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INFLUENCE OF SELECTED PARAMETERS OF THE FRAGMENTATION WARHEAD ON ITS EFFECTIVENESS

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Abstract

The aim of the paper is to present the results of research on the influence of fragmentation warhead selected parameters on spreading capabilities. Fragmentation warhead is used to combat shaped charges and consists of metallic cover, explosive material and fragmentation liner. Fragmentation liner is built from metal balls or cylinders embedded in the resin. The explosives, initiated by a igniter, causes driving the liner in a few milliseconds up to about 900 m/s. The liner, as well as the case, fragments into many parts during this dynamic load. Geometric parameters of the fragmentation warhead affect the fragments velocity, their mass or geometric dimensions which are the most important parameters determining effectiveness of the warhead. In order properly to describe behaviour of fragmentation warhead arbitrary Lagrangian-Eulerian (ALE) and fluid-structure interaction (FSI) approach was used. In this method, the fragmentation liner is modelled using Lagrange description while the resin, the explosive charge and the surrounding air are modelled using Euler description. A three dimensional model of directed fragmentation warhead along with the fragmentation liner was prepared in MSC.Patran software and the dynamic phenomena analysis used a nonlinear finite element method implemented in the LS-DYNA program.

Keywords: *directed fragmentation warheads, dynamics, finite element method*

1. Introduction

The growing threat to military vehicles from missiles with shaped charges enforces development of solutions to improve protection against this type of threat. In this type of missiles, a jet stream originating from dynamic loaded liner is used for penetrating the armour of attacked vehicle. Such missiles are very popular because of the wide availability, low price and ease of use.

Over the years, researchers have attempted to develop more effective methods defences against such threats. One of them is to use an active protection system. These systems detect and destroy (or damage) approaching missile before it reaches its direct contact with the protected vehicle. Among existing or currently developing active protection systems, we can distinguish to main groups [1-3]:

– softkill systems – their purpose is to influence electronic systems (mostly those responsible for guiding) of an incoming missile,
– hardkill systems – their purpose is to physically destroy or damage incoming threat (Fig. 1).

Fragmentation warhead, presented in the article, is part of the hardkill system in which in the direction of the approaching missile the anti-missile is shot. Fragmentation warhead is in the form of a cylinder with a length of 100 mm and diameter of 80 mm. It consists of such elements as case, fragmentation liner and explosive material. The aim of fragmentation warhead is to produce a cloud of fragments resulting from fragmentation process of case and fragmentation liner originating from detonation of explosive material.

Fig. 1. Example of an active protection system [4]

In order to achieve the desired values of the parameters characterizing the effectiveness of such warheads, i.e. fragments dispersion angles or their velocity (which directly translates into energy) it is necessary to choose appropriate values of the fragmentation warhead parameters. These include geometrical shape of the warhead, type of material from which the elements of the warhead are made or parameters of selected explosive material.

Following article present results of the research on the impact of the fragmentation warhead inner case thickness on the one of the main parameters characterizing effectiveness of the warhead – velocity of the fragments. Numerical analyses were performed using arbitrary Lagrange-Euler (ALE) method with fluid-structure interaction (FSI) feedback. Numerical model was developed in the MSC Patran software and the calculation was performed using LS-DYNA solver.

2. Numerical model of fragmentation warhead

The object of research is fragmentation liner in the form of a cylinder with a length of 100 mm and a diameter of 80 mm. In the warhead construction, we can distinguish four main parts: outer case, fragmentation liner, explosive material along with the igniter and outer case. Fragmentation liner consists of steel balls with diameter of 5 mm, which are embedded, in resin. Tested fragmentation liner is presented in Fig. 2.

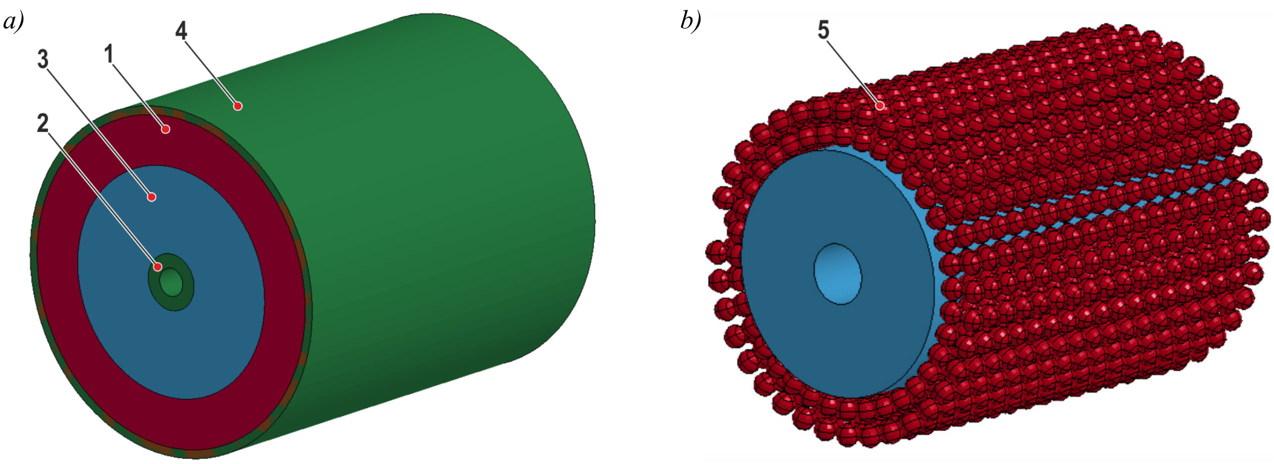

Fig. 2. Numerical model of the fragmentation warhead: whole model (a), and close-up on fragmentation liner (b); 1 – fragmentation liner, 2 – outer case, 3 – explosive material, 4 – inner case, 5 – steel balls

The fragmentation process of the fragmentation warhead can be described using few different methods. One of them, which provide very good accuracy of obtained results, is arbitrary Lagrange-Euler (ALE) with fluid-structure interaction (FSI) feedback. Classical methods for describing bodies use Lagrange formulation in which deformation of the body is followed by the deformation of the finite elements mesh. In the case of the Euler formulation body moves against the finite elements, mesh which describes the body. Arbitrary Lagrange-Euler approach combines both of the above formulations. Specific fragmentation elements are modelled in this approach with use of the continuum mechanics equations in the Lagrange description. In contrast, the adhesive (resin, air) is modelled with the same equations but in the Euler description. The application of the ALE approach also requires the define the air which surround the entire considered system which significantly increase the number of finite mesh elements needed for the job description.

The fragmentation liner (Fig. 2b) consists of 1296 balls (5 mm in diameter) embedded in the resin. For their description, 54432 solid finite elements were used. To describe their parameters a bilinear material model with parameters corresponding to the S350 (St3 in the old classification) steel was used. In this constitutive model, material behaviour is described by three characteristic points determining the stress and strain at which it occurs (ES, EPS). It is assumed that the starting point corresponds to zero strain. Between points, material behaviour is linear [5]. As a failure criterion, maximum strain at failure ε_f was applied. Material constants used in numerical analyses are presented in Tab. 1.

Tab. 1. Bilinear material properties [7]

Parameter	Unit	Value
ρ	kg/mm^3	$7.89\cdot10^{-6}$
E	GPa	210
ν	–	0.3
ε_f	–	0.2
EPS1	–	0.02
EPS2	–	0.4
ES1	GPa	0.21
ES2	GPa	0.218

Mechanical properties of the steel case (both external and internal) were described using a simplified Johnson-Cook type material [6].This model correctly reproduces the behaviour of the described material during dynamic interaction with high strain rates and strains. Transition into plastic state depends on the product of a function depended on the strain and strain rate. The influence of the strain rate on the material behaviour is identical as in the classical Johnson-Cook model. The simplified model does not take into account thermal effects [7]:

$$\sigma_{flow} = [A + B(\varepsilon^p)^n](1 + C\ln\dot{\varepsilon}^{p*}), \tag{1}$$

where:

A, B, C, n, m – material constants,

$\dot{\varepsilon}^{p*} = \dot{\varepsilon}^p / \dot{\varepsilon}_0^p$ – normalized effective plastic strain rate,

$\dot{\varepsilon}^p$ – effective plastic strain rate,

$\dot{\varepsilon}_0^p$ – quasi-static threshold strain rate.

The surrounding air was described using Mie-Gruneisen equation [5, 8]. Due to the fact that resin has low strength compared to other materials, the same material model was used for its description:

$$p = p_0 + \gamma \rho E\,, \tag{2}$$

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

The following constant values in the equation were taken from the literature [9]: $\gamma = 1.4$, $\rho = 1.185$ kg/m^3, $p_0 = 1013$ hPa.

For driving the fragmentation liner, a commonly used C4 explosive was chosen. Due to its physico-chemical characteristics, this material is often used for driving the fragments. The detonation process was described using programmed burn model approximations [5, 8], and the behaviour of the detonation products was described with the JWL (John, Wilkins, Lee) equation [6, 9]:

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

where:
E – internal energy,
$V = \rho_0 / \rho$,
ρ_0 – initial density,
ρ – density of detonation products,
A, B, R_1, R_2, ω – constant values.

3. Numerical analyses

Numerical analyses were performed with use of arbitrary Lagranege-Euler (ALE method) and fluid-structure interaction (FSI) feedback. The software used for analysis was LS-DYNA as a solver and LS Prepost as postprocessor.

The numerical analyses assumed that the point of detonation initiation is located at one end of the fragmentation warhead at the contact point between the explosive material and internal case (Fig. 3). Authors analysed only first millisecond of the phenomenon, because after this time the pressure of the detonation products is so small that it practically does not increase the speed of the fragments.

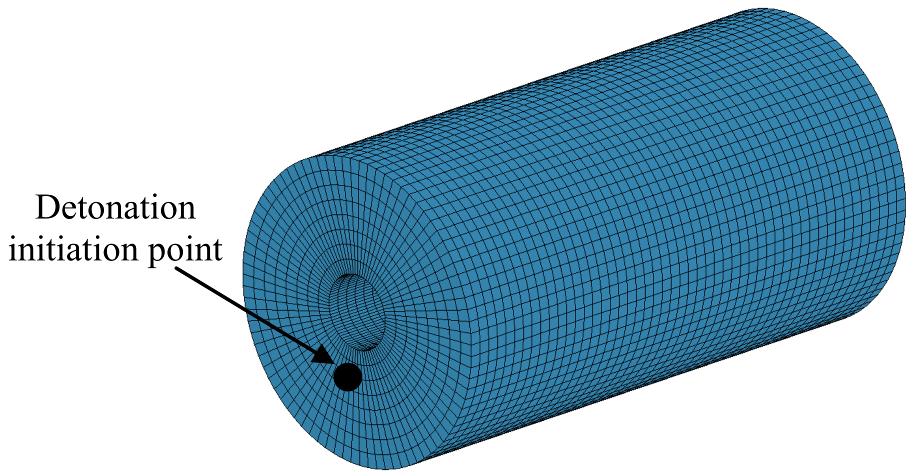

Fig. 3. Localisation of detonation initiation point

During the numerical analyses, we investigated the influence of the inner case thickness on the basic parameter of fragmentation warhead – the velocity of fragments. Because of the position of the detonation initiation point on the one of the edges of the warhead, it was necessary to check velocity of the fragments in two points: on the left and right side of the fragmentation warhead.

Numerical analyses were performed in the following variants:

1. thickness of the inner case: 3.75 mm,
2. thickness of the inner case: 2 mm,
3. thickness of the inner case: 1 mm,
4. without inner case.

Figure 4 and 7 presents behaviour of the fragments resulting from the fragmentation of the case (outer and inner) and the fragmentation liner for cases when the inner case thickness was 3.75 mm and 1 mm. For the same case, in Fig. 5-6 and 8-9 authors presented a graph of fragments velocity for both ends (left and right) of the fragmentation warhead.

The thickness of the inner case has a great influence on the speed of the fragments. The difference between the 3.75 thick inner case and situation when there are not any inner case is approximately 18 % for the fragments on the edge where was detonation initiation point located amd 17% for the opposite edge. Difference between 3.75 mm thick inner case and 1 mm thick is slightly smaller and is about 7% for the edge with detonation initiation point and 5% for the opposite edge.

Tab. 2. Summary of the results

	Inner case thickness: 3.75 mm	Inner case thickness: 2 mm	Inner case thickness: 1 mm	No inner case
Fragments velocity [m/s] in the edge where detonation point was located	667	638	621	546
Fragments velocity [m/s] on the opposite edge	474	455	453	392

4. Summary

The use of the ALE method along with FSI feedback allowed for correct performation of the numerical analyses of the direct fragmentation warhead fragmentation process. Compared to traditional methods this approach allows for results that are more accurate.

The article presents an analysis of inner case thickness on the effectiveness of fragmentation warhead, which is characterized by the maximum velocity reached by the fragments. Obtained results show that this parameter has significant influence. Difference between 3.75 mm thick inner case and situation when there is no inner case was approximately 18 %, which translates into significant difference in velocity reached by the fragments.

Acknowledgements

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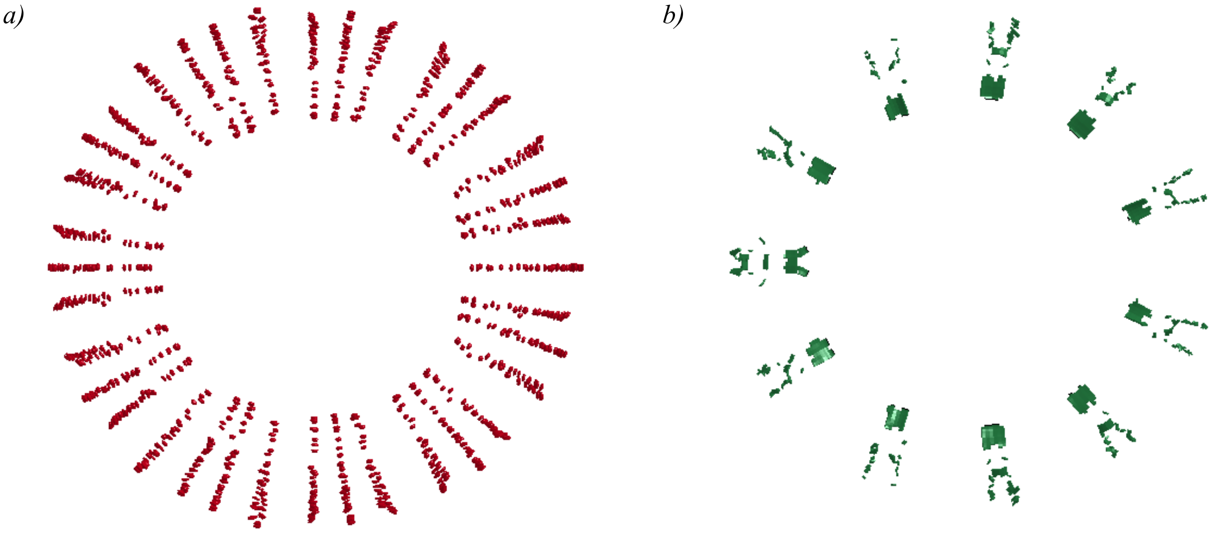

Fig. 4. 3.75 mm thick inner case: behaviour of fragmentation liner (a) and cases (b) in t = 0.25 ms

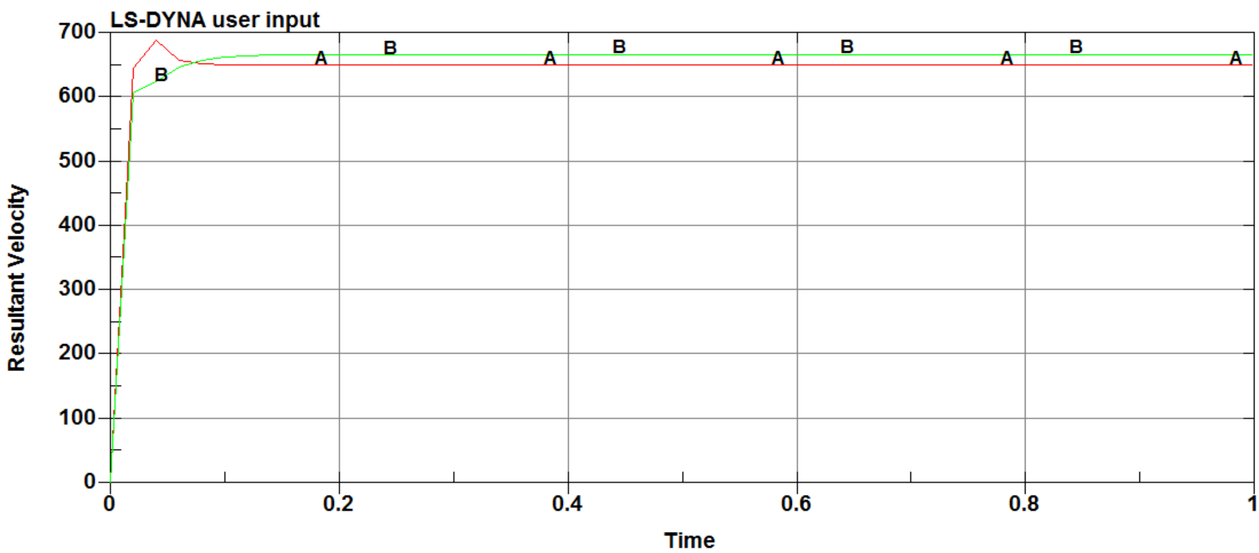

Fig. 5. Velocity of the fragments measured above the edge where the detonation initiation point was located; 3.75 mm thick inner case

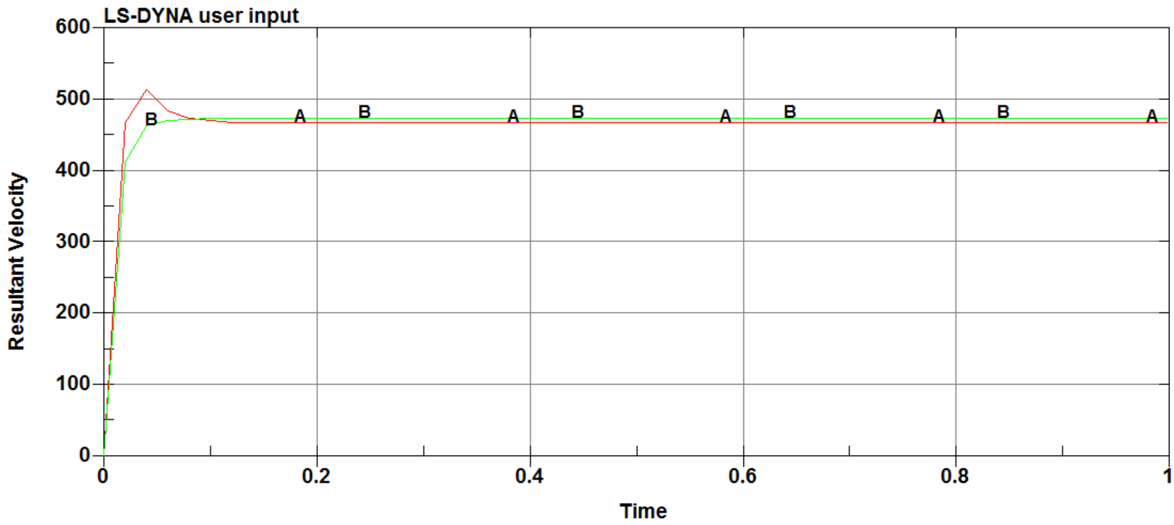

Fig. 6. Velocity of the fragments measured above the opposite edge where the detonation initiation point was located; 3.75 mm thick inner case

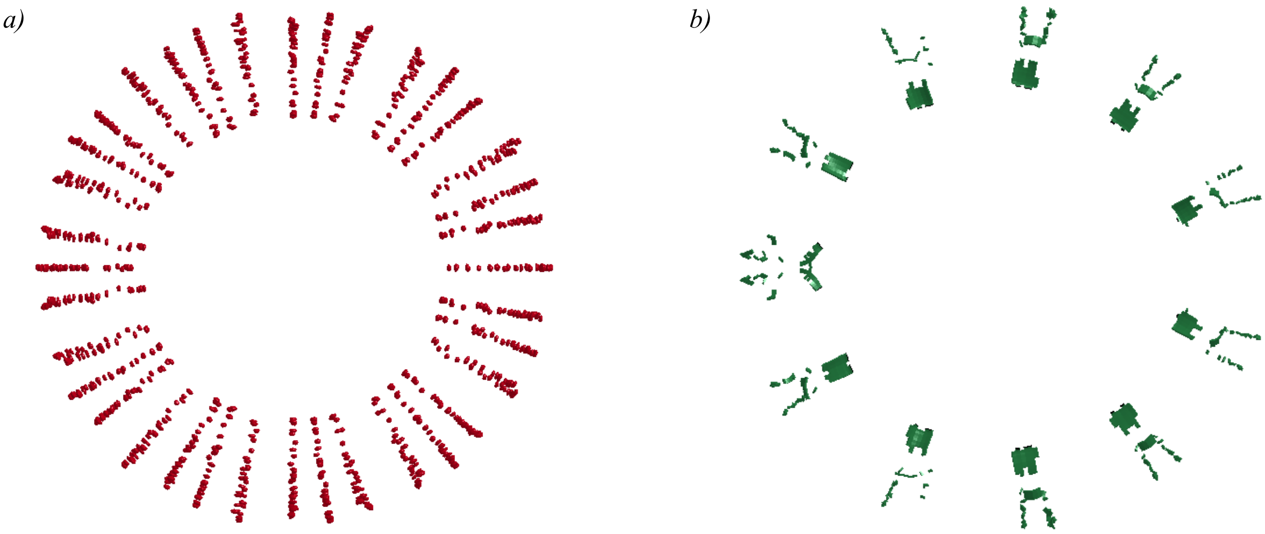

Fig. 7. 1 mm thick inner case: behaviour of fragmentation liner (a) and cases (b) in t = 0.25 ms

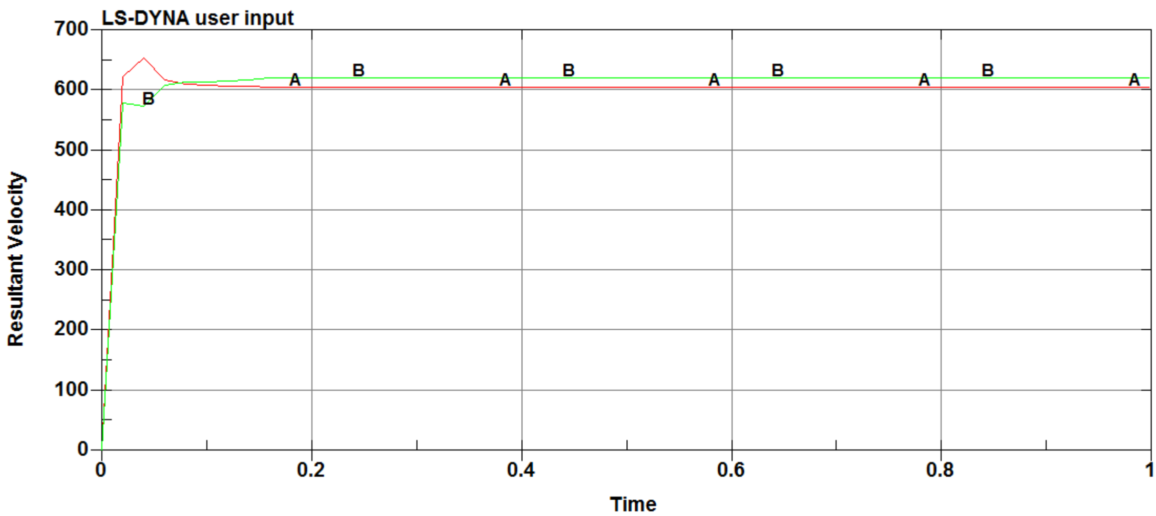

Fig. 8. Velocity of the fragments measured above the edge where the detonation initiation point was located; 1 mm thick inner case

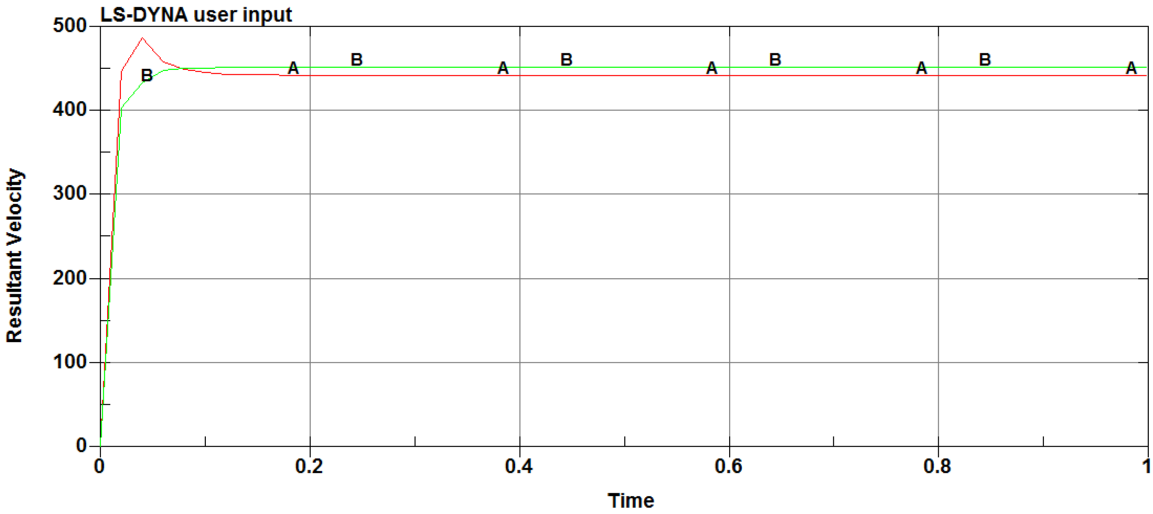

Fig. 9. Velocity of the fragments measured above the opposite edge where the detonation initiation point was located; 1 mm thick inner case