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Study on the Close Distance Perforation Capabilities of Explosively Formed Penetrators

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STRESZCZENIE: The paper presents a study of the perforation capabilities of Explosively Formed Penetrators (EFP) at small distances between the charge placement and a target for the selected charge configurations. The specific design of the warhead is considered, where the casing is made of light, low-strength material and the warhead may be installed directly on the obstacle, which makes it valuable for special applications. The problem was solved using modelling and simulation methods, in particular, CFD-FEM implemented in the Ls-Dyna code. It was assumed as an axisymmetric issue in computational fluid dynamics, where space discretization for each option was built with two-dimensional elements, which ensured efficient calculations. The core numerical model was successfully validated based on the available data in quantitative terms. Analyses showed that at close ranges, under two diameters of the liner, the projectile fails to reach its optimal parameters, impacting the target with relatively low velocity. This effectiveness is also deteriorated by the projectile's geometry, which at this moment is still not final. Studies on the projectile's post perforation energy revealed a dependency on the EFP's distance from the target, with the most significant effects observed within a range of one liner diameter. Beyond the distance of two diameters, further changes in effectiveness are minimal, with slight variations attributed to computational method inaccuracies.

SŁOWA KLUCZOWE: Explosively Formed Penetrator, EFP, Perforation, Computational Mechanics, Arbitrary Lagrangian-Eulerian.

1. Introduction

The application of Explosively Formed Projectiles (EFPs) was first described in 1930s [1]. A significant increase in the number of publications in this field occurred when numerical simulation also emerged. Contact interfaces, the type and mesh structure, discretization issues, detonation wave characteristics, constitutive models, and the application of alternative computational methods are disputed [2]. However, the majority of the research focuses on the influence of charge geometry (especially the liner shape) and other factors on projectile formation and its further performance [3]. Some of these studies mainly discuss the impact and penetration process and focus on the material and structure of single and multi-layered targets [4]. The process is also examined on the basis of metallographic examination of the material within the shock influence area. Multi point initiation may enhance EFP perforation ability because it influences projectile velocity, length-diameter ratio, and most importantly change in velocity gradient [5].

EFP is considered to be a structure which has high penetration ability at long distances. In the literature, the penetration capabilities of EFPs at short distances between the charge placement and impact point are rarely considered [6]. Therefore, the aim of this study is to analyze the influence of the charge placement distance on the perforation capability for selected EFP charge configurations.

2. Investigation plan

In the paper, a number of variants were analyzed. The basic concept of the de-sign is based on [7], where experimental validation of an explosively formed projectile with variable thickness liner was presented. The authors also provided a detailed description of a numerical model including data for material models. Three designs were investigated; however, liner number II is believed to form potentially the best projectile in terms of its penetrability.

Table 1. EFP structure configuration studied.

Symbol	Description	Liner material
72cV	72 mm liner (validation)	Copper
72c	72 mm liner	Copper
72cM	Modified 72 liner: 75% original thickness	Copper
72i	72 mm liner	Iron
200c	200 mm liner	Copper

3. Model validation

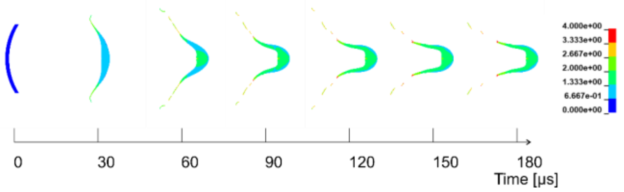
The paper [7] was used in terms of the EFP formation process as the basis for validation of the basic 72cV numerical model proposed in this paper. Than other models were elaborated assuming that they can predict properly physical phenomena because were derived based on prior validated model. The validation was based on comparing the dimensions of the projectile and its velocity. The results presented in Table 2 show a maximum error of 6%, which is fully satisfactory.

Table 2. EFP structure configuration studied.

	Length (mm)	Diameter (mm)	Velocity (m/s)
Type II liner [18]	52.0	33.1	1806
72cV	50.4	31.2	1728
Error [%]	3	6	4

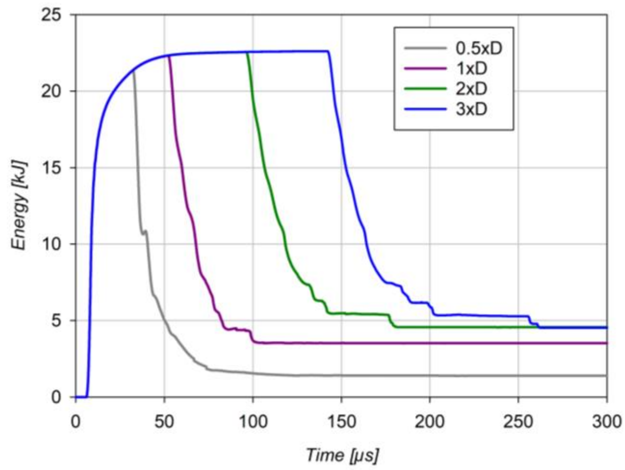
4. Results and discussion

The process of penetrator formation, for the selected variant 72c, is shown in Fig. 3a (the shapes presented in the figure represent two-dimensional cross-sections). The near axial part of the liner moved the fastest and formed the projectile's head, but fragments further from the axis of symmetry created its tail. The application of the constitutive model with the failure option allowed for the observation of liner fragmentation due to the limited tensile strength of copper. The EFP should contain practically the entire mass of the liner, and here the described loss was insignificant. Beyond 120 μs changes in the geometry were not substantial (final diameter and length were 35.9 and 44.5 respectively), this refers to 180 mm distance, which can be expressed as 1.8 diameter of the liner (1.8xD). Another analyzed factor was the kinetic energy of the projectile, which resulted from the interaction of the detonation wave with the liner material. This parameter continued to increase until it reached its maximum value. At this point, the expansion of detonation products no longer affected the projectile's energy. Given the presence of numerical noise, it was imperative to establish a criterion for final assessment of the maximum energy. It was defined as 99% of the value at the termination time of the simulation, and in the case discussed, it was achieved after 51 μs. Thus, it can be seen that this was before the projectile reached its final shape.



Rys. 2. Effective plastic strain distribution at different moments in time for 72c EFP formation.

The perforation of the armor plate resulted in significant deformation of both copper and armored steel components. This caused a rapid decrease in the velocity of the projectile and, consequently, its kinetic energy. In Fig. 5 the graphs of kinetic energy versus time are presented for different warhead locations for the single design variant 72c. During the initial 30-51 microseconds, depending on the distance, there is a rise in the liner's energy resulting from the load by detonation products, followed by a swift dissipation of energy upon collision with the plate. After the perforation process, when the main part of the projectile passes the target, there are still slight drops on the charts. This is related to the fragments of material that detached from the main part of the projectile and reached the plate later. In the final phase, the energy was not changed any more, and this value can be considered as a characteristic parameter for each case studied.



Rys. 2. Kinetic energy time history of copper liner/EFP for 72c, where the warhead was placed at different distances

5. Conclusions

The effectiveness of an Explosively Formed Penetrator (EFP) as determined by numerical calculations is a nonlinear function of its distance from the target. Particularly at close ranges, under two diameters of the liner, the projectile fails to reach its optimal parameters, impacting the target with relatively low velocity. This effectiveness is also deteriorated by the projectile's geometry, which at this moment is still not final. Thus, impact is not concentrated in a narrow area, leading to less effective perforation. Studies on the projectile's energy post armor perforation revealed a dependency on the EFP's distance from the target, with the most significant effects observed within a range of one liner diameter. Beyond a distance of two diameters, further changes in effectiveness are minimal, with slight variations attributed to computational method inaccuracies. The analyses conducted have demonstrated that the specific design of the EFP, where the casing is made of low-strength material and the warhead is placed at a short distance from the tar-get, enables effective target engagement, rendering it valuable for special applications.

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