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3D NUMERICAL SIMULATION OF NON-ENERGETIC REACTIVE ARMOR

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ABSTRACT

Non-energetic reactive armors also called bulging armors are known for their effectiveness against shaped charges. These composite structures consist of two metal plates and an intermediate non-metallic layer. Soft materials like rubber or polymers are often preferred for the intermediate layer. In this paper, interaction of shaped charge jet with bulging armor is studied and the effects of material parameters of the intermediate layer are investigated by using 3d numerical simulations.

INTRODUCTION

Shaped charge warheads are used in anti-tank weapons against main armors of armored vehicles such as tanks. Reactive armors have been developed to reduce penetration capability of shaped charges. These armors are used as add-on armors in front of main armors. Reactive armors could be divided into three main subgroups. These are *explosive reactive armor*, *non-explosive reactive armor* and *non-energetic reactive armor*.

Explosive Reactive Armor

Explosive reactive armors possess explosive material in their intermediate layer, [Held, 1970]. This type of reactive armor is more effective than non-energetic reactive armors. The protective mechanism of explosive reactive armors is as follows: After the interaction with the shaped charge jet the intermediate explosive layer explodes. As a result of the explosion the outer metallic layers of the armor are accelerated in opposite directions reaching very high velocities. During this movement, metallic layers interact with the shaped charge and disturb its unity. However, the high velocity of the metallic layers is a serious threat for the environment which is the significant disadvantage of explosive reactive armors in comparison to non-energetic reactive armors.

Non-Explosive Reactive Armor

Non-explosive reactive armor is similar to explosive reactive armor in that, it possess an energetic but non-explosive interlayer. It is less effective than explosive reactive armor but with significantly reduced collateral damage.

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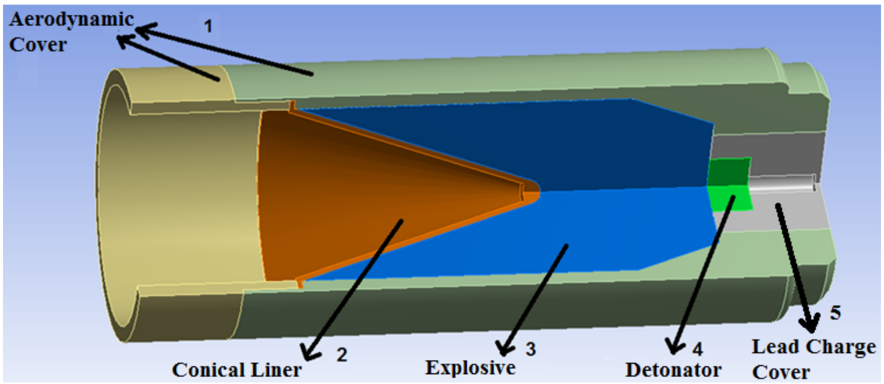

Figure 1: Shaped charge model used in simulations

Non-Energetic Reactive Armor

Non-energetic reactive armors (Bulging armor), which were first proposed in [Held, 1973], consist of inert materials such as rubbery or polymeric materials rather than explosives in their intermediate layers. The protective mechanism of bulging armors is slightly different than explosive reactive armors. When a shaped charge jet hits the inert intermediate layer, a shock wave interactions through the interlayer results in bulging of the metallic layers [Yaziv, Friling and Kivity , 1995], [Gov, Kivity, Yaziv, 1992], [Mayseless et al., 1993]. Then, moving metallic plates interact with the incoming jet and distort it. The main disadvantage of bulging armors is that they are less effective against shaped charges than explosive reactive armors. More detailed comparison about two types of armors was given in [Held , 1993].

In this study, the former two-dimensional work of the authors [Kurt et al., 2014] is extended. The interaction of shaped charge jet with bulging armor is studied numerically and the effects of material parameters of the intermediate layer on the performance of the armor are investigated by using 3d numerical simulations. First, the jet formation is simulated from the shaped charge using the 2d Euler solver of AUTODYN. In a second step, the formed jet is transferred in the 3d Lagrange solver of AUTODYN by remapping. Therefore, the jet-armor interaction is analyzed by the 3d Lagrange solver.

MODELLING

The shaped charge model used in this study is presented in Figure 1. Different colors refer to different materials in the shaped charge. Orange, blue, green and light green-gray colors are conical liner, main explosive, detonator and cover, respectively.

In order to understand the effect of mesh size on the results of the jet formation analysis (2d Euler analysis), a mesh sensitivity analysis similar to [Deniz, Gümüş, 2010] was conducted. To this end, the model is meshed with 0.5, 0.4, 0.25, and 0.2 mm element sizes. It was observed that for mesh sizes smaller than 0.25 mm the results for jet velocity, jet momentum, and jet kinetic energy do not change significantly. The results of jet formation for different mesh sizes are given in Table1.

The shaped charge formation is simulated in Euler mesh solver and the resultant jet is transferred to

Table 1: Jet properties for different mesh sizes after jet formation

Element size $[mm]$	Jet tip distance [mm]	Jet tip velocity $[km/s]$	X-momentum $[mg.m/s]$	Energy $[mg.m^2/s^2]$
0.5	281.47	6.83	$1.2243 \cdot 10^8$	$2.35 \cdot 10^{11}$
0.4	281.09	7.07	$1.2207 \cdot 10^8$	$2.36 \cdot 10^{11}$
0.25	281.52	7.45	$1.2228 \cdot 10^8$	$2.39 \cdot 10^{11}$
0.2	283.79	7.58	$1.2213 \cdot 10^8$	$2.38 \cdot 10^{11}$

Table 2: Jet properties for different mesh sizes after transferring Euler mesh to Lagrange mesh

Element size [mm]	Mass [mg]	X-momentum [mg.m/s]	Energy $[mg.m^2/s^2]$
0.5	$1.25 \cdot 10^5$	$1.476 \cdot 10^8$	$2.82 \cdot 10^{11}$
0.4	$9.57 \cdot 10^4$	$1.22 \cdot 10^8$	$2.36 \cdot 10^{11}$
0.25	$9.62 \cdot 10^4$	$1.222 \cdot 10^8$	$2.39 \cdot 10^{11}$
0.2	$9.45 \cdot 10^4$	$1.17 \cdot 10^8$	$2.28 \cdot 10^{11}$

a Lagrange mesh to simulate the interaction of the shaped charge jet with the bulging armor. Several mesh sizes are tested for the transfer and mapping of Euler meshes to Lagrange meshes in order to see the effect of mesh size on mapping. The results can be seen in Table 2. For element sizes smaller than 0.5 mm transferred jet has nearly the same mass, x-momentum and energy.

A reactive armor consists of three plates named as the backward moving plate (BMP), the forward moving plate (FMP) and the mid-plate. The BMP is metallic and first interacts with the jet. As a result of expansion of the intermediate layer the BMP moves in the opposite direction to the jet. The FMP interacts with the jet lastly and it moves in the same direction with the jet. Mid-plate is an inert material often made of a polymeric material. Its main purpose is to expand and cause the BMP and the FMP to bulge.

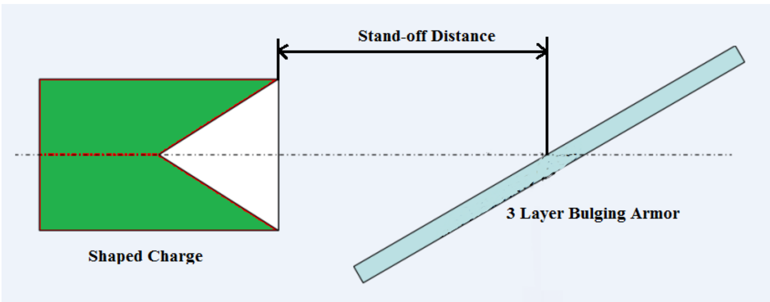

Figure 2: A schematic view of the problem. Shaped charge is initiated at a stand-off distance from the bulging armor. The jet hits the armor obliquely.

There are several parameters effecting the penetration performance of the jet when it interacts with a reactive armor. Stand off distance, the interaction angle with the jet direction and normal axis of the armor plane (NATO angle), and thicknesses of the plates and materials used are among these parameters. In this study all the parameters are taken constant except the material parameters of the inert mid-plate. A schematic view of the model is presented in Figure 2.

RESULTS

In order to evaluate the performance of armor momentums and kinetic energies of the BMP, the FMP and the jet are computed and compared for different intermediate layer materials. Furthermore gauge points are located on the BMP, the FMP, the jet and the intermediate layer. Through these gauge points time histories of the pressure and velocity are recorded.

In this study the goal is to study the effects of inert layer material properties on the performance of the armor against shaped charge. Three material parameters of the inert layer are investigated, these are the density and the shock-Hugoniot parameters. Figure 3 shows some screenshots of the interaction of the jet with the bulging armor for four different instances.

The effects of material density on the kinetic energy, the X and Y-momentum of the FMP are presented in Figure 4. Three values of the density, $\rho = 1.1, 1.2$ and 1.3 g/cm^3, are considered in simulations. X-direction coincides with the flow direction of the jet, while Y-direction is perpendicular to the flow

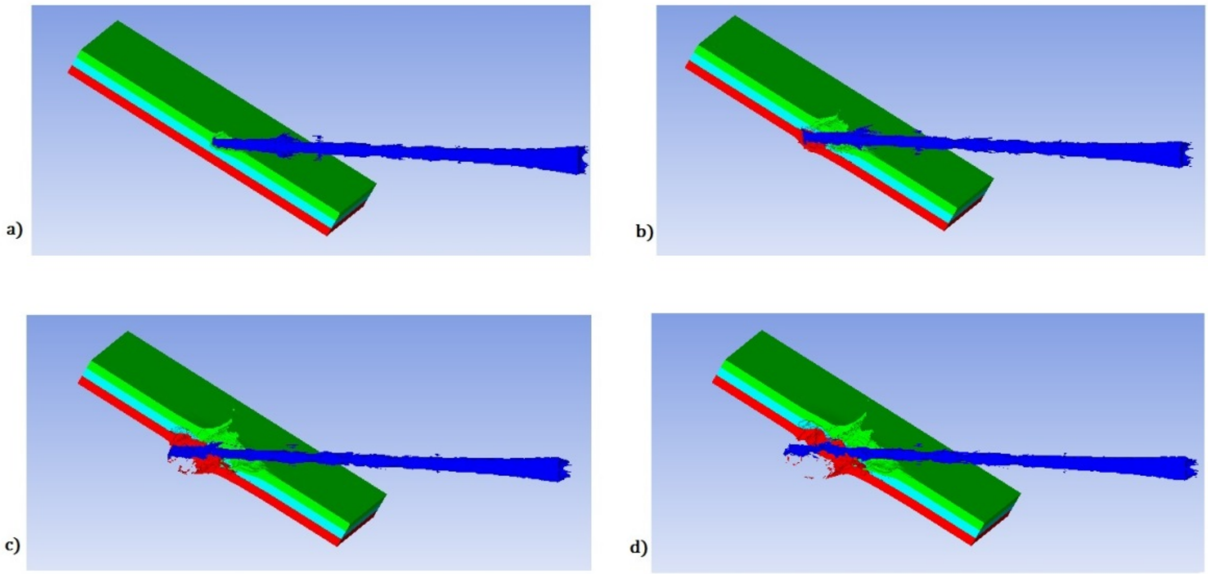

Figure 3: Interaction of the jet with the armor. Green layer is the BMP, red layer is the FMP and cyan layer is the inert intermediate plate.

direction of the jet. As expected the kinetic energy and the X, Y-momentum of the FMP increases as the jet penetrates into the armor. However, the increment of kinetic energy and the X, Y-momentum is bigger for higher densities of the inert layer. As can be seen in Figure 4 a higher density of the intermediate layer causes a higher X and Y-momentum of the FMP. Therefore, these three plots indicate that the rising of density increases the performance of the armor against the jet. In the literature an analytical model was developed to investigate mechanical properties of intermediate layer affecting bulging armor performance [Yadav, 2004]. According to this model, the shock energy in the intermediate inert layer is higher, i.e. performance of the armor is better, for higher densities of the intermediate layer. Effect of density results of our numerical study agrees with the analytical model [Yadav, 2004].

The effects of bulk sound velocity of the intermediate layer on the kinetic energy and X, Y-momentum of the FMP are presented in Figure 5. Three values of the bulk sound velocity, $C_1 = 3.2, 4.2$ and 5.2 km/s, are considered in simulations. The kinetic energy and the X, Y-momentum of the FMP reach to higher values for higher values of the bulk sound velocity. Similar to the conclusion reached from Figure 4, these three plots indicate that higher bulk sound velocity increases the performance of the armor against the jet. The authors [Rosenberg, Dekel, 1998] worked on 2D numerical analyses of bulging armors. They concluded that higher density and higher bulk sound speed of intermediate layer lead to better performance of the bulging armor.

Next the effect of impedance $Z = \rho \cdot C_1$ of intermediate layer on the armor performance is studied. For this purpose, both the density and the bulk sound speed values are changed simultaneously while keeping the impedance constant. The bulk sound speed and the density are taken as $C_1 = 3.2$ km/s and $\rho = 1.2$ g/cm^3. Three curves shown in Figure 6 have same impedance $Z = 3.84 \cdot 10^5$ g·cm^{-2}·s^{-1}. According to this figure, the momentum and the kinetic energy of the FMP are almost constant for different materials with same impedance. Therefore, it is inferred that the effects of the density and the bulk sound speed on the armor performance are very similar.

Finally, gauge points are introduced on three layers as shown in Figure 7. The x and y velocity values of one gauge point on FMP are analysed to study the effect of bulk sound speed and density on the performance of the armor.

As can be clearly seen in Figure 8, response or bulging time of FMP is fast when the bulk sound speed is increased. Therefore, the shock wave reaches to FMP faster when high C_1 is used for the

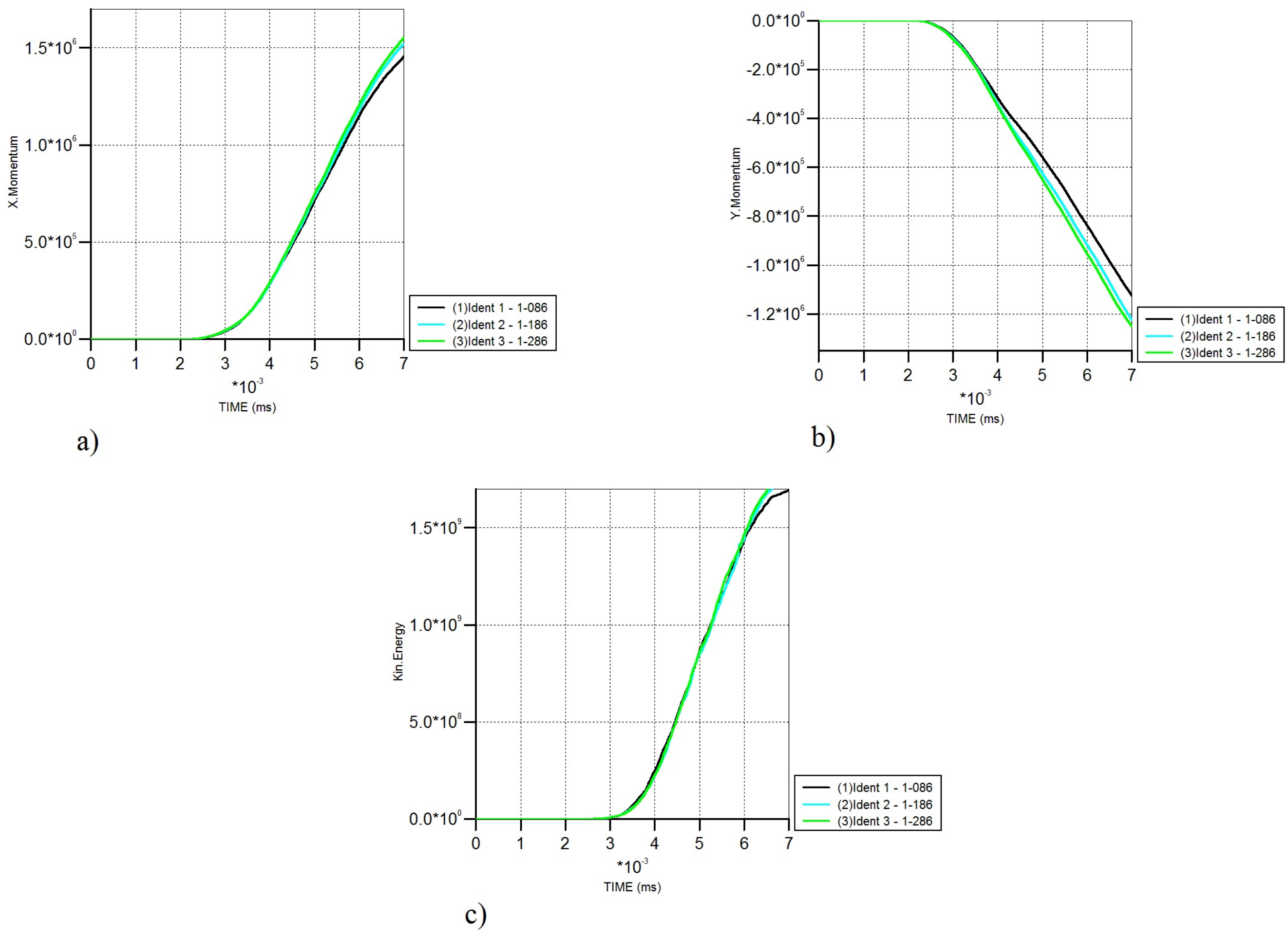

Figure 4: Variation of a) the X-momentum b) the Y-momentum and c) the kinetic energy of the FMP by changing the density of the intermediate layer.

intermediate layer. As the bulging starts earlier the FMP would interact more with the jet. Therefore, from the velocity plot of a gauge point on the FMP, it can also be concluded that higher bulk sound speed of the intermediate layer leads to a better performance of the armor.

According to Figure 9, response time which is 5 microseconds is same for all three density values but bulging performance is different each other. The effect of density difference on bulging FMP occurs at 6 microseconds for x velocity and approximately 5.8 microseconds for y velocity. After these times, FMP moves at higher velocities because of high density value of the intermediate layer. For instance, the gauge point's y velocity reaches nearly 35 m/s for the highest density at 6 microseconds and others' are lower than this. It is also come to a conclusion which supports previous comparison that density is an important mechanical property for higher performance armor.

CONCLUSION

Non-energetic reactive armors also called bulging armors are analysed for their effectiveness by using AUTODYN software. 3D model of this armor which is formed two metal layers and one intermediate non-metallic layer is made and then impact analysis between a shaped charge jet and bulging armors are conducted. Two important properties which are bulk sound speed and density are investigated for higher performance of the armor. X and y momentum, kinetic energy and x, y velocity are compared for both the bulk sound speed and density. It is concluded that the bulk sound speed affects the shock wave travelling time so higher bulk sound speed increases the performance of the armor against the

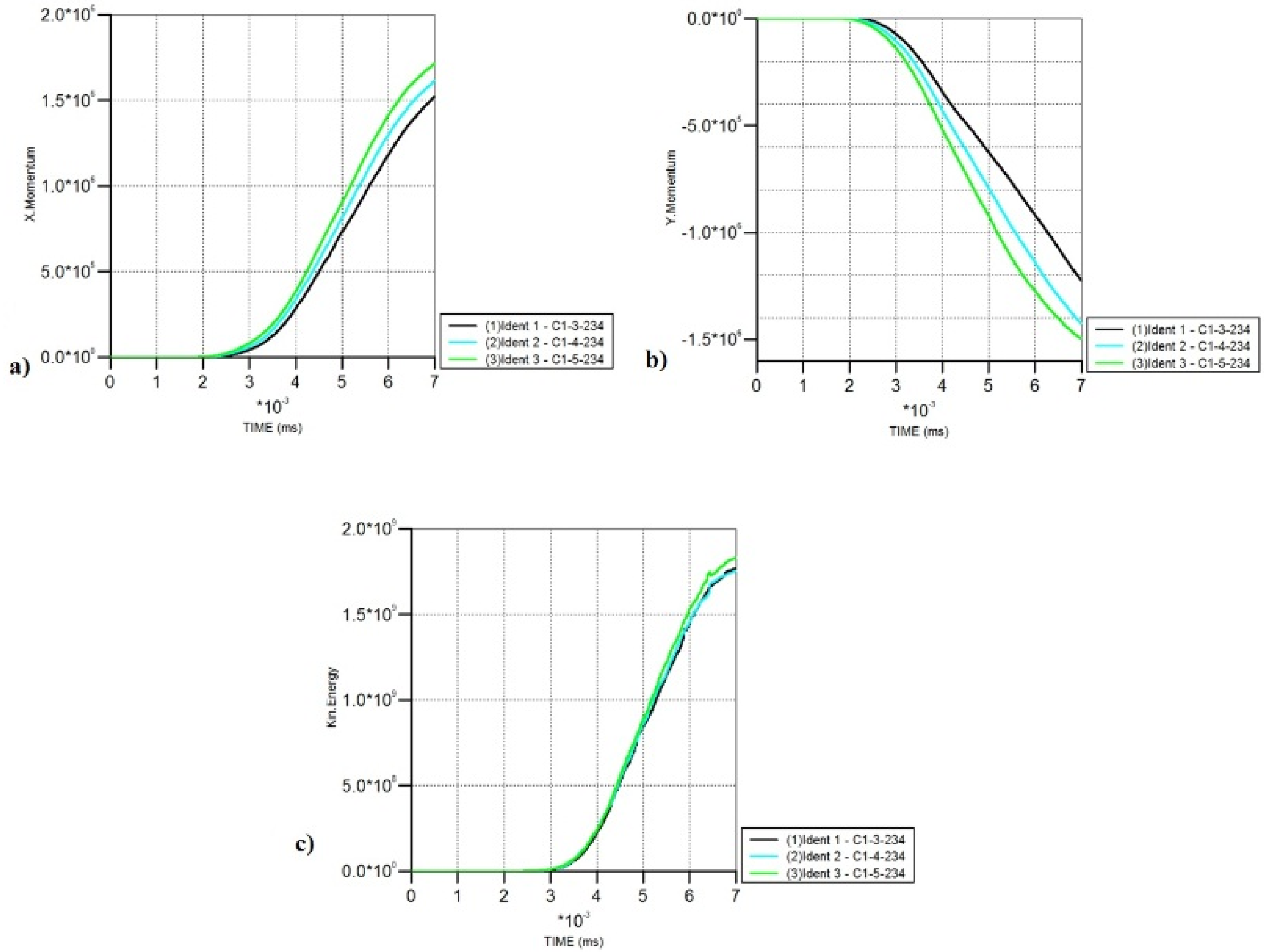

Figure 5: Variation of a) the X-momentum b) the Y-momentum and c) the kinetic energy of the FMP by changing the bulk sound velocity of the intermediate layer.

jet. Moreover, when the density of the intermediate layer is made high, FMP which is critical layer for long interaction time with the jet gets a higher X and Y-momentum. This case is preferred for the bulging armors.

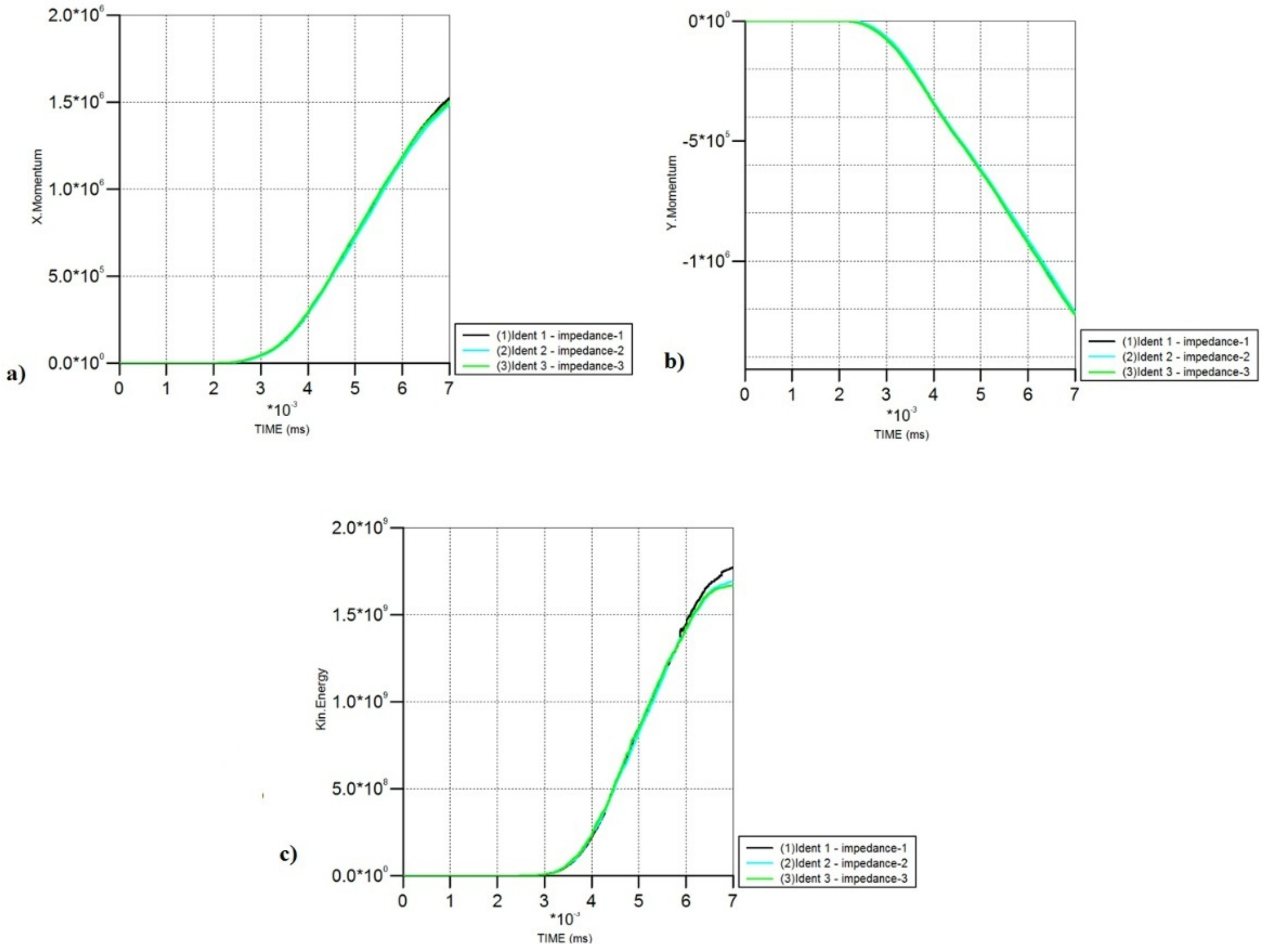

Figure 6: Variation of a) the X-momentum b) the Y-momentum and c) the kinetic energy of the FMP by the same impedance value of the intermediate layer.

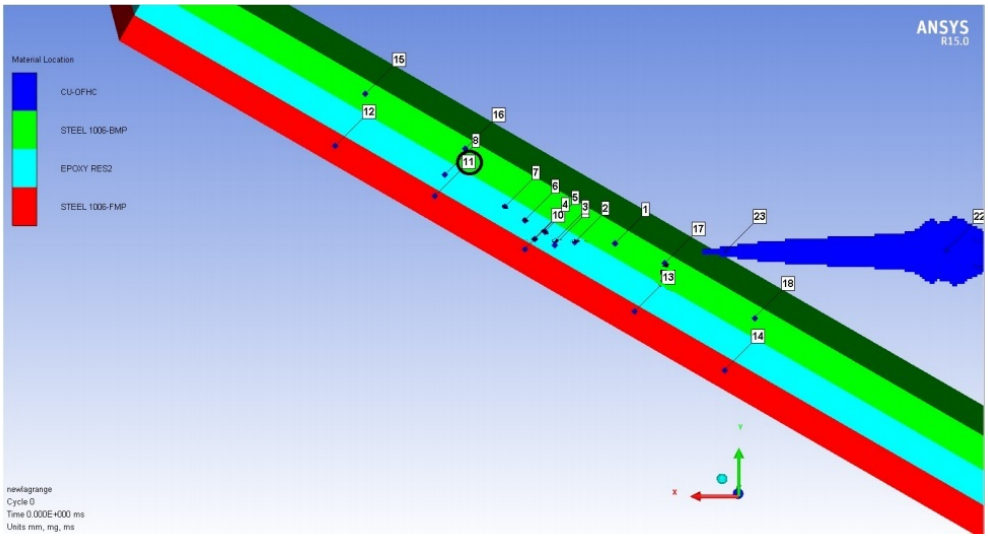

Figure 7: Analysed gauge point is shown in black circle

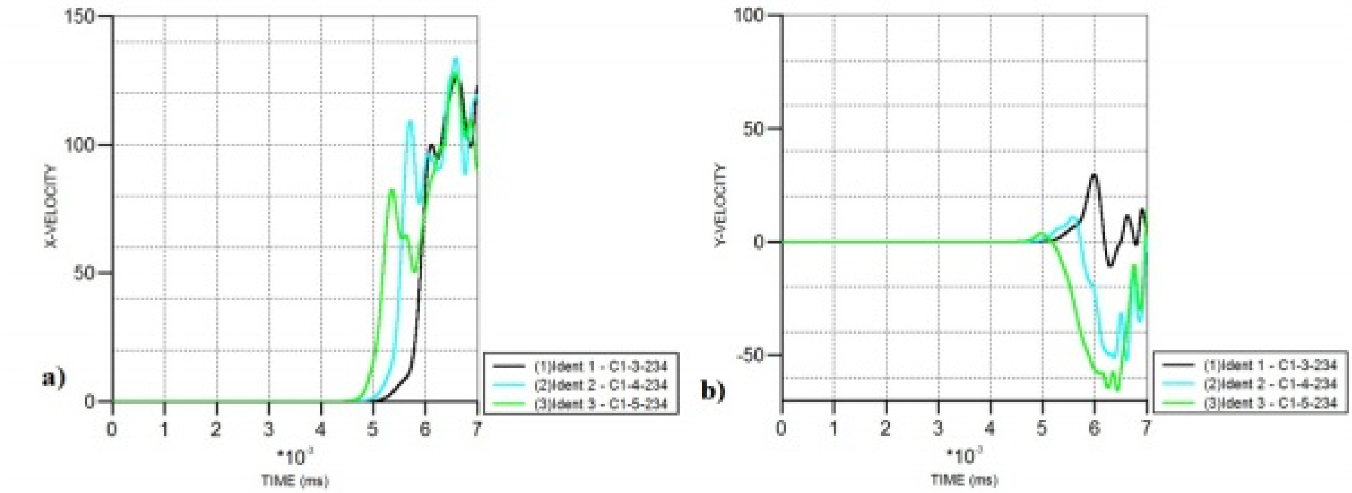

Figure 8: x and y velocity plots of the analysed gauge point

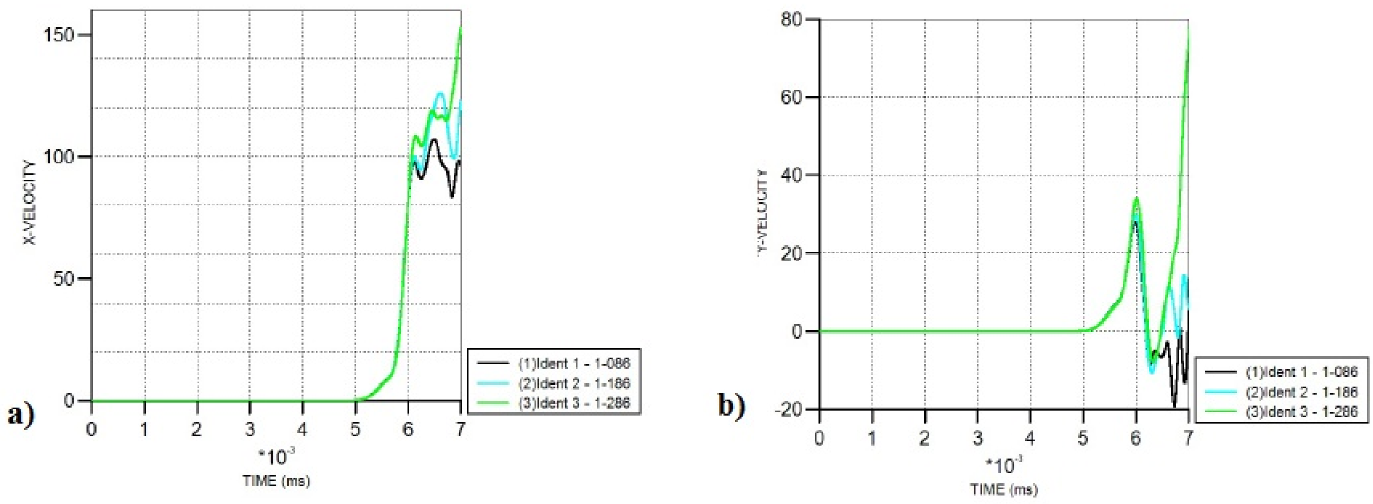

Figure 9: x and y velocity plots of the analysed gauge point

References

T. Deniz, U. Gümüş (2010), Çukur İmla Benzetimlerinde Erezyon ve Eleman Boyu Etkileri 6. Savunma Teknolojileri Kongresi (SAVTEK), 23-25 June 2010, Ankara, Turkey.

M. Held, (1970), Explosive Reactive Armor, Patent, No 2008156.

M. Held, (1973), Schutzeinrichtung gegen Geschosse, insbesondere Hohlladungsgeschosse (protection device against projectiles, especially shaped charges). Patent, No 2358227.

M. Held, (1993), Armour, 14th International Symposium on Ballistics, 45-57, September 26-29, 1993, Quebec City, Canada.

M.C Kurt, F. Seaidi, T. Deniz, E. Gürses (2014), Çukur İmla Şişen Zirh Etkileşiminin Sayisal Yöntemlerle Incelenmesi 7. Savunma Teknolojileri Kongresi (SAVTEK), 25-27 June 2014, Ankara, Turkey.

D. Yaziv, S. Friling, and Y. Kivity, (1995), The Interaction of Inert Cassettes with Shaped Charge Jets, 15th International Symposium on Ballistics, 461-467, May 21-24, 1995, Jerusalem, Israel.

N. Gov, Kivity Y., and D. Yaziv, (1992), On the Interaction of a Shaped Charge Jet with a Rubber Filled Metallic Cassette, 13th International Symposium on Ballistics, 95-102, June 1-3, 1992, Stockholm, Sweden.

M. Mayseless, E. Marmor, N. Gov, Y. Kivity, J. Falcovitz, and D. Tzur, (1993), Interaction of a Shaped Charge Jet with Reactive or Passive Cassettes, 14th International Symposium on Ballistics, 439-448, September 26-29, 1993, Quebec City, Canada.

H.S. Yadav, (2004), Study of Jet Interaction with Interlayer Material of Bulging Armor, Propellants, Explosives, Pyrotechnics, 29, 349-353, 2004.

Rosenberg, Z. and Dekel, E., (1998), A Parametric Study of the Bulging Process in Passive Cassettes with 2-D Numerical Simulations, International Journal of Impact Engineering, 21, 297-305, 1998.