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Metallographic analysis of piercing armor plate by explosively formed projectiles

Adam Kurzawa [a,*], *Dariusz Pyka* [b], *Miroslaw Bocian* [b], *Krzysztof Jamroziak* [b], *Janusz Sliwinski* [c]

[a] *Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Foundry, Plastics and Automation, 25 Smoluchowskiego Street, 50-372 Wroclaw, Poland*

[b] *Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Mechanics, Materials Science and Engineering, 25 Smoluchowskiego Street, 50-372 Wroclaw, Poland*

[c] *Military Institute of Engineer Technology, Ammunition Testing Laboratory, 136 Obornicka Street, 50-961 Wroclaw, Poland*

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ABSTRACT

This work discusses the impact consequences of Explosively Formed Projectiles (EFP) on the process of armor penetration. Based on the example of piercing shields made of armor steel ARMOX 370T with anti-vehicle mine of MPB type to verify the effectiveness of EFP charge. The influence of the projectile on the armor wall was analyzed on the basis of metallographic examination of the material from the armor, its plastic deformation and the change in the structure of the material within the shock influence area. As a result of the slug projectile impact on the armor surface a crater as a hole was formed with a diameter of approx. 105–120 mm, with noticeable traces of dynamic plastic deformation which occur at high speeds and high temperatures. In addition, microstructure analysis of the mines liner was performed, as in before and after piercing based on the analysis of EDS for phase precipitates identification.

1. Introduction

Destructive means such as Explosively Formed Projectiles (EFP), also known as Explosively Formed Penetrators, are in their principle of operation a type of cumulative charges. A characteristic feature of cumulative charges is a cumulative liner. This is the part of the entire cumulative charge which to the greatest extent determines the capacity for penetration of the projectile, keeping in mind optimizing the volume of the charge, type of the explosive, size of the charge casing and the method of initiation.

Commonly the liners are shaped as a cone, a hemisphere or a spherical cap of small height. Liners in the shape of a flat semicircular disk shape the Explosively Formed Projectile (EFP) which, during detonation, turns into a hard piece of metal of a

* Corresponding author.
E-mail addresses: adam.kurzawa@pwr.edu.pl (A. Kurzawa), dariusz.pyka@pwr.edu.pl (D. Pyka), miroslaw.bocian@pwr.edu.pl (M. Bocian), krzysztof.jamroziak@pwr.edu.pl (K. Jamroziak), sliwinski@witi.wroc.pl (J. Sliwinski).
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regular shape or into a penetrator, not into an extended stream of material. This rod is aerodynamically stable and can reach speeds of up to 2000 m/s. Creating a penetrator instead of a cumulative stream is dependent on the opening angle of the liner (above 140°). Example of an EFP device is shown in Fig. 1.

Explosively Formed Projectile with slightly worse parameters in respect to the cumulative charge, as well as due to the lack of a clearly defined focal length (i.e. the distance from the armor) at the time of the explosion, were used mainly in artillery sub-munition, in aircraft sub-munition, for MPB mines, anti-helicopter mines and in the technology of improvised explosive devices [1,2].

The technology [3] and the principle of operation of EFP is known and regularly improved with the development of a variety of explosives [4,5]. With many studies assigned to charges, in which their development is presented [6] with a detailed construction of the liner [7]. Efficiency of the explosively formed penetrator depends largely on the design of liners and produced precision of the entire charge, as well as on the penetrated armor. Most of the work is related to the optimization of the liner in order to improve the capacity for armor penetration. The scope of the research conducted in recent years was focused mainly on the development of optimal models, which at the beginning were based on the Bernoulli law [8], then they were developed through the introduction of empirical parameters considering the fragmentation of the slug projectile [9] with further improvement considering fast changing processes based on the equilibrium law of mass and momentum, or with a model of rod penetration [8,10]. With the development of numerical mathematical models [11] empirical studies were verified by computer simulations which were based on empirical studies. Analysis were mainly focused on the reliability of the head and the formation of slug projectiles. The researchers developing the efficiency considered improving of EFP aeroballistic characteristics[12], estimated EFP head performance [13] and design data for optimal configuration [14]. Another ones [15] decided to arrest further development of the Euler–Lagrange coupling in GRALE2D, because of most commercially available software are focused on three-dimensional problems whereas there is a lack of well supported two-dimensional hydro codes. Their main objective was to enhance the efficiency of jet formation, thereby to improve passive ballistic shields penetration. In papers performed research on the velocity [16] and morphology [17] change of the EFP leads to improvement of its performance. Studies on high velocity impact on layered target at different angles are showed in papers [18,19]. The results of the numerical analysis of the EFP formation characteristics according to different material models are presented in order to show the improvement of penetration efficiency [20] and minimization of side damage with fragments [21]. The work [22,23] were oriented on the influence of the water medium to review the effectiveness of EFP. However, it is also important to optimize the entire charge, including explosives, what was considered in other works such as [24,25].

Rapid development of EFP, despite the exhaustion of its possibilities has been conducted as a combination of fallowing methods: classically shaped charge and the EFP [26]. In this way, the possibility of inflicting damage on armored targets has been increased. In this case, considering efficiency of the EFP with respect to the ballistic shields requires analysis of the nature of the material structures [27] which construct ballistic shields. Researchers consider various material sets [28], including cermet materials[29], which parameters are quite similar to ballistic plates based on aluminum [30] and copper alloys [31]. The performance efficiency of the slug projectile on the shield is discussed in papers [32,33].

However, few studies considered the nature of energy absorption of the structure under the influence of EFP. Thus, authors of this work focused on steel ballistic armor in terms of structural transformations due to penetration by MPB (off-route anti-vehicle combat landmine) mine operating as EFP. Therefore, there is a need to study the ballistic resistance of the steel armor in terms of structural changes to the impact of high-speed explosive forming projectiles.

2. Materials and methodology of the research

Tests were conducted using MPB-ZN mines with the non-contact detonator, detonating it into a shield made of ballistic armor plate ARMOX 370 T. The experiment consisted of shelling of a plate of $1.0 \times 1.5 \times 0.1$ m dimensions permanently embedded in a stand with a MPB mine from a distance of 50 m. The shelling rig station is illustrated in Fig. 2.

The research was to carry out the identification of resistance of the steel ballistic shield against an impact from an EFP off-route mine projectile. The aim was to determine the mechanism of the protection penetration based on the metallographic analysis. The research involved performing an experiment, a metallographic assessment of the vicinity of the impact area included microstructure analysis using optical and scanning electron microscopy, identification of excretions using the EDS analyzer, and determination of the mechanism of fracture formation.

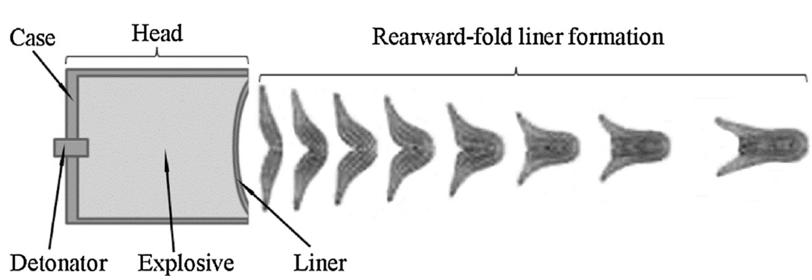

Fig. 1 – A generic EFP charge to form EFPs.