NUMERICAL MODEL FOR SIMULATION OF THE VELOCITY FIELDS FOR THE EXPLOSIVELY FORMED PENETRATOR

ЧИСЛЕН МОДЕЛ ЗА СИМУЛАЦИЯ НА СКОРОСТНИТЕ ЗОНИ ПРИ ЗАРЯДИ ОТ УДАРНО ЯДРО

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Abstract: *The current paper presents numerical approach of velocity performances estimations for the* ***EFP*** *(****E****xplosively* ***F****ormed* ***P****rojectiles). The proposed method mathematically develops velocities parameters of a particular segment for EFP liner propelled by explosive process. The numerical method is developed, to provide estimations about behavior of projectile vs. time in the EFP forming process powered by explosion. The model is valid for performances estimations of EFP warheads and design data for optimal EFP configuration. Simulations are supported by the software Autodyn for numerical modeling respectively. The obtained numerical results are compared with the available experimental data.*

KEYWORDS: EXPLOSIVE FORMED PENETRATOR, NUMERICAL SIMULATION, VELOCITIES DISTIBUTION, AUTODYN,

1. Introduction

Nowadays, the EFP warheads are present in many systems that expect appropriate modernization and/or optimization; as artillery sub-munitions, antitank missiles, mines etc. Approaches which define the processes of explosively formed projectiles [1-4] are one of the most sophisticated problems of rigid body mechanics based on the elastic to plastic theory. The distinguishing problem of the EFP projectiles is the velocity of the EFP liner. This velocity is generated in the explosively driven process and the dynamics of their evolution is the main topic of this paper. Recently, most papers are based on numerical methods [5-10] which determine the projectiles velocity performances based on detailed modeling of the loadings and deformation process during explosion. Numerical software, particularly Autodyn, which is often used for detailed analyses in numerical simulations, require comprehensive preparation of the expected initial data but some others methods as it analytical are less precise but enough reliable and provides much faster data obtaining for the applications of warheads performances estimations.

The current paper presents software based on the previously studied analytical method as a solution to provide the ability to preliminarily estimations as well as numerical solution of the same rooted liners velocities. This methodology provides ability to analyze the adopted design of warhead’s performances by more precise numerical software like Autodyn.

The research based on the analytical models presented in papers [1-5], provides crucial information about the EFP performances in a short time without required comprehensive initial data preparation. The algorithm presented in further papers provides the possibility to directly export the adopted geometry of EFP liners integrated with warheads into Autodyn numerical software, from the software package Matlab, which considerably decreases preparation time.

The results of numerical method contribute in improving the accuracy of EFP velocity estimations. This is achieved by an appropriate augmentation in the number of the grid elements for the method used.

2. Numerical approach

Numerical approach based on the finite element method is used in this research in order to be compared with experimental data.

The properties of the adopted simulation model mesh [12-19] are given in Table 1. The mesh density is determined taking into account accuracy as well as reasonable simulation run time within available computer facilities.

Figure 1a and 1b shows configuration of EFP warhead as well as appearance of created mesh for each component separately.

The simulation sample volume in numerical approach is observed as the quarter shown on the figure 1a and 1b.

Presented analysis uses fully Lagrangian solver, where after 35 µs, detonation products are not influenced into forming processes. But that average liners final velocity comparative with analytical modeling corresponds not to the 35 µs instant of forming time then about 70-150 µs where dynamical process is fully completed (figures 5 and 6).

A wide range of metal powders (from light alloys through steels to super-alloys and composites) is currently available for DMLS process and other new materials are under development. Table 1 lists mechanical properties of selected powder materials.

Table 1: *Grid properties of the numerical approach* [3]

	Type 1		Type 2*	
Conditions	1	2	1	
Liner	7776	6125	7776	6125
Explosive	10496	9000	10496	9000
Cover	15006	12000	-	-
Back plate	768	450	768	450
1 – nodes; 2 –elements;				

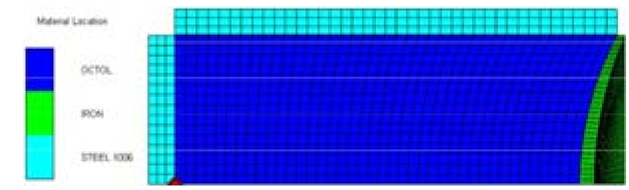

Figure 1a: *Geometrical configuration of EFP sample type1 (with cover) and finite elements mesh*

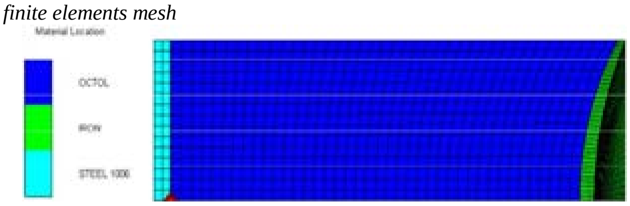

Figure 1b: *Geometrical configuration of EFP sample type2 (without cover) and finite elements mesh*

The loading forces distribution model is expressed by the detonation pressure products and is determined according to Jones-Wilkins-Lee [1] by the equation of state:

$$p = K\left(1-\frac{\omega}{R_1 V}\right)e^{(-R_1 V)} + K_1\left(1-\frac{\omega}{R_2 V}\right)e^{(-R_2 V)} + \frac{\omega E}{V} \qquad (1)$$

where V and E are represented as $V = \rho_0/\rho$, $E = \rho_0 e$, ρ_0 is the current density, ρ is the reference density, e is the specific internal energy and K, K_1, R_1, R_2 and ω are constants for the given explosive material [1,2].

3. Simulation model

The comparison of these methods is performed on the sample design fig 2, with accepted, fixed EFP liner form and explosive charge, with and without metal cover. Adopted explosively driven projectile model and its elements of geometry, presented in the paper [2], and design characteristics of testing sample as in the [14] are shown in Fig. 2. The model does not include the fuze and wave shaper integrated in the warhead design and influenced on the real performances modeling.

The properties of explosive and other materials used in simulations are given in Table 1 [14]. In tested examples, the initiation point is located on the warhead bottom and lies on axis of symmetry [14] (Fig. 1).

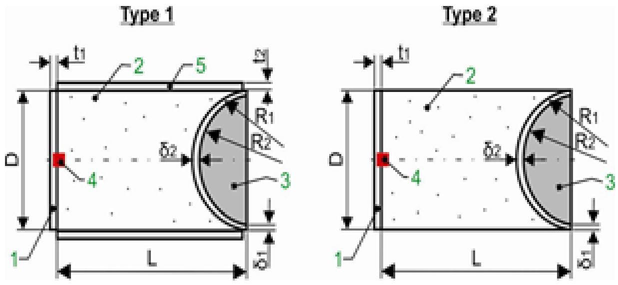

Figure 2: *Types of testing sample and their basic dimensions: 1 -back plate, 2 -explosive charge, 3 - liner, 4 - initiation point, 5 –cover.*

Table 2: Geometrical parameters for EFP sample models [3]

Design parameter		Type 1	Type 2*
Length of charge	L [mm]	85	85
Caliber	D [mm]	57.2	57.2
Thickness of back plate	t1 [mm]	5	3
Cover thickness	t2 [mm]	5	-
Inner radius	R1 [mm]	60.4	71.3
Outer radius	R2 [mm]	60.4	71.3
Thickness of liner edge	δ1 [mm]	1.5	1.5
Thickness of liner center	δ2 [mm]	2.7	2.7
Type initiation		p.	p.
* -experiment; p. –point initiation			

Analytical and numerical approach used Octol as explosive material with density of 1.82 g/cm3 and detonation velocity 8480 m/s as well as steel as cover and iron as liner material. The experimental sample was tested on the proving ground as a type 2 [14] in Table 2.

4. Results and discussion

Two types of simulation samples of the liners and explosives integrated have been considered through represented modeling in numerical approach.

Figures 3 and 4 show energy distribution vs. time during projectile forming. Kinetic energy represents penetration capability of formed projectiles.

The plastic works, is important for liners' design and for selection of appropriate material. Figure 3 and 4 represents nonlinear and uniform distribution of plastic energy. It means that liner during formation had proper deformation also influenced on the velocities distribution. If that curve in initial phase of formation has no permanent increase, this indicates the liner had the fracture.

Table 3 shows differences in the energy distribution obtained by the numerical and analytical approach. In table 3 are presented next values: absolute initial velocity V0 [m/s], kinetic energy Ek [J], axial deformation energy ADE [J], radial deformation energy RDE [J] and plastic deformation energy/plastic work PW [J].

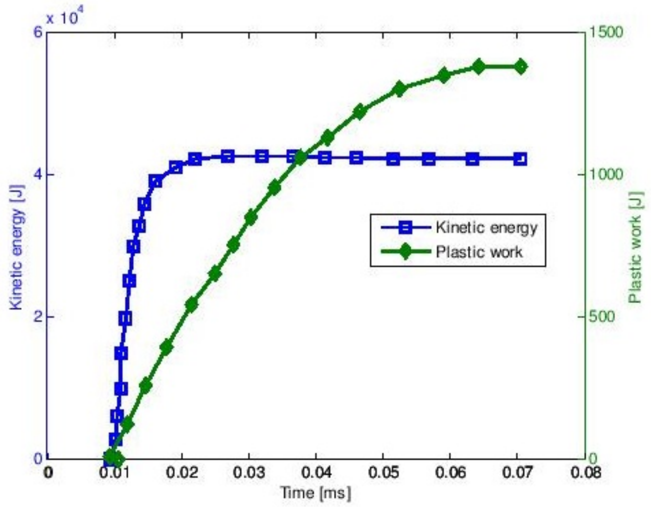

Figure 3: *Energy distribution during time of the forming of explosively formed projectile, sample type 1, obtained by numerical method [3]*

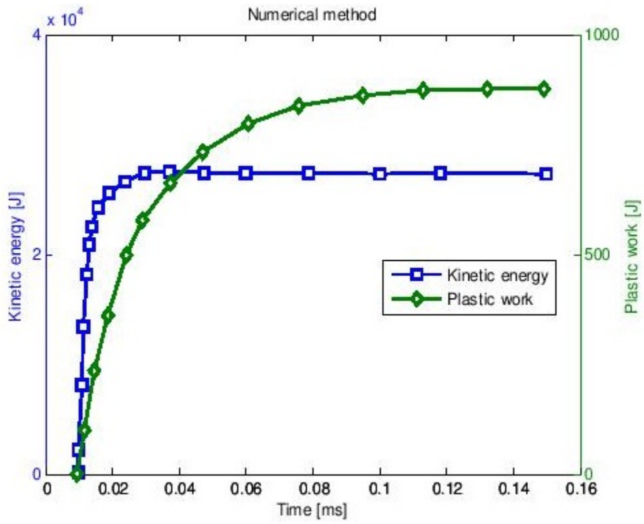

Figure 4: *Energy distribution during time of the forming of explosively formed projectile, sample-type 2, obtained by numerical method [3]*

These parameters are collected as the consequence of considering problems of deformation energy in the numerical and in the analytical models. Differences between two types of samples show that cover of the explosive sample influences as to increase of kinetic energy of projectile and also the increase of total plastic deformation work [1,2,10,13,20].

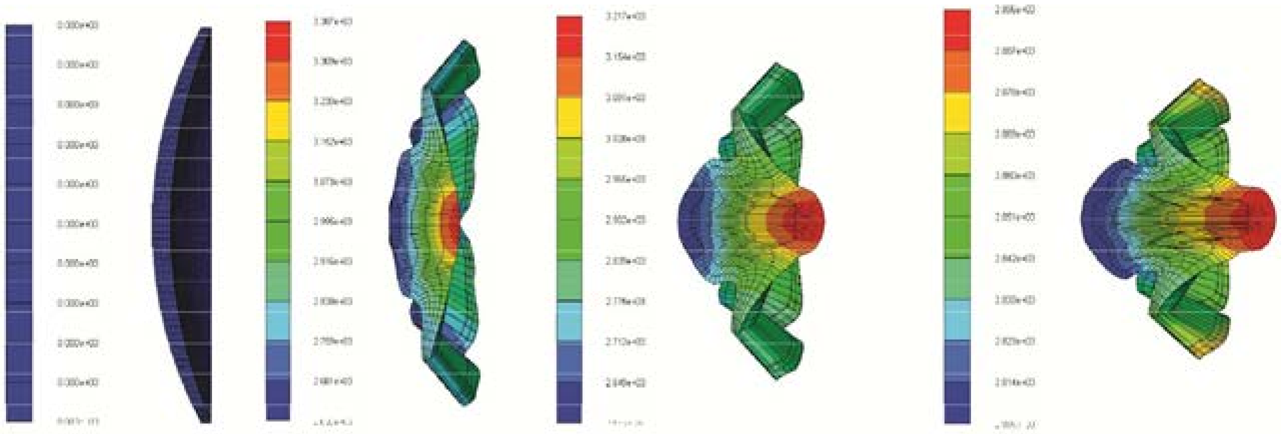

Figure 5: *Shape of projectile configuration during forming to the final shape in 70 µs of sample-type 1*

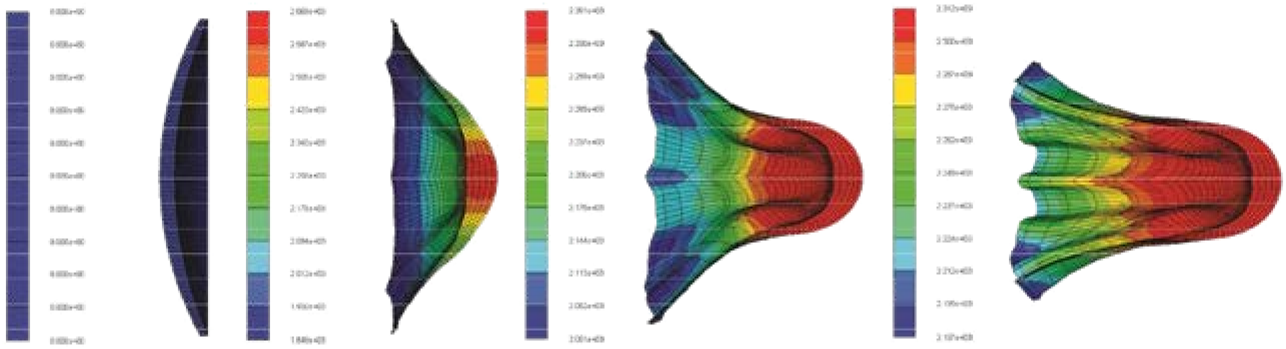

Figure 6: *Shape of projectile configuration during forming to the final shape in 150 µs of sample-type 2*

Numerical simulation also reproduces expected shapes of projectiles at the end of forming process shown in (Figs. 5 and 6). For the sample type 1 (Fig. 5) projectile is formed with its final shape after t=70.5 µs at the distance 265.31mm, realizing final velocity of about 2860 m/s. For the sample type 2 (Fig. 6) these values are corresponding to the instant t=150 µs, at the distance 418.2 mm and velocity 2435 m/s. That means that sample type 2 has much less coefficient of energy efficiency than covered warhead charges [10]. The final projectile shape joint with considered velocity performances influences two basic performances important for EFP warhead design – penetrability and precision.

5. Conclusion

The next conclusions are presented as the result of this study:

The numerical approach is a well-designed tool for the EFP velocity and energy modeling and estimations.

Numerical method gives more accurate results regarding velocity in comparison with analytical methods and these results are very close to experimental data, with error of les then 1.5%. It should be noted that numerical method is useful for the shortening the development time of EFP warheads during design and reduces the cost of their experimental testing.

The same configuration of liners and explosive charges with and without metal covers produced different shapes of explosive formed projectiles. Sample *type 1* produced EFP as the plastic solid shape less adoptable for distance flight, and sample *type 2* produced EFP with more adoptable shape for distance flight regarding aerodynamical drag.

6. Literature

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