ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1166017

SELECTED ASPECTS OF MODELLING A PHENOMENA OCCURRING WITH VERY LARGE STRAIN RATES ON THE EXAMPLE OF THE SHAPED CHARGE JET STREAM FORMING PROCESS AND EXPLOSIVE FORMED PROJECTILES

Robert Panowicz, Marcin Konarzewski

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 261 839849, fax. +48 261 839355
e-mail: robert.panowicz@wat.edu.pl, marcin.konarzewski@wat.edu.pl

Jacek Borkowski, Eugeniusz Milewski

Military Institute of Armament Technology
Wyszyńskiego Street 7, 05-220 Zielonka, Poland
tel.: +48 22 7614422, fax: +48 22 7614444
e-mail: borkowskij@witu.mil.pl, milewskie@witu.mil.pl

Abstract

During the process of the shaped charge jet stream formation and creation of the explosive formed projectiles, we have to deal with strain rates reaching level of 10^7 1/s and strains larger than in other dynamic phenomena. Therefore, the correct numerical analyses of such problems are especially demanding, both in terms of preparation of the numerical model and time needed for obtaining the solution. For their execution, both meshfree and Euler description based computational methods are used. Due to very large deformations and associated with them numerical analyses errors, computational methods based on the Lagrange description are not used. Description of the materials behaviour has to take into account influence of the strain rate in wide range of parameters. In most cases, it is realized by using in computational analyses Johnson-Cook or Steiberg-Green constitutive models. These models provide an accurate description of the material parameters not only in the wide range of strain rates, but also in large scope of strains and temperatures. Article presents results of the numerical analyses concerning the influence of selected numerical and geometric parameters of the system on the process of shaped charge jet stream formation and creation of explosive formed projectile.

Keywords: *charge jet, EFP, finite element method, Euler method*

1. Introduction

Both explosive formed projectile (EFP) and shaped charge consists of three main parts: case, explosive charge and liner (Fig. 1)

An explosive material placed in the charge is suitably shaped allowing for targeting and condensation of detonating explosive material. In the case of the classical shaped charge shaping of the charge is performed by making a conical cavity with an opening angle from 40° to 60° in the front portion of the explosive, while in the EFP this angle is significantly smaller. In order to increase effectiveness of such a charge, liners made from: high purity, oxygen-free copper with small grain, ARMCO iron characterized by very high ductility and other materials, can be inserted into the conical cavity [1].

Stimulation of an explosive on its axis of symmetry results in generation and movement of an axisymmetric detonation wave. At some point, this wave reaches the liner and begins to move along it, from the inside to the outside. The products of detonation, characterized by high temperature and pressure, resulting from exothermic conversion of the explosive material, affect the liner.

In the case of the shaped charge collapse of the mass on the axis of symmetry occurs, thereby increasing pressure and temperature. The pressure drives the material of the liner along the axis of symmetry. Jest stream and cluster is created in the process. Jet stream moves at a speed of several kilometres per second and can penetrate up to 9 calibres of liner.

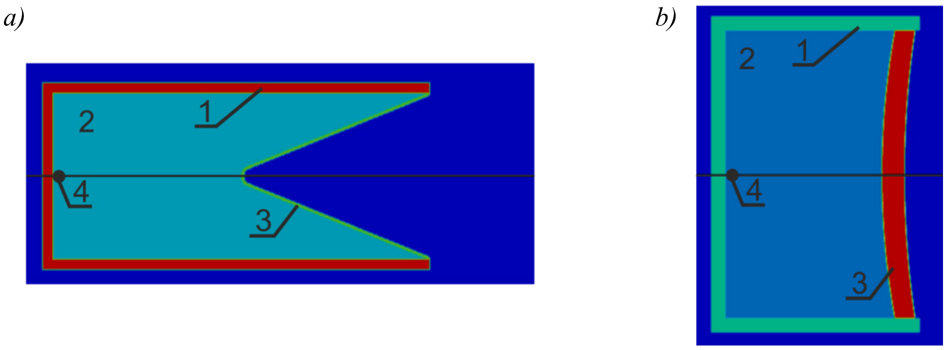

Fig. 1. Shaped charge (a) and explosive formed projectile (b): 1 – case, 2 – explosive charge, 3 – liner, 4 – point of explosive charge boost

Explosive charge in the explosive formed projectile causes different effects. Depending on the geometric parameters of the charge, the solid projectile or layered projectile is created or liner becomes fragmented. Velocity of explosive formed projectile is not greater than 2.5 km/s and it can penetrate not more than 0.7 calibre of liner. Compared to the shaped charge diameter of the hole created by the EFP is much greater than created by the shaped charge. An example of the formation process of the EFP is shown in Fig. 2.

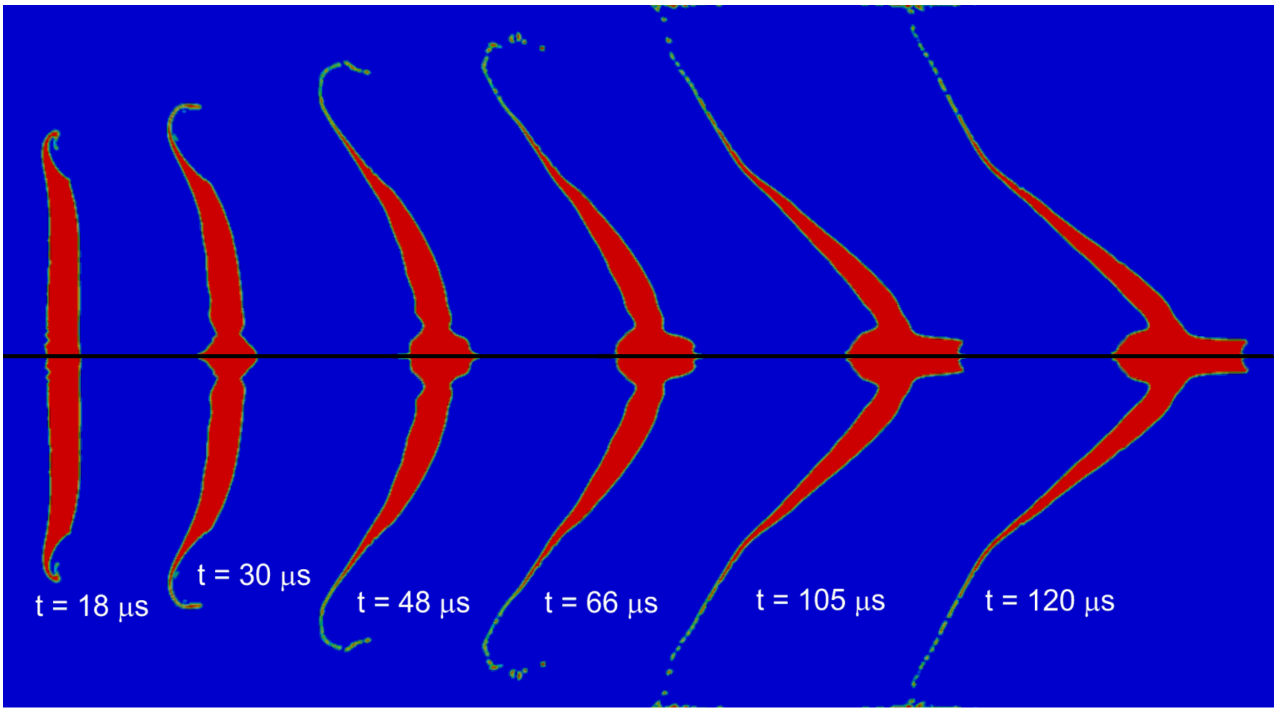

Fig. 2. EPF formation process

Bothe presented systems are used in the army to destroy military vehicles and other armoured objects. Shaped chargers are mainly mounted on guided and non-guided missiles. This group includes RPG launcher missiles. These are the most popular missiles with shaped charges developed in the former USSR. EFP charges are used in the side mines and the most advanced missiles witch attacks vehicles from the upper hemisphere, such as SMArt 155 mm system [2].

Due to the specificity of the formation process, they can be accurately analysed only by using computer based mechanics methods. The numerical analyses result in limiting the number of the costly experimental tests; thus, they significantly reduce the cost of developing new solutions.

The analyses presented in this work were based on continuum mechanics equations utilizing Euler description, which are implemented in the LS-DYNA software [3]. Due to presence of the dissipation processes in calculations, second order scheme was used owing to the spatial variables (van Leer scheme) and time. This article presents the results of the research on the impact of the Euler domain size on the process of shaped charge jet stream formation and creation of explosive formed projectile.

2. Description of the analysed system

A scheme of the analysed system is presented in Fig. 1. In the analyses, the authors assumed the case to be made of aluminum, the liner is made of oxygen-free copper, and plastic explosive material was used for driving it. The behaviour of the metallic components in dynamic loads conditions was described using Johnson-Cook constitutive model [4]. It is the first phenomenological relationship with a wide range of application. The model includes a range of high temperatures, high strain and strain rate. It is one of the simplest equations for which numerous material data are available.

The stress in the area of plastic strain is defined by equation:

$$\sigma_{flow} = (A + B\,\varepsilon_p^n)(1 + C\ln\dot{\varepsilon}^*)(1 - T^{*m}), \tag{1}$$

where:

$$\dot{\varepsilon}^* = \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}, \quad T^* = \frac{T - T_r}{T_m - T_r}, \tag{2}$$

T – temperature,
T_r – ambient temperature,
T_m – melting point,
$\dot{\varepsilon}$ – strain rate,
$\dot{\varepsilon}_0$ – reference strain rate,
ε_p – plastic strain,
σ_{flow} – flow stress,
A, B, n, C, m – material constants.

The detonation process was described using programmed burn model approximations [1, 5]. This method involves determining the initial values describing explosion, such as: explosive material detonation velocity, point of explosion initiation, parameters on the front of the detonation wave (D – detonation velocity, p_{CJ} – Chapman-Jouguet pressure, ρ_{CJ} – density in the Chapman-Jouguet point) and an equation describing behaviour of the detonation process products. In this approach, the detonation wave front portion moves with predetermined, constant velocity and forms a surface of strong discontinuity.

To determine the pressure of the detonation process products, JWL (Jones-Wilkins-Lee) equation was used [6, 7]:

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)^{-R_2 V} + \omega\rho E, \tag{3}$$

$$V = \rho_0 / \rho, \tag{4}$$

where:
ρ_0 – initial density,
ρ – density of the detonation process products,
A, B, R_1, R_2, ω – constant values.

Numerical analyses were performed in axisymmetric approximation using the finite element method with Euler description. In this method, not only the analysed system is defined by a finite element mesh, but also all the space in which the phenomenon is examined. The elements, which in the initial moment of the analysis do not contain the considered system, are assigned with properties of a very low density liquid or parameters corresponding to the air. In the numerical analyses, it was assumed that the system is surrounded by the air. This approach is closer to real-life conditions. On the boundaries of the considered system, non-reflecting boundary conditions with constant pressure were applied.

Material properties of the air were described using Mie-Gruneisen equation [6]:

$$p = p_0 + \gamma \rho E , \tag{5}$$

where:
p – pressure,
p_0 – initial pressure,
γ – Gruneisen coefficient,
ρ – density,
E – internal energy.

In the works carried out for the air region, the following parameters of Euler domain were assumed: $\gamma = 1.4$, $\rho = 1.185$ kg/m^3, $p_0 = 1013$ hPa [6]. Other parameters used in the analysis are shown in Tab. 1-3.

Tab. 1. Johnson-Cook equation constants [4, 8]

Material	A [MPa]	B [MPa]	n [–]	C [–]	m [–]
Cu	90	292	0.31	0.025	1.09
2024	265	426	0.34	0.015	1.00

Tab. 2. JWL equation constants [6]

A [GPa]	B [GPa]	R_1 [–]	R_2 [–]	ω [–]
373.8	3.747	4.15	0.9	0.35

Tab. 3. Parameters characterizing TNT used in the calculations [6]

ρ_0 [kg/m^3]	D [m/s]	p_{CJ} [GPa]	ρ_{CJ} [kg/m^3]
1630	6930	21	2230

3. Results

Process of shaped charge jet stream formation and creation of explosive formed projectile was analysed according to the size of Euler domain, which was declared at the begging of calculations. The influence of domain being greater than explosive charge from 5 to 45 mm was analysed.

We found that the size of this area under considered values has no effect on the shaped charge jet stream formation process (Fig. 3). However, the Euler domain size has significant influence on the EFP creation process, as shown in Fig. 4.

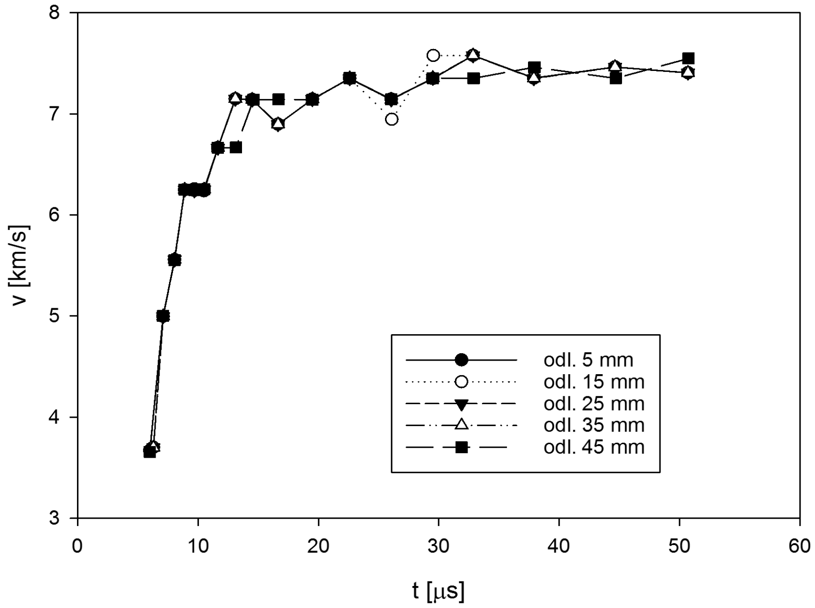

Fig. 3. Speed of the tip jet depending on the Euler domain size

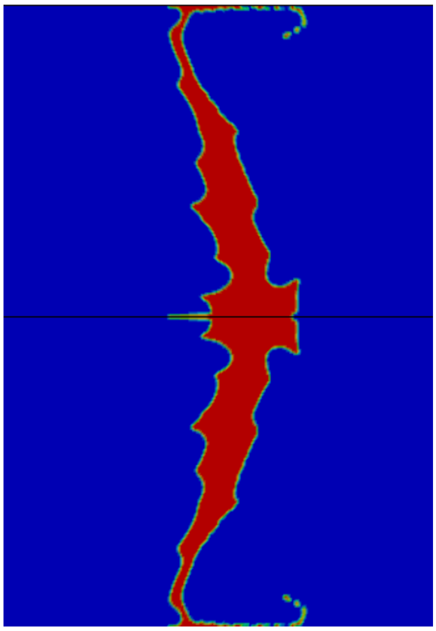

Fig. 4. The result of EFP creation process in too small Euler domain

It turns out that despite placing on the edges of the calculation area nonreflecting boundary conditions, the phenomenon of reflecting occurs. These reflections are not big enough that their influence can be visible in such short time period. Therefore, it is such important in the case of EFP creation process and it does not matter in the shaped charge jet stream formation process. The jet stream creation process takes only tens of microseconds, while the other analyses process – a few hundred microseconds. This also translates into the number of calculation steps and the size of the area of the disturbance propagation originating from different locations of the analysed system. Instabilities created during the calculation process can develop during this time.

4. Summary

The article presents the results of the numerical analyses of the influence of the Euler domain size on the jet and EFP formation process originating from a typical conical liner.

We found that the size of this domain would not affect the result of the numerical analyses of the shaped charge jet stream formation process. However it is completely opposite in the case of numerical analyses involving EFP creation process. In this case, the Euler domain size is essential. Too small size causes the appearance of waves resulting in EFP creation process disturbing.

Acknowledgements

Article was co-funded by The National Centre for Research and Development – project number DOBR-BIO4/031/13249/2013.

References

[1] Jach, K. i in., *Komputerowe modelowanie dynamicznych oddziaływań metodą punktów swobodnych*, PWN, Warszawa 2001.
[2] http://www.copybook.com/military/diehl-bgt-defence/articles/ammunition.
[3] Hallquist, J. O., *LS-DYNA Theory Manual*, Livermore Software Technology Corporation, Livermore, CA, 2005.
[4] Johnson, G. R., Cook, W. H., *A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures*, 7th International Symposium on Ballistics, 1983.
[5] Bdzil, J. B., Stewart, D. S., Jackson, T. L., *Program burn algorithms based on detonation shock dynamics: discrete approximations of detonation flows with discontinuous front models*, Journal of Computational Physics, Vol. 174, pp. 870-902, 2001.
[6] Włodarczyk, E., *Wstęp do mechaniki wybuchu*, PWN, Warszawa 1994.
[7] Panowicz, R., Barnat, W., *Wpływ umiejscowienia ładunku wybuchowego na intensywność fali podmuchowej*, Biuletyn WAT, Vol. 59, No. 1, 2010.
[8] Meyers,M. A., *Dynamic Behaviour of Materials*, Johns Wiley & Sons, Inc., New York-Chichester-Brisbane-Toronto-Singapoure 1994.