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ANALYSIS OF THE INFLUENCE OF THE FINITE ELEMENTS MESH DENSITY ON THE DETERMINED SHAPED CHARGE JET PARAMETERS

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Abstract

Article presents results of numerical analyses of the finite elements mesh density influence on the shaped charge jet stream formation process and its selected parameters. Authors considered classical shaped charge, which consists of the plastic explosive material, copper liner and aluminium case. To properly described, material properties of the liner and case of the shaped charge, the Johnson-Cook material model was used. Detonation process was described using burn model approach. Behaviour of the detonation process products was described by commonly used John-Wilkins-Lee equation of state. Due to the nature of the presented phenomenon, in which we are dealing with large strains and strain rates, for its modelling authors utilized Euler description, implemented in the LS-Dyna software. In these method material flows by the finite elements and mesh is not deformed. Such approach allows for modelling phenomena where large and very large deformations occur. Unfortunately, it can result in a destabilizing of the systems energy balance. In order to minimize dissipation processes, in calculations was used second order scheme because of the spatial variables and time. Analyses were performed in axially symmetric setup, which was possible due to the symmetry of the analysed system. Influence of the finite elements size on the process of jet stream formation and its selected parameters was analysed.

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

1. Introduction

Shaped charge consists of three main parts: case, explosive charge and liner (Fig. 1).

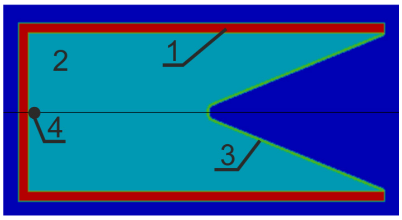

Fig. 1. Shaped charge; (1) case, (2) explosive charge, (3) liner, (4) point of explosive charge boost

An explosive material placed in the charge is suitably shaped allowing for targeting and condensation of detonating explosive material. 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. 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 ~~a~~ high temperature and pressure, resulting from exothermic conversion of the explosive material, affect the liner causing its deformation and movement along and towards the axis of symmetry. Rapid accumulation of the liner material occurs on the axis of symmetry, which also causes a rapid increase in pressure, especially in the axis of the system. In the direction where pressure is lower (symmetry axis), the propagation of the material and formation of the jet stream occur. The jet stream represents about 20% of the liner weight and moves at the speed of several kilometres per second along the axis of symmetry of the charge. The rest of the liner creates so-called "cluster", which moves with relatively small velocity. The jet stream has the form of a thin metal strip with a speed gradient between the front the stream, the temperature of which is approx. 800 K, and the rear part of the stream which contacts with the "cluster", the temperature of which is about 400 K. the speed gradient is responsible for breaking the integrity of the jet stream and reducing its effectiveness. Its thickness in the middle part is a few millimetres.

Generation of jet stream requires a shaped charge characterized by a very slight variation in the symmetry [2, 3].

The discoverers of the "Munroe effect" were E. Munroe and Forster [4, 5].

Shaped charges are mainly used in military applications for destroying armours of vehicles. The most popular are RPG missiles, which are equipped with this type of warheads [6].

Due to the specificity of the jet stream formation process, it 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.

This article presents the results of the research on the impact of the finite element size on the shaped charge jet stream formation process and its selected parameters.

The analyses were based on continuum mechanics equations utilizing Euler description, which are implemented in the LS-Dyna software [7]. Due to presence of the dissipation processes in calculations, second order scheme was used owing to the spatial variables (van Leer scheme) and time.

Numerical calculations were performed in an axially symmetric setup.

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 [8]. 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:

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

where:

$\dot{\varepsilon}^* = \dot{\varepsilon}/\dot{\varepsilon}_0$, $T^* = \dfrac{T - T_r}{T_m - T_r}$,

T – temperature,
T_r – ambient temperature,

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

The detonation process was described using programmed burn model approximations [1, 9]. 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 [10, 11]:

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

where:
$V=\rho_0/\rho$, 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 [10]:

$$p = p_0 + \gamma\rho E ,$$

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 [10]. Other parameters used in the analysis are shown in Tab. 1-3.

Tab. 1. Johnson - Cook equation constants [8, 12]

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

Tab. 2. JWL equation constants [10]

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

Tab. 3. Parameters characterizing TNT used in the calculations [10]

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

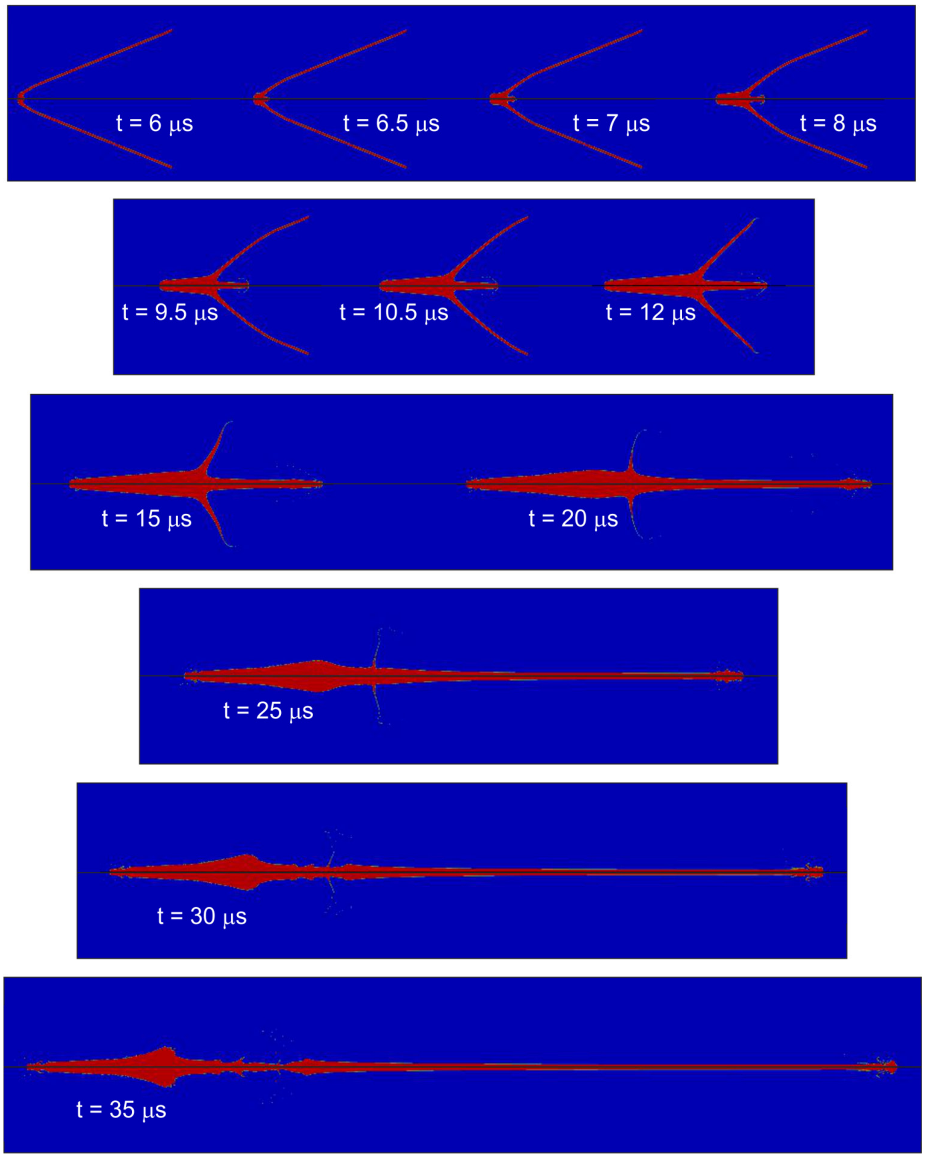

Fig. 2. Jet stream formation process - size of finite elements dx = 0.05

3. Results

The jet stream formation process was analysed depending on the size of the finite elements. The authors considered quad elements with a side length of 0.05 to 0.4 mm. the results in the form of a jet stream shape for selected time stamps and element sizes are presented in Fig. 2 and 3.

There are no apparent differences in the shape of both a "cluster" and a jet stream. There are small variations in the thickness of these elements. For the analyses shown in Fig. 2, a flash of jet stream material at its front is observed, what results from interaction with the air. This phenomenon is observed during the experimental tests [13]. For other materials, this phenomenon cannot be observed due to the element size.

Figure 4 presents the speed of the jet stream front part depending on the size of the finite elements size. In the first phase of driving, the finite elements size does not significantly affect the jet stream speed. The differences can be observed only in the later stage of the numerical analysis. For the biggest elements, the jet stream speed is about 6600 m/s, for the smallest – 7400 m/s.

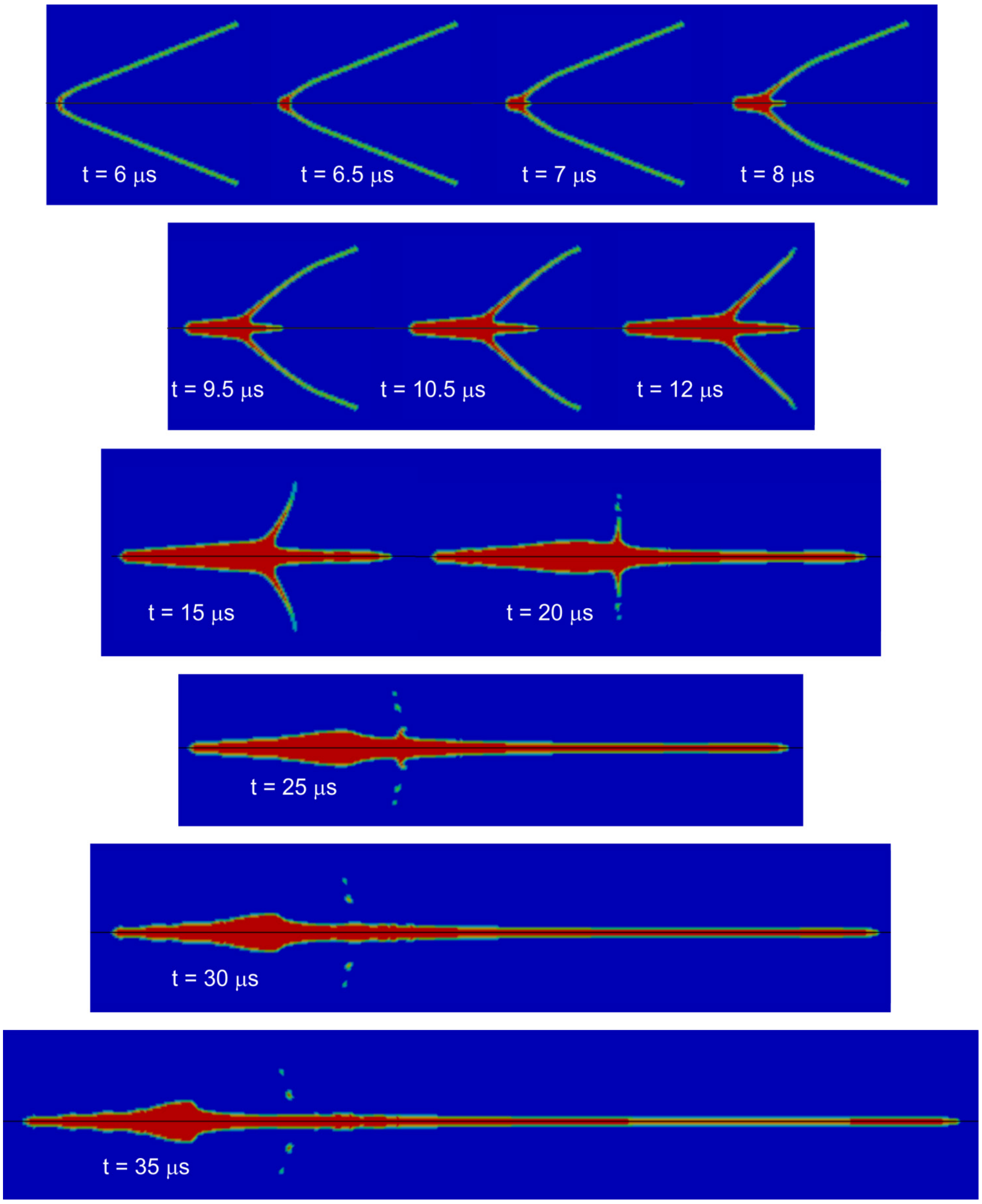

Fig. 3. Jet stream formation process - size of finite elements dx = 0.4

4. Summary

The article presents the results of the numerical analyses of the influence of the finite elements size on the jet stream formation process originating from a typical conical liner.

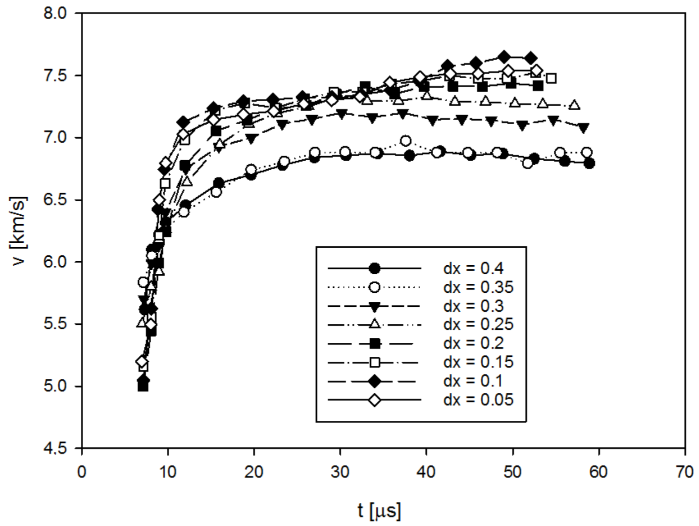

Fig. 4. Speed of front part of the jet stream; dx - size of finite elements

The presented analyses show~~s,~~ that the largest size of the finite elements for describing the jet stream formation process with the use of Euler description, is 0.2 mm. If a secondary importance phenomenon, e.g. taking place in the front part of the stream, is the point of interest, the size of the elements should be less than 0.05 mm.

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