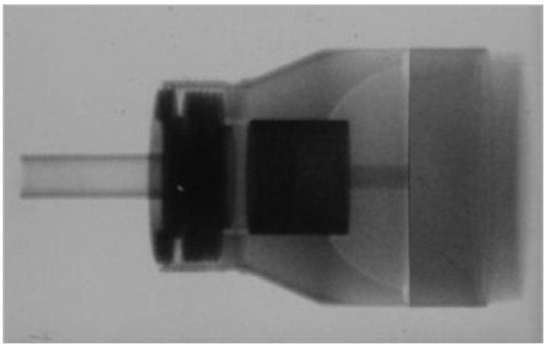
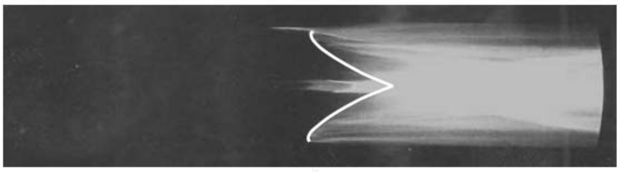
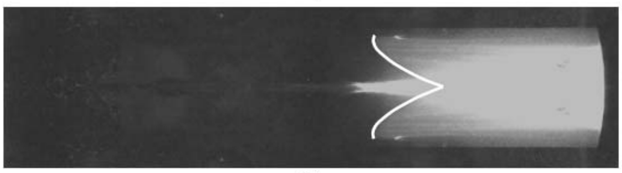


Figure 17. Radiographs of the 60 mm experimental model with a standard explosive charge

Based on the high speed camera techniques, the streak recordings of an emerging detonation wave were given: a) for a 10 mm high explosive charge and b) for a 20 mm high explosive charge. The streak recording speed was 8000 m/s. The 50% filter on the camera objective and a mask with a 0.3 mm depth of slot were used in the experiment. The photographs of the emerging detonation wave on the end side of the explosive charge are shown in Fig.18.



a)



b)

Figure 18. Streak recordings of the emerging detonation wave: a) 10 mm high explosive charge; b) 20 mm high explosive charge

Numerical simulation

A sample of the previous experimental 60 mm shaped charge model was considered for numerical simulation. Fig. 19 illustrates the initial coupled Lagrange-Euler meshing of the shaped charge given in the pre-processing procedure. A modified nonlinear Euler meshing was made by using changeable cells of the following dimensions: from 1×1 mm on the peripheral zone to 0.25×0.25 mm near the symmetry axis of the shaped charge.

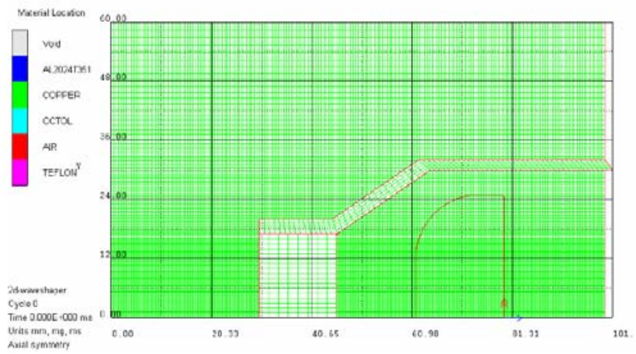


Figure 19. Initial meshing of the 2D modeled parts of the 60 mm shaped charge

The computed profile of the detonation wave is shown in Fig.20. The figure illustrates the most important details of the interaction of the detonation wave and the waveshaper with a family of isobars.

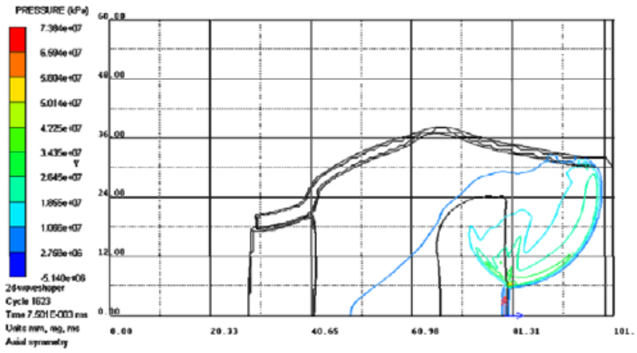


Figure 20. Computed profile of the 7.5 μs detonation wave after the initiation of the explosive charge

As it can be seen from the figure, the waveshaper takes a role of an absorber reducing the intensity of pressure in the shock wave. Therefore, the detonation wave arrives in the explosive charge practically simultaneously with the shock wave reaching the waveshaper on its end side. Both the peripheral initiation of the main explosive charge and the presence of the waveshaper enable the optimization of the detonation wave profile.

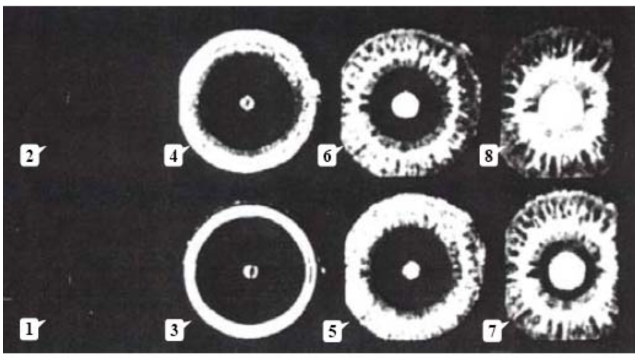


Figure 21. Frames recording of the emerging detonation wave on the frontal side of the initiating and detonating device

The functioning of the initiating and detonating device (Fig.13) was tested separately with a main idea to verify the regular initiation and the waveshaper role as a shock wave absorber. The obtained results confirm that the initiation of the explosive charge occurs only over the peripheral ring surface (Fig.21, frame 3).

Results and discussion

The streak recordings in Fig.18 are used to redesign the real profile of the detonation wave in a standard (mono-block) explosive charge. The comparative diagrams of the detonation wave profiles, 10.25 μs after initiation, given by computing (Fig.22a) and the experiment (Fig.22b), are very close to each other.

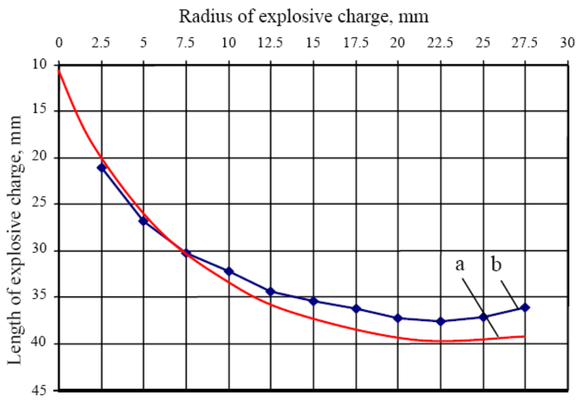


Figure 22. Comparison of the computing and testing profile of the 10.25 μs detonation wave after the explosive charge initiation: a) calculated profile based on the finite element method; b) experimental curve based on streak recordings

On the other hand, the real profile of the detonation wave at the moment of arrival on the free conical surface of the two-part explosive charge was calculated on the basis of the streak recording (Fig.16) and shown in Fig.23.

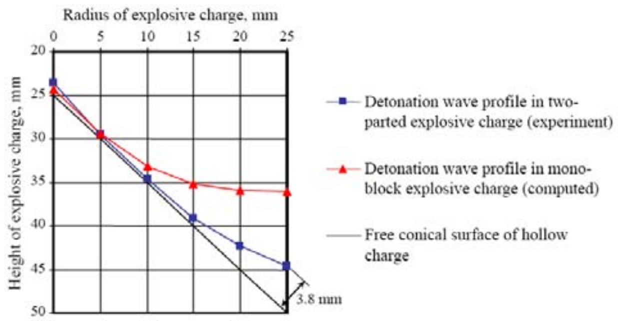


Figure 23. Calculated real profiles of the detonation wave at the moment of its emerging on the free conical surface of the explosive charge (~12.0 μs after the initiation of the explosive charge)

The comparative analysis of the detonation wave emerging on the conical free surface of the explosive charge shows that the two-part explosive charge generates a more acceptable form of the detonation wave than the other-one with the standard mono-block explosive charge (calculated in [7]). Regarding the peripheral zone of the charge, the detonation wave in the two-part explosive charge is more inclined to the metallic liner (Fig.23) contributing to better liner collapsing parameters and some functional improvement of the shaped charges.

The maximum deviation between the calculated real profile of the detonation wave and its desirable conical form is 3.8 mm. This result may be considered as an acceptable approximation for the first practical trial to generate a conical detonation wave.

Conclusion

Based on the results of the theoretical analysis and experimental testing of shaped charge initiation as well as on the research into the possibilities of correction of the detonation wave in the shaped charge peripheral zone, the following can be concluded:

- The process of shaped charge initiation and processes appearing during the interaction of the detonation wave and the waveshaper were clarified. Regular and centric initiations of explosive charges are very important for a maximum penetrability of shaped charges. Almost perfect centric initiation and further axis-symmetric propagation of detonation waves is possible by the use of a special self-centering device.
- Consideration of the possibilities to optimize detonation wave profiles in shaped charges showed that generating a desirable detonation wave form was possible. In order to generate the conical detonation wave profile and contribute primarily to the decrease of the detonation wave attack angle, the principle of the two-part explosive charge made of explosives with different detonation velocities was successfully used. A significant increase in the metallic liner collapsing parameters in the peripheral zone of the charge was thus achieved as well as some functional improvement of the shaped charge. This was achieved by some corrections of the explosive charge without any redesign of other components of the shaped charge. The results of the numerical simulation of the detonation wave propagation were compared with the results of the testing of real detonation wave profiles in the 60 mm shaped charge experimental model, confirming the given theoretical predictions.

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Inicijacija i korekcija detonacionog talasa u perifernoj zoni kumulativnog punjenja

Regularno i centrično iniciranje i dalje osnosimetrično prostiranje detonacionog talasa ima važnu ulogu u funkcionisanju kumulativnog punjenja. Takođe, generisani oblik detonacionog talasa predstavlja bitan parameter urušavanja metalne obloge i celokupnog kumulativnog efekta. Izbor najprihvatljivijeg profila detonacionog talasa omogućava povećanje probojnosti ovog punjenja. Sa ove tačke gledišta, razmatrani su neki aspekti inicijacije eksplozivnog punjenja i mogućnosti oblikovanja detonacionog talasa u kumulativnom punjenju. U pokušaju da se generiše deotnacioni talas željenog oblika u perifernoj zoni punjenja, analizirano je dvodelno eksplozivno punjenje izrađeno od eksploziva različite brzine detonacije. Prikazani su određeni rezultati koji se odnose na numeričku simulaciju i eksperimentalno ispitivanje detonacionog talasa u modelima kumulativnog punjenja kalibra 60 mm.

Ključne reči: **fizika eksplozije, kumulativno punjenje, iniciranje, detonacioni talas, numerička simulacija, kalibar 60 mm**.

Инициирование и коррекции волны детонации в периферической зоне кумулятивного заряда

Регулярное и сосредоточенное инициирование и дальнейшее осесимметричное распространение детонационной волны играет важную роль в функционировании кумулятивного заряда. Кроме того, созданная форма детонационной волны является важным параметром повреждения и урушения металлического покрытия и общего кумулятивного эффекта. Выбор более приемлемого профиля детонационной волны увеличить свойство проникновения этого заряда. С этой точки зрения, обсуждены некоторые аспекты инициирования заряда взрывчатого вещества, а также и возможности формирования детонационной волны в кумулятивном заряде. В попытке создать желаемую форму детонационной волны в периферийной зоне заряда, были проанализированы заряды взрывчатого вещеста из двух частей, изготовлены из взрывчатых веществ различных скоростей детонации. Здесь представлены и некоторые результаты которые относятся к численному моделированию и к экспериментальным испытаниям детонационной волны в моделях кумулятивного заряда калибра 60 mm.

Ключевые слова: **физика взрыва, совокупный (кумулятивный) инициирование, детонационная волна, численное моделирование, калибр 60 mm.**

Initiation et correction de l'onde de détonation dans la zone périphérique de la charge creuse

L'initiation régulière et centrée et ci-après la propagation axiale symétrique de l'onde de détonation joue un rôle important dans le fonctionnement de la charge creuse. La forme produite de l'onde de détonation représente le paramètre essentiel de l'effondrement de la couche métallique ainsi que de l'effet cumulatif complet. Le choix du profil le plus acceptable de l'onde de détonation permet l'augmentation de pénétration de cette charge. On a considéré, de ce point de vue, certains aspects de l'initiation chez la charge explosive et les possibilités de la formation de l'onde de détonation dans la charge creuse . Essayant de réaliser l'onde de détonation de forme désirée dans la zone périphérique de la charge on a analysé la charge explosive à deux parts faite des explosives ayant les différentes vitesses de détonation. On a présenté certains résultats qui se rapportent à la simulation numérique et à l'essai expérimental de l'onde de détonation pour les modèles de la charge creuse de calibre de 60 mm.

Mots clés: **physique de l'explosion, charge creuse, initiation, onde de détonation, simulation numérique, calibre de 60 mm.**