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Numerical analysis of a frontal impact of a 12.7 mm projectile on an armor plate

Численный анализ лобового удара снаряда 12,7-мм по бронелисту

Нумеричка анализа фронталног удара пројектила 12,7 mm у панцирну плочу

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ABSTRACT:

Introduction/purpose: The paper presents a numerical simulation of an impact of a 12.7 mm projectile on an armored metal plate with a velocity of 500 m/s at a distance of 900 m. Numerical simulations offer the possibility of drastically reducing the time required to obtain results in comparison to the time required for planning, organization and execution of experiments. The numerical simulation is done by variations in the thickness of the armor metal plate, specifically an armor metal plate of a thickness of 10 mm, 17 mm, 18 mm, and 23 mm. The mentioned armored plate thicknesses were chosen based on the results in order to determine the limit thickness of the armored plate for the projectile perforation limit, as well as for complete ballistic protection.

Methods: Finite element modeling is used for analyzing stresses and deformations of the armored plates. The mentioned method calculates the impact of the projectile on the obstacle, precisely the collision of the projectile and the armor plate.

Results: For the comparative analysis, the parameters used are the values of the stress and the displacement. For each of the above-mentioned thicknesses of the armored metal plate, the values of stress and displacement during projectile impact were determined.

Conclusion: If the physical and chemical characteristics of the armored plate remain unchanged, as the thickness of the armored plate increases, the possibility of projectile penetration decreases, and vice versa. This research is of essential importance because it analyzes the stresses and deformation of armor plates whose basic role is the protection of personnel and equipment from the projectile impact. In this regard, the thickness of the armored plate for semi-penetration of the projectile is determined.

KEYWORDS: armor plate, projectile, impact, finite element modeling.

Р е з ю м е :

Введение/цель: В данной статье представлено численное моделирование удара снаряда 12,7-мм по бронелисту со скоростью 500 м/с на расстоянии 900 м. Численное моделирование позволяет значительно сократить время, необходимое для получения результатов, по сравнению со временем, необходимым для планирования, организации и проведения экспериментов. Численное моделирование проводилось на пластинах разной толщины, их толщина составляла: 10 мм, 17 мм, 18 мм и 23 мм. Упомянутые толщины бронелиста были выбраны на основании полученных результатов с целью определения предельной толщины бронелиста и бронепробиваемости снаряда, а также для полной баллистической защиты.

Методы: Конечно-элементное моделирование используется для анализа напряжений и деформаций бронированных пластин при пробитии снарядом. Упомянутый метод вычисляет удар снаряда о препятствие, а именно столкновение снаряда с бронелистом.

Результаты: Для сравнительного анализа использовались параметры, представляющие значения напряжения и смещения. Для каждой из вышеупомянутых толщин бронированной стальной пластины были определены значения напряжений и смещений при ударе снаряда. Результаты данного исследования показывают, как толщина бронелиста влияет на взаимодействие снаряда и броневой плиты.

Выводы: Если физические и химические характеристики бронеплиты остаются неизменными, то по мере увеличения толщины бронеплиты вероятность пробития снарядом уменьшается, и наоборот. Данное исследование имеет особую значимость, поскольку в нем анализируются напряжения и деформации бронелистов, основной ролью которых является защита личного состава и оборудования от проникновения снаряда. В связи с этим определяется толщина бронелиста для предотвращения пробития снарядом.

К л ю ч е в ы е с л о в а : бронелист, снаряд, удар, метод конечных элементов.

ABSTRACT:

Увод: У овом раду представљена је нумеричка симулација удара пројектила 12,7 mm у панцирну плочу брзином од 500 m/s на растојању од 900 m. Нумеричке симулације нуде могућност драстичног смањења времена потребног за добијање резултата у поређењу са временом потребним за планирање, организацију и извођење експеримената. Нумеричка симулација је урађена за различите дебљине плоча: 10 mm, 17 mm, 18 mm и 23 mm. Поменуте дебљине панцирних плоча изабране су на основу резултата, а ради одређивања граничне дебљине панцирне плоче за продор пројектила, као и за потпуну балистичку заштиту.

Метод: Метода коначних елемената примењена је како би се анализирали напони и деформације панцирних плоча приликом удара пројектила. Помоћу наведене методе рачуна се удар пројектила у препреку, односно колизија пројектила и панцирне плоче.

Резултати: За упоредну анализу коришћени су параметри: вредност напона и апсолутног померања. За сваку од наведених дебелина панцирне металне плоче одређене су вредности напона и апсолутног померања при удару пројектила. Резултати овог истраживања показују како дебелина плоче утиче на интеракцију пројектила и панцирне плоче.

Закључак: Уколико физичко-хемијске карактеристике панцирне плоче остану непромењене, са повећањем дебелине панцирне плоче смањује се могућност пробоја пројектила, и обрнуто. Ово истраживање је од суштинског значаја, јер анализира напоне и деформације панцирних плоча, чија је основна намена заштита људства и опреме од дејства пројектила. С тим у вези, одређена је дебелина панцирне плоче за задор пројектила.

KEYWORDS: панцирна плоча, пројектил, удар, метода коначних елемената.

INTRODUCTION

Small-caliber bullet protection is a key concern for both military and civilian facilities, especially at distances up to 100 m. The main task is how to protect infantry from the effects of anti-materiel rifles in calibers of 10 mm to 20 mm. Modern war implies that infantry is transported by combat vehicles such as Infantry Fighting Vehicles (IFVs), also known as Mechanized Infantry Combat Vehicles (MICVs), or Mine-Resistant Ambush-Protected (MRAP) wheeled armored vehicles.

Troops transported by such vehicles are a very easy group target, and because of that, it is very important to protect troops inside vehicles from the effect of projectiles. In order to reduce the penetrability of vehicles, armored steel plates are added. Metallic armor plates are often used to protect moving and stationary platforms from a variety of projectiles. However, it is necessary to be careful, because the addition of armor plates affects the overall weight of the vehicle and reduces the mobility and passability of the vehicle.

Large deformation, erosion, high strain rate, dependent nonlinear material behavior, and fragmentation are all problems associated with high-velocity impact and projectile penetration.

The basic task of this paper is to determine the thickness of the plate that will be resistant to the impact of a projectile of 12.7 mm, thus protecting the infantry, and which will not affect the performance of the vehicle. For this study, only a frontal impact of a projectile into a plate of various thicknesses was considered.

The bullet used in this analysis is 12.7 mm and it is shown in Figure 1.

The core of the bullet is made of an alloy of copper and zinc, and the core of this bullet is the projectile used in the simulation. The ballistic characteristics of the core are presented in Table 1.

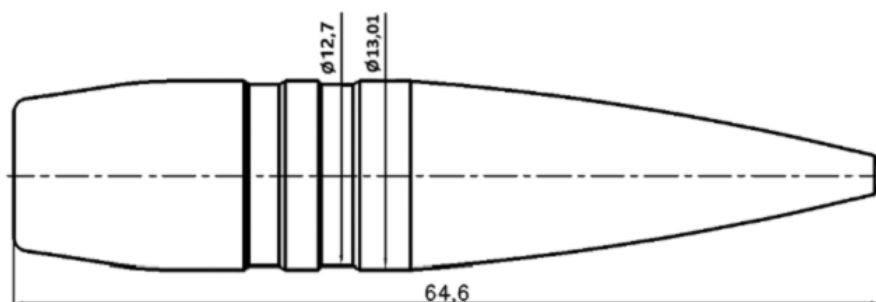


FIGURE 1

Bullet 12.7 x 108

Рис. 1 – Пуля 12.7 x 108

Слика 1 – Метак 12,7 x 108

TABLE 1
Ballistic characteristics of the bullet core

Projectile velocity (at a distance of 25 m)	V_{25}	805 m/s
Projectile velocity (at a distance of 300 m)	V_{300}	720 m/s
Pressure	$P_{\max}$	304 MPa
Precision	R_{s300}	10 cm
Core weight	m	51,3 g

Таблица 1 – Баалистическије карактеристики сердечника пули
Табела 1 – Баалистичке карактеристике зрна метка

The material characteristics of the core of the bullet for the explicit dynamic analysis are given in Table 2.

TABLE 2
Material characteristics of the core of the bullet for the explicit dynamic analysis

	Parameters		Values
Johnson-Cook parameters	Yield stress	A [MPa]	112
	Proportionality coefficient	B [MPa]	505
	Strain rate Impact parameter	C	0.009
	Temperature impact parameter	m	1.68
	Reinforcement exponent	n	0.42
	Melting temperature	T_m [K]	1189
	Room temperature	T_r [K]	293
	Constant		1
Johnson-Cook damage parameters	Damage parameters	D_1	0.54
		D_2	4.89
		D_3	3.03
		D_4	0.014
		D_5	1.12
EOS parameters	Mie-Gruneisen equations of state parameters	M [m/s]	3667
		S_1	1.507
		S_2	0.000
		S_3	0.000
		Γ	2.086
		a	0.485
General parameters	Density	ρ [t/mm ³]	8.52E-9
	Young's modulus	E [MPa]	110
	Shear modulus	G [GPa]	40
	Poisson's ratio	ν	0.375
	Specific heat	Cp [J/kgK]	385

Таблица 2 – Характеристики материала сердечника пули и для явного динамического анализа
Табела 2 – Материјалне карактеристике зрна метка и параметри потребни за експлицитну динамичку анализу

FINITE ELEMENT MODELING

The penetration, damage, and failure mechanisms when the projectile impacts the armor plate were investigated using a computational model based on finite elements (Jena et al, 2019). Theoretical models are used in simulations with real material properties (projectiles and armor plates) to show how the projectile interacts with the armor plate. LS-DYNA (Livermore Software Technology, 2014), a commercially available finite element software, was used for finite element modeling and analysis (Mahfuz et al, 1999).

A two-dimensional finite element model of the armor plate and the bullet core was developed as shown in Figure 2.

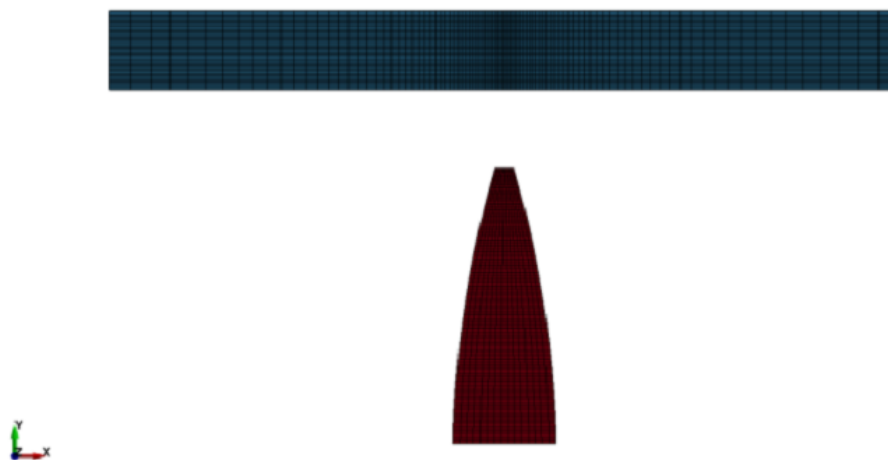


FIGURE 2
Finite element model

Рис. 2 – Модель конечных элементов

Слика 2 – Модел коначних елемената

The armor plate was meshed with four-node continuum hexahedral elements. Two-dimensional finite elements provide better computational performance/cost than fully integrated 3D elements. The element size was smallest in the region where the projectile impacted the armor plate and the element size was increased in regions away from the impact point. The overall finite element model had 8400 2D four-noded hexahedral elements. Contact was defined between the projectile and the armor plate with a hard contact definition for normal contact. The developed finite element model was used to investigate the penetration of the projectile through the base armor plate. The numerical calculation was performed at a distance of 900 m when the projectile velocity was 500 m/s.

THEORETICAL BASIS

Penetration is the motion process of a penetrator through an obstacle (armor plate for this study). The term, penetrator, means anything that is intended for penetration, and the obstacle is the environment that is exposed to the action of the penetrator. The study of the penetration process is of great importance both in the field of military technology and in the field of civilian application (Feng et al, 2020). Terminal ballistics is one of the basic disciplines that deals with defining the mechanisms of penetration, which significantly contributes to the optimization of the design of the projectile, penetrating, and destructive action, as well as for the design of armor protection (Meng et al, 2021).

Depending on the outcome of the penetration process, there are four different cases:

Perforation - means the penetration of the entire penetrator through the obstacle (armor plate for this study), forming a regular, approximately cylindrical hole in the obstacle.

Limit perforation - represents the limit case of penetration because the hole in the obstacle is of irregular shape and a smaller area than the cross-sectional area of the penetrator, unlike the perforation, i.e. only parts of the broken penetrator pass through the hole.

Semi penetration - characterizes the stopping (jamming) of the penetrator in the obstacle or its breaking during penetration.

Ricochet - is the repulsion of the penetrator due to sliding on the surface of the obstacle if it is tilted.

The penetrating power of a penetrator is the ability to break through an obstacle. Increasing the penetrating power of the penetrator can be achieved by increasing the length and density of the penetrator, as well as by reducing its diameter. In opposition to this, the ability to resist penetration is the resistance of an obstacle. Increasing the resistance of the obstacle is achieved by increasing its thickness and density, as well as by improving the mechanical properties of the material. When considering penetration, the impact velocity, output velocity, and velocity of the ballistic limit are of greatest importance.

Impact velocity V_s (or V_0) is the instantaneous value of the penetrator line velocity at the moment of initial contact with the obstacle. It is assumed that the impact velocity vector is collinear with the penetrator axis, i.e. the flight of the penetrator with zero angle of attack is always assumed. The effects of the angular velocity of the penetrator around its own axis, in the case of gyro-stabilized penetrators, are not taken into account (Rajole et al, 2020).

Output (residual) velocity V_r is the velocity of the penetrator at the moment of passing the bottom of the penetrator through the plane determined by the rear surface of the obstacle.

The velocity of the ballistic limit is one of the basic characteristics of the penetrator-obstacle system and can be defined in several ways. Theoretically, this is the minimum value of the impact velocity at which the penetration occurs, or the maximum value of the impact velocity at which the penetration through the obstacle does not occur.

Johnson-Cook material model

The Johnson-Cook plasticity model was used to calculate the strain rate-dependent plastic deformation of the projectile core and armor plate material. Metal high-strain rate deformation has been successfully defined using the Johnson-Cook plasticity model (Wang & Shi, 2013). The effects of strain, strain rate, and adiabatic heating on flow stress are included in the Johnson-Cook plasticity model. The Johnson-Cook plasticity model is represented by Equation 1.

$$\sigma = [A + B\varepsilon^n][1 + C \ln \dot{\varepsilon}^*][1 - (T^*)^m] \quad (1)$$

where A, B, C, n, and m are the material parameters determined from experimental data. The temperature is determined from equation 2.

$$T^* = \frac{(T - T_{ref})}{(T_{melt} - T_{ref})} \quad (2)$$

where T_{ref} is the temperature below which material shows no temperature dependence on flow stress. The strain rate is given by equation 3.

$$\dot{\varepsilon}^* = \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \quad (3)$$

The initiation of damage is determined by equation 4, which gives the equivalent plastic strain at the onset of damage.

$$\varepsilon^{pl} = \left[d_1 + d_2 e^{(-d_3 \eta)} \right] \left[1 + d_4 \ln \left(\frac{\dot{\varepsilon}^{pl}}{\dot{\varepsilon}_0} \right) \right] (1 + d_5 T^*) \quad (4)$$

where d_1 , d_2 , d_3 , d_4 , and d_5 are the material damage parameters and $\dot{\varepsilon}_0$ is the reference strain rate. The damage in the material is defined by using a parameter D with a value between 0 and 1 where 0 means no damage and 1 means fully damaged material. Material failure occurs when D reaches a value of 1.

Material characteristics and initial conditions

AISI 4340 steel material characteristics were used for the armor plate and are shown in Table 3, while the projectile material characteristics were the ones from a copper alloy and are shown in Table 2.

TABLE 3
Material characteristics of the armor plate for the explicit dynamic analysis

	Parameters		Values
Johnson-Cook parameters	Yield stress	A [MPa]	792
	Proportionality coefficient	B [MPa]	510
	Strain rate Impact parameter	C	0.014
	Temperature impact parameter	m	1.03
	Reinforcement exponent	n	0.26
	Melting temperature	T_m [K]	1793
	Room temperature	T_r [K]	293
	Constant		1
Johnson-Cook damage parameters	Damage parameters	D_1	0.05
		D_2	3.44
		D_3	-2.12
		D_4	0.002
		D_5	0.61
EOS parameters	Mie-Gruneisen equations of state parameters	M [m/s]	3850
		S_1	1.354
		S_2	0.000
		S_3	0.000
		Γ	1.707
		a	0.430
General parameters	Density	ρ [t/mm ³]	7.85E-9
	Young's modulus	E [MPa]	210
	Shear modulus	G [GPa]	80
	Poisson's ratio	ν	0.29
	Specific heat	C_p [J/kgK]	477

Таблица 3 – Характеристики материала бронелиста и характеристики для явного динамического анализа
Табела 3 – Материјалне карактеристике балистичке плоче и параметри потребни за експлицитну динамичку анализу

RESULTS AND DISCUSSION

In accordance with theoretical and practical knowledge, it is very easy to conclude that with increasing the thickness of the obstacle (it is important to mention that the same physical and chemical characteristics are maintained) the probability of achieving the effect of penetration decreases.

Within this paper, a numerical simulation of the penetration of a 12.7 mm projectile was performed for four different cases, i.e. for four different obstacle thicknesses.

Model 1

Figures 3-7 show the field of distribution of the von Mises equivalent stress for model 1. For this case, the impact projectile velocity was 500 m/s, the armor plate thickness 10 mm, and the simulation time 0.2 ms.

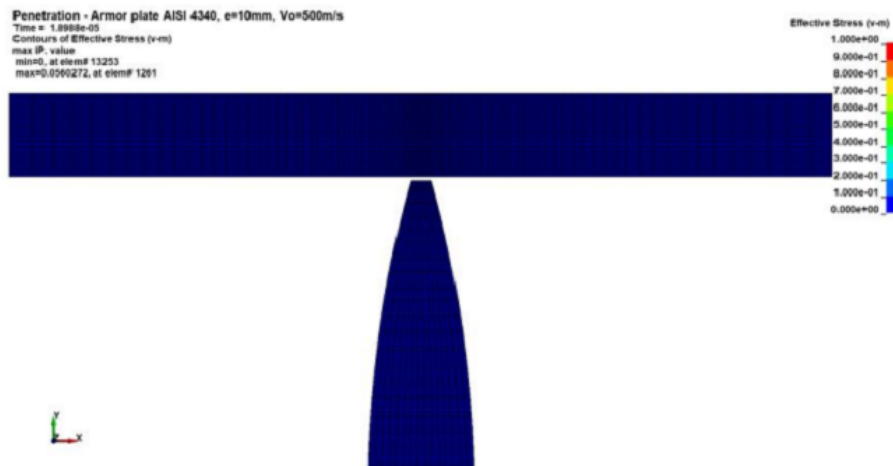


FIGURE 3

Von Mises equivalent stress, time of analysis 0.01 ms – Model 1

Рис. 3 – Von Mises эквивалентное напряжение, время анализа 0.01 ms – Модель 1

Слика 3 – Von Mises-ов еквивалентни напон, време анализе 0,01 ms – модел 1

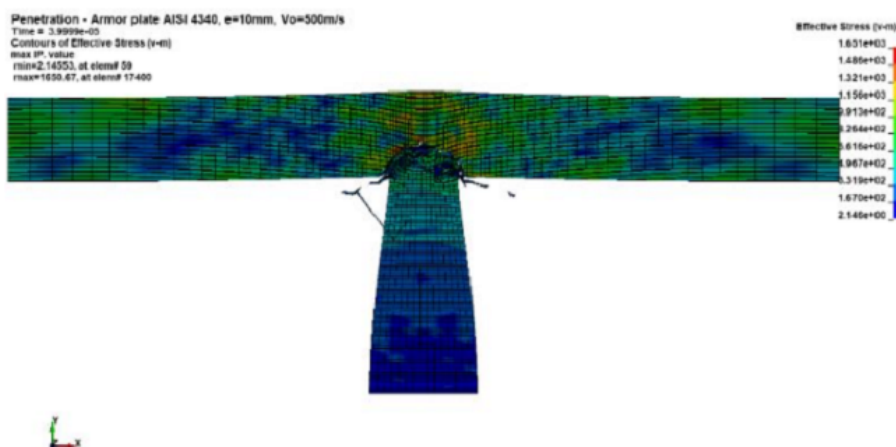


FIGURE 4

Von Mises equivalent stress, time of analysis 0.03 ms – Model 1

Рис. 4 – Von Mises эквивалентное напряжение, время анализа 0.03 ms – Модель 1

Слика 4 – Von Mises-ов еквивалентни напон, време анализе 0,03 ms – модел 1

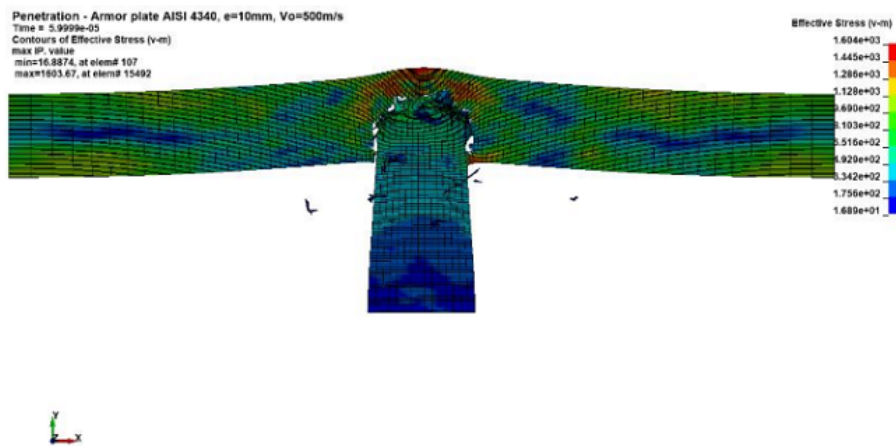


FIGURE 5

Von Mises equivalent stress, time of analysis 0.05 ms – Model 1

Рис. 5 – Von Mises эквивалентное напряжение, время анализа 0.05 ms – Модель 1

Слика 5 – Von Mises-ов еквивалентни напон, време анализе 0,05 ms – модел 1

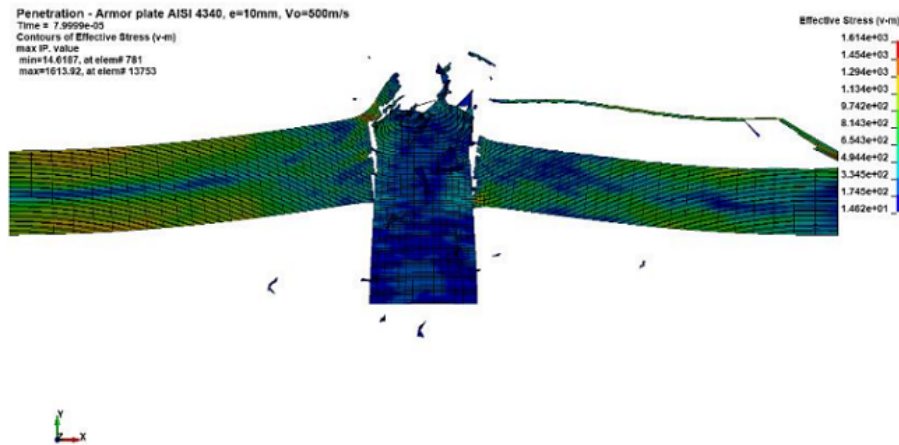


FIGURE 6

Von Mises equivalent stress, time of analysis 0.07 ms – Model 1

Рис. 6 – Von Mises эквивалентное напряжение, время анализа 0.07 ms – Модель 1

Слика 6 – Von Mises-ов еквивалентни напон, време анализе 0,07 ms – модел 1



FIGURE 7

Von Misses equivalent stress, time of analysis 0.1 ms – Model 1

Рис. 7 – Von Misses эквивалентное напряжение, время анализа 0.1 ms – Модель 1

Слика 7 – Von Misses-ов еквивалентни напон, време анализе 0,1 ms – модел 1

As it can be seen from the previous figures, for the case when the thickness of the armor plate is 10 mm, the penetration of the projectile occurs.

The projectile velocity after the impact and penetration is shown on the diagram in Figure 8.

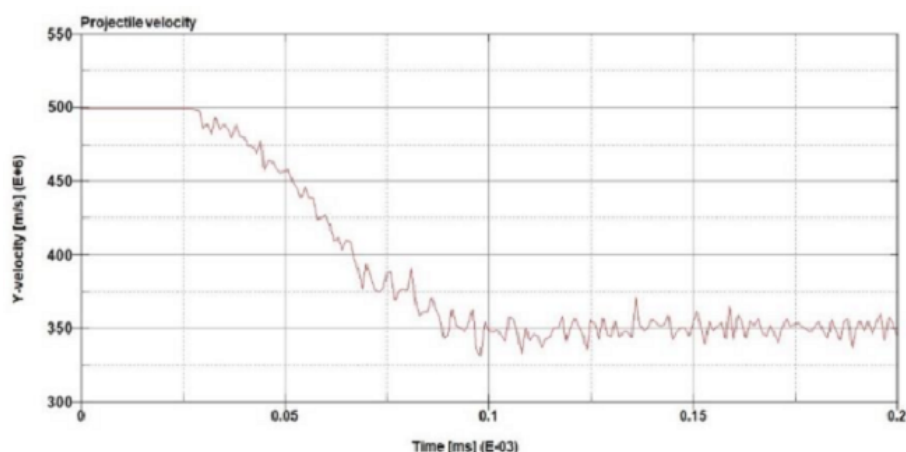


FIGURE 8

Velocity of the projectile in relation to time

Рис. 8– Скорость снаряда в зависимости от времени

Слика 8 – Брзина пројектила у зависности од времена

From the diagram in Figure 8, it can be seen that the projectile perforates the armor plate after 0.03 ms. It can be noticed that the projectile velocity decreases between 0.03 ms and 0.1 ms, for the perforation required time. The projectile velocity after 0.1 ms is 350 m/s.

The displacement of the armor plate after the impact and perforation is shown on the diagram in Figure 9. The first displacements occur after 0.03 ms.

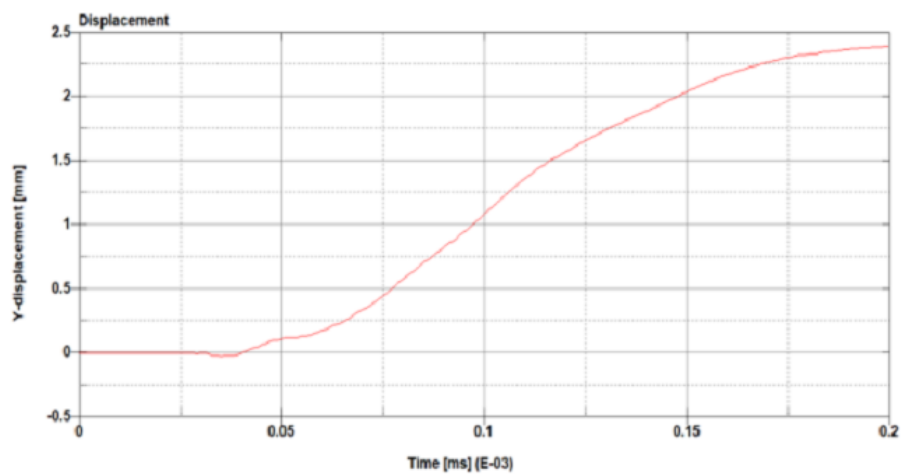


FIGURE 9

Displacement of the armor plate in relation to time

Рис. 9 – Смещение в зависимости от времени

Слика 9 – Померање у зависности од времена

Model 2

Figures 10-14 show the field of distribution of the von Misses equivalent stress for model 2. For this case, the impact projectile velocity was 500 m/s, the armor plate thickness 23 mm, and the simulation time 0.2 ms.

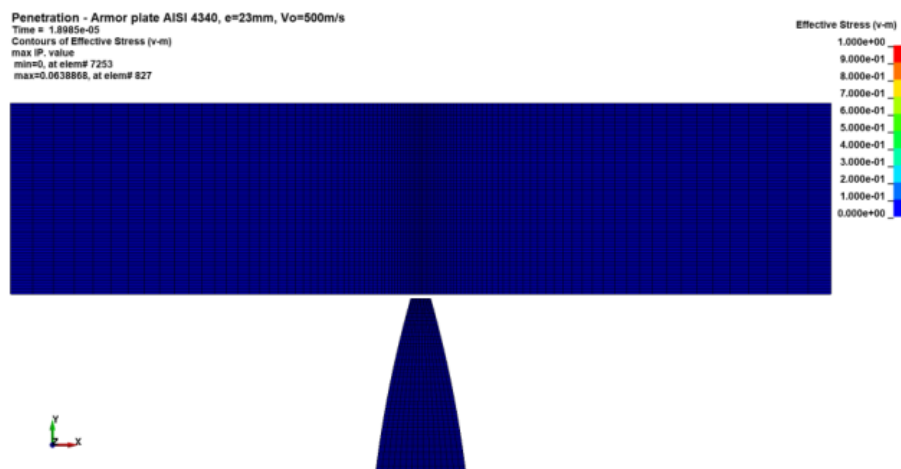


FIGURE 10

Von Misses equivalent stress, time of analysis 0.01 ms – Model 2

Рис. 10 – Von Misses эквивалентное напряжение, время анализа 0.01 ms – Модель 2

Слика 10 – Von Misses-ов еквивалентни напон, време анализе 0,01 ms – модел 2

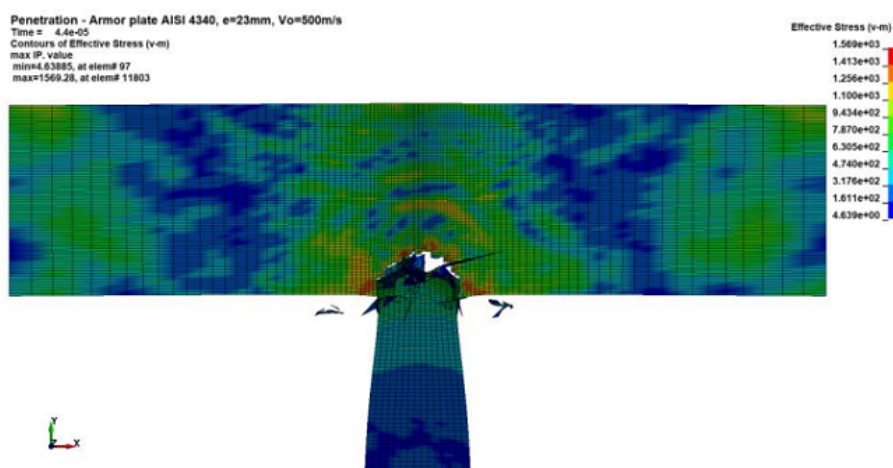


FIGURE 11

Von Mises equivalent stress, time of analysis 0.04 ms – Model 2

Рис. 11 – Von Mises эквивалентное напряжение, время анализа 0.04 ms – Модель 2

Слика 11 – Von Mises-ов еквивалентни напон, време анализе 0,04 ms – модел 2

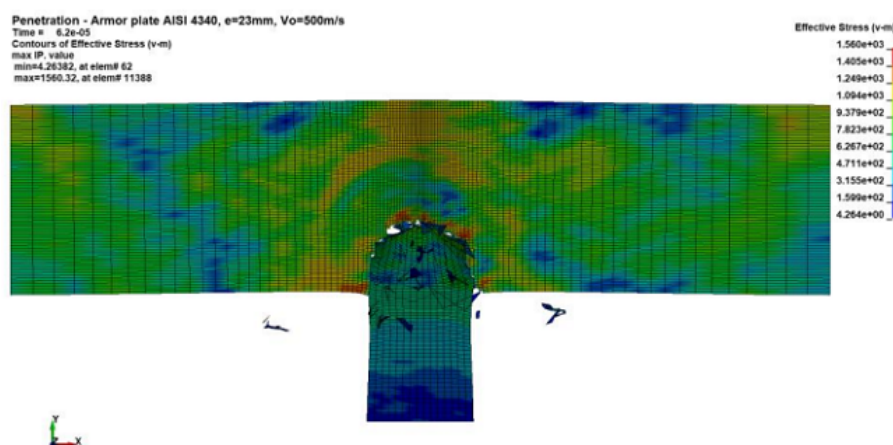


FIGURE 12

Von Mises equivalent stress, time of analysis 0.06 ms – Model 2

Рис. 12 – Von Mises эквивалентное напряжение, время анализа 0.06 ms – Модель 2

Слика 12 – Von Mises-ов еквивалентни напон, време анализе 0,06 ms – модел 2

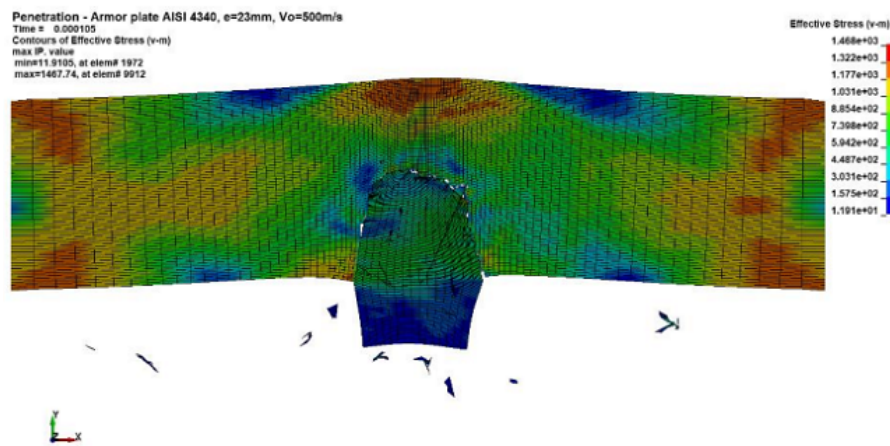


FIGURE 13

Von Mises equivalent stress, time of analysis 0.1 ms – Model 2

Рис. 13 – Von Mises эквивалентное напряжение, время анализа 0.1 ms – Модель 2

Слика 13 – Von Mises-ов еквивалентни напон, време анализе 0,1 ms – модел 2

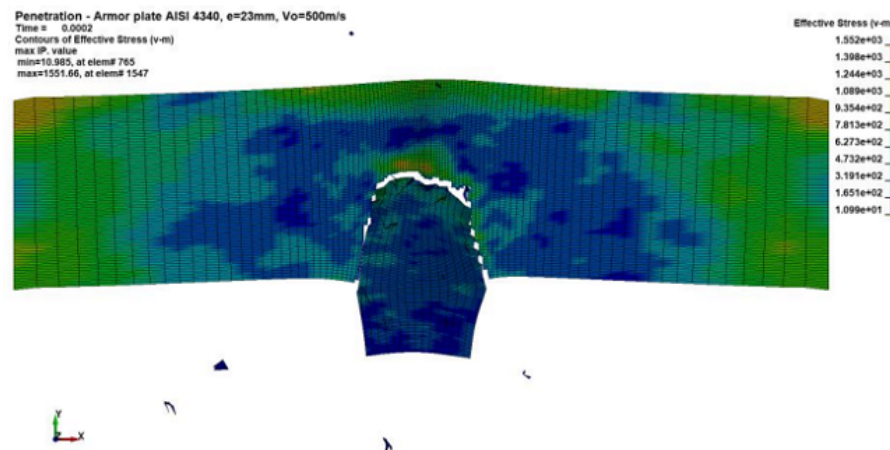


FIGURE 14

Von Mises equivalent stress, time of analysis 0.2 ms – Model 2

Рис. 14 – Von Mises эквивалентное напряжение, время анализа 0.2 ms – Модель 2

Слика 14 – Von Mises-ов еквивалентни напон, време анализе 0,2 ms – модел 2

As it can be seen from the previous figures, for the case when the thickness of the armor plate is 23 mm, the perforation of the projectile does not occur.

The projectile velocity after the impact and semi-penetration is shown on the diagram in Figure 15.

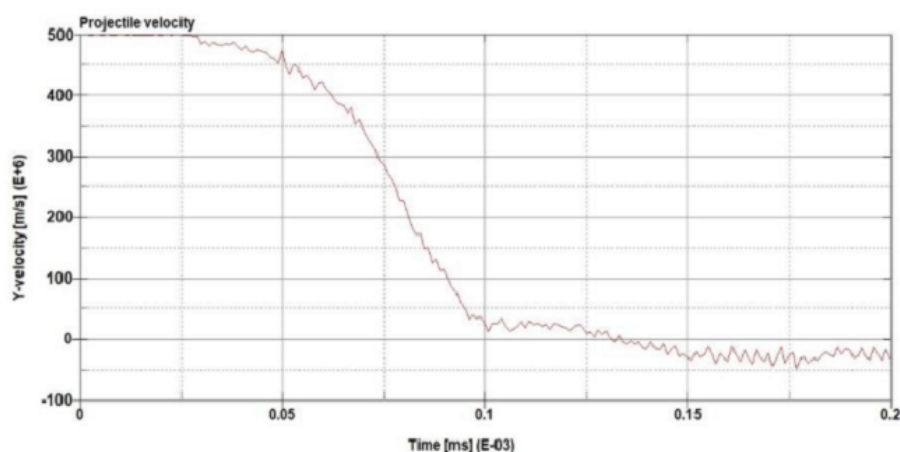


FIGURE 15

Velocity of the projectile in relation to time

Рис. 15 – Скорость снаряда в зависимости от времени

Слика 15 – Брзина пројектила у зависности од времена

From the diagram in Figure 15, it can be seen that semi-penetration occurs.

The displacement of the armor plate after the impact and semi-penetration is shown on the diagram in Figure 16. The first displacements occur after 0.03 ms. After 0.13 ms of the analysis, the maximum values of the displacements are achieved.

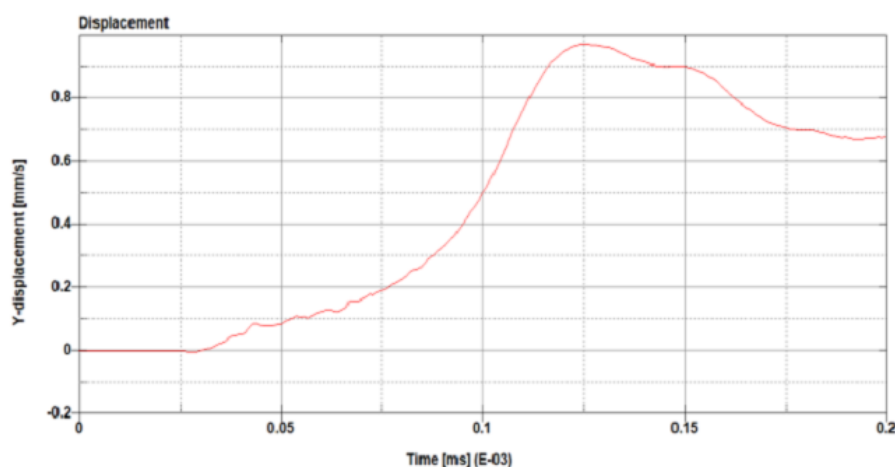


FIGURE 16

Displacement of the armor plate in relation to time

Рис. 16 – Смещение в зависимости от времени

Слика 16 – Померање у зависности од времена

Additional numerical simulations

It is of great importance to determine the maximum value of the plate thickness at which the penetration effect occurs, as well as the minimum value of the plate thickness at which the semi-penetration effect occurs, at the same impact velocity.

After presenting the results obtained by the numerical simulation of the penetration process, it is easy to conclude in which cases the projectile has enough energy to break through obstacles of certain thicknesses. In this case, an armor plate made of AISI 4340 alloy was used as an obstacle and it was determined that the

12.7 mm armor projectile at an impact velocity of 500 m/s achieves the effect of penetration on the armor plate with a thickness of 10 mm, while in the case of an armor plate with a thickness of 23 mm it achieves the effect of semi penetration, i.e. no penetration occurs.

In accordance with the previously defined models, using the same initial and boundary conditions, additional numerical simulations were performed and on that occasion, it was determined that the penetration effect is realized on up to 17 mm thick plates, and then the limit penetration effect occurs.

Model 3

Figures 17-21 show the field of distribution of the von Mises equivalent stress for model 3. For this case, the impact projectile velocity was 500 m/s, the armor plate thickness 17 mm, and the simulation time 0.2 ms.

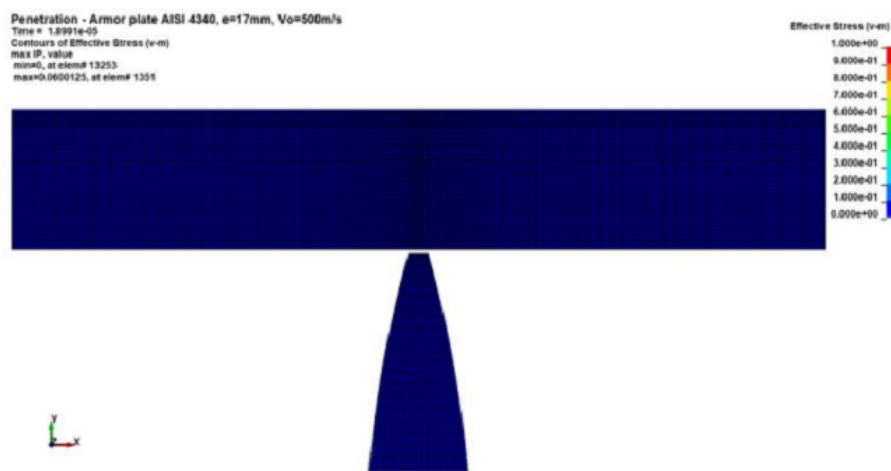


FIGURE 17

Von Mises equivalent stress, time of analysis 0.01 ms – Model 3

Рис. 17 – Von Mises эквивалентное напряжение, время анализа 0.01 ms – Модель 3

Слика 17 – Von Mises-ов еквивалентни напон, време анализе 0,01 ms – модел 3

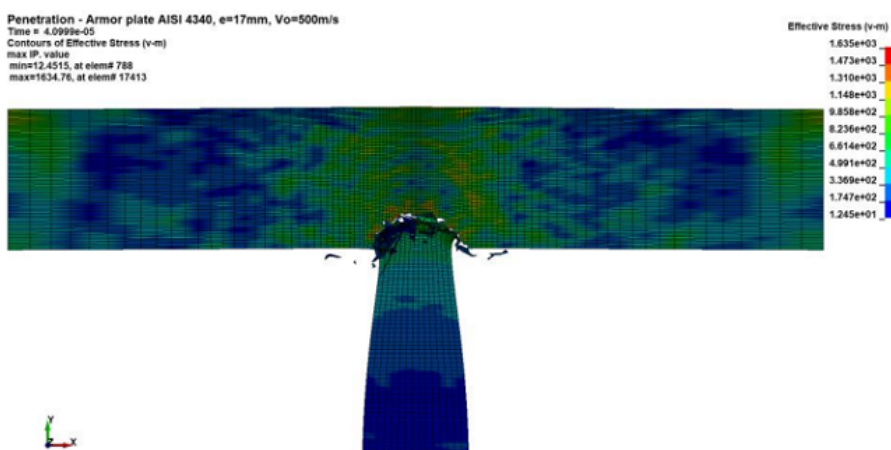


FIGURE 18

Von Mises equivalent stress, time of analysis 0.04 ms – Model 3

Рис. 18 – Von Mises эквивалентное напряжение, время анализа 0.04 ms – Модель 3

Слика 18 – Von Mises-ов еквивалентни напон, време анализе 0,04 ms – модел 3

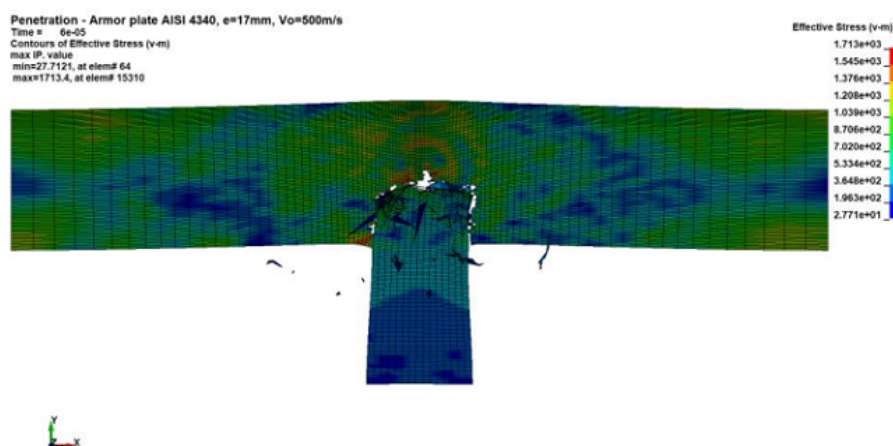


FIGURE 19

Von Mises equivalent stress, time of analysis 0.06 ms – Model 3

Рис. 19 – Von Mises эквивалентное напряжение, время анализа 0.06 ms – Модель 3

Слика 19 – Von Mises-ов еквивалентни напон, време анализе 0,06 ms – модел 3

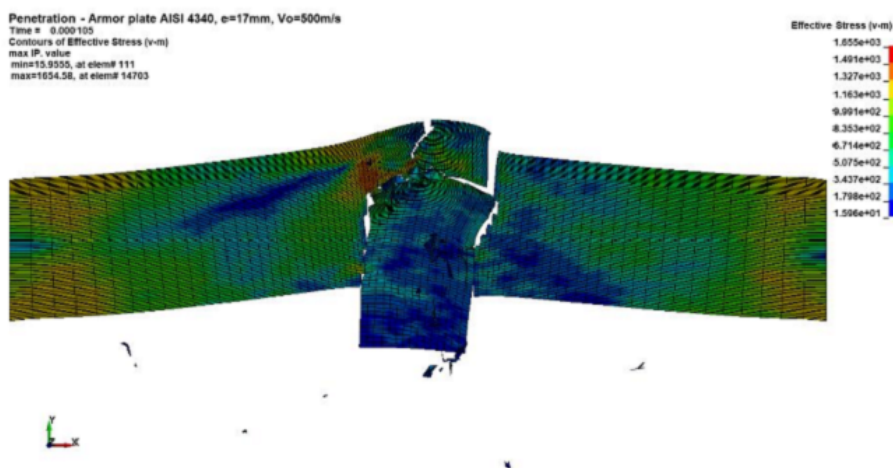


FIGURE 20

Von Mises equivalent stress, time of analysis 0.1 ms – Model 3

Рис. 20 – Von Mises эквивалентное напряжение, время анализа 0.1 ms – Модель 3

Слика 20 – Von Mises-ов еквивалентни напон, време анализе 0,1 ms – модел 3

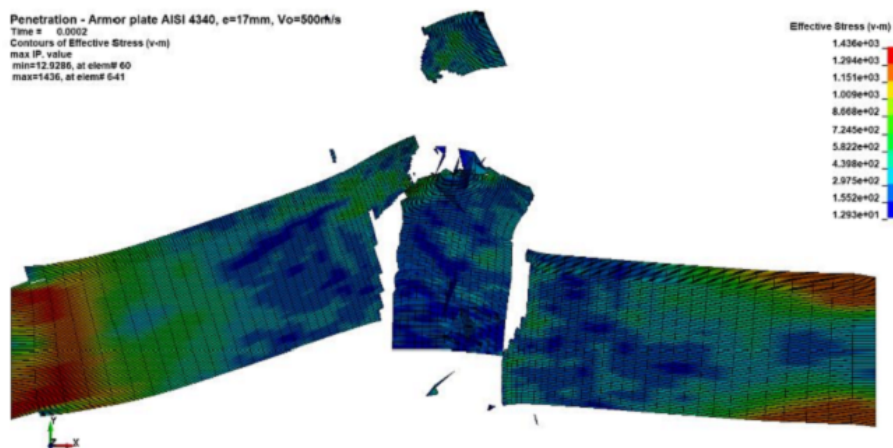


FIGURE 21

Von Misses equivalent stress, time of analysis 0.2 ms – Model 3

Рис. 21 – Von Misses эквивалентное напряжение, время анализа 0.2 ms – Модель 3

Слика 21 – Von Misses-ов еквивалентни напон, време анализе 0,2 ms – модел 3

As it can be seen from the previous figures, for the case when the thickness of the armor plate is 17 mm, the penetration of the projectile occurs.

The projectile velocity after the impact and penetration is shown on the diagram in Figure 22.

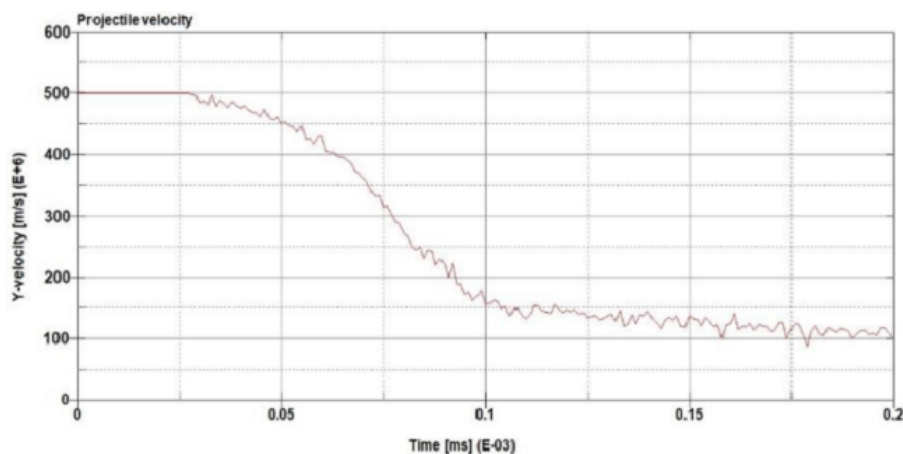


FIGURE 22

Velocity of the projectile in relation to time

Рис. 22 – Скорость снаряда в зависимости от времени

Слика 22 – Брзина пројектила у зависности од времена

From the diagram in Figure 22, it can be seen that the limit perforation occurs after 0.03 ms. It can be noticed that the projectile velocity decreases between 0.03 ms and 0.1 ms, for the limit perforation required time. The velocity of projectile fragments after 0.1 ms is 140 m/s.

The displacement of the armor plate after the impact and limit perforation is shown on the diagram in Figure 23. The first displacements occur after 0.03 ms.

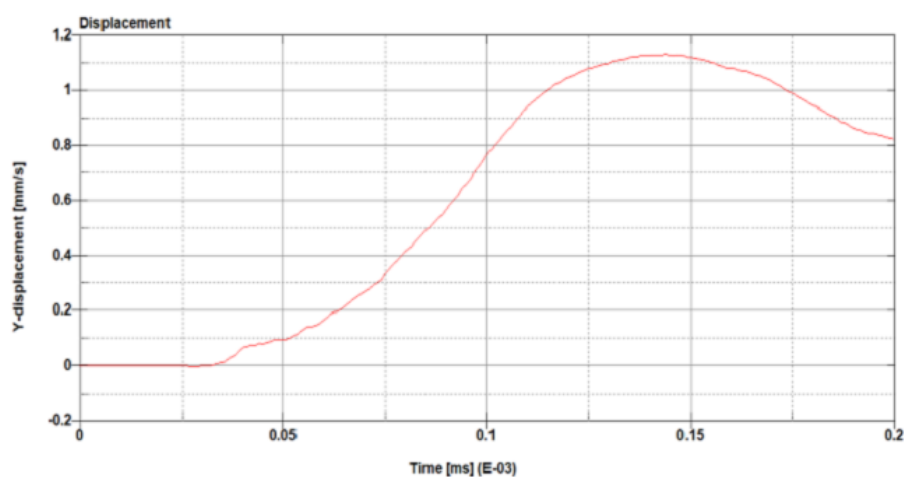


FIGURE 23

Displacement of the armor plate in relation to time

Рис. 23 – Смещение в зависимости от времени

Слика 23 – Померање у зависности од времена

Model 4

Figures 24-28 show the field of distribution of the von Mises equivalent stress for model 4. For this case, the impact projectile velocity was 500 m/s, the armor plate thickness 18 mm, and the simulation time 0.2 ms.

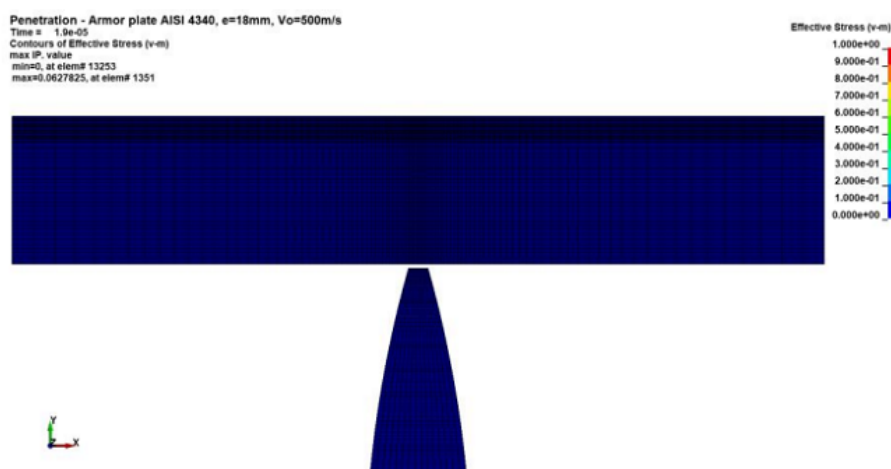


FIGURE 24

Von Mises equivalent stress, time of analysis 0.01 ms – Model 4

Рис. 24 – Von Mises эквивалентное напряжение, время анализа 0.01 ms – Модель 4

Слика 24 – Von Mises-ов еквивалентни напон, време анализе 0,01 ms – модел 4

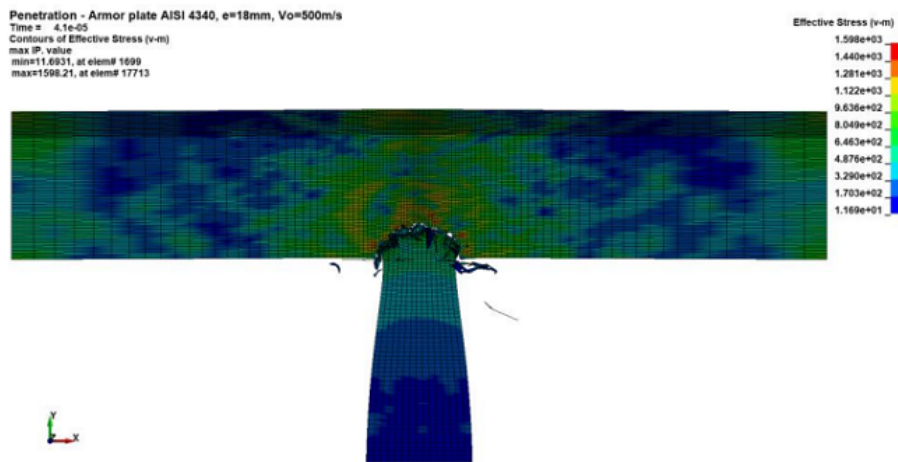


FIGURE 25

Von Mises equivalent stress, time of analysis 0.04 ms – Model 4

Рис. 25 – Von Mises эквивалентное напряжение, время анализа 0.04 ms – Модель 4

Слика 25 – Von Mises-ов еквивалентни напон, време анализе 0,04 ms – модел 4

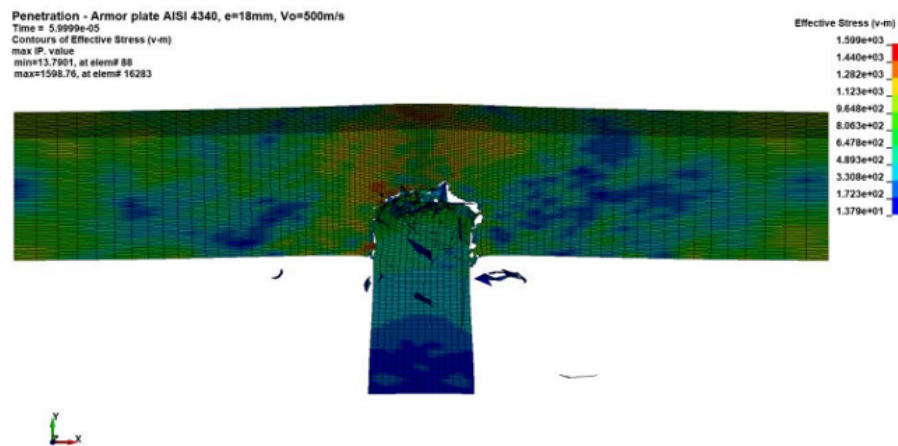


FIGURE 26

Von Mises equivalent stress, time of analysis 0.06 ms – Model 4

Рис. 26 – Von Mises эквивалентное напряжение, время анализа 0.06 ms – Модель 4

Слика 26 – Von Mises-ов еквивалентни напон, време анализе 0,06 ms – модел 4

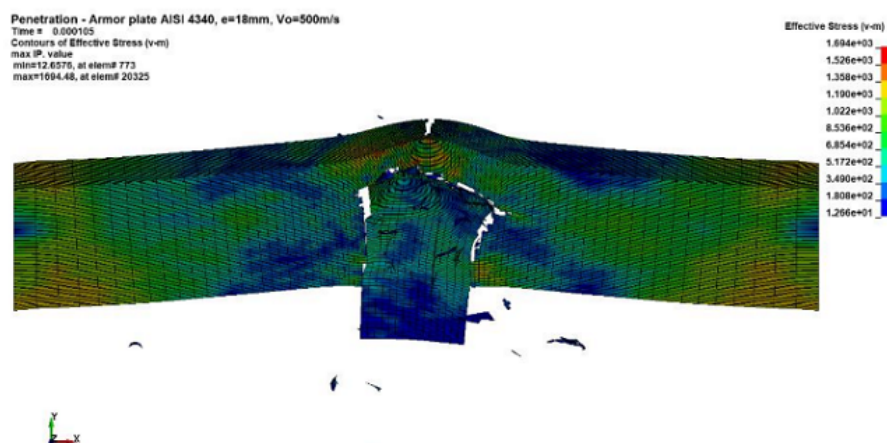


FIGURE 27

Von Mises equivalent stress, time of analysis 0.1 ms – Model 4

Рис. 27 – Von Mises эквивалентное напряжение, время анализа 0.1 ms – Модель 4

Слика 27 – Von Mises-ов еквивалентни напон, време анализе 0,1 ms – модел 4

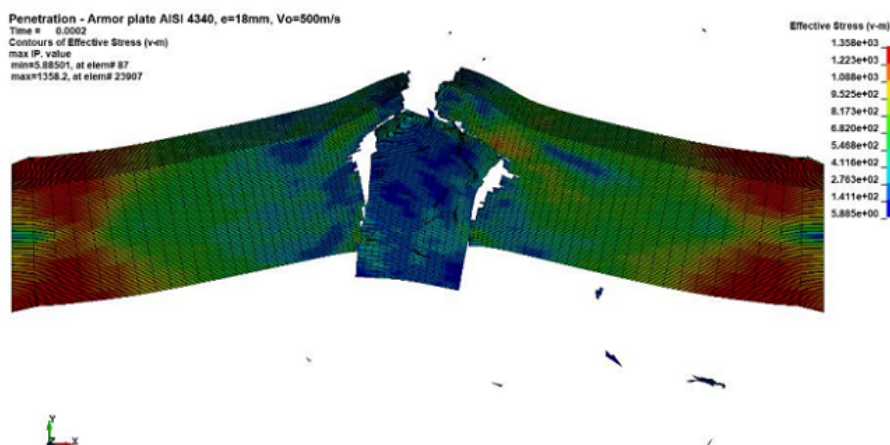


FIGURE 28

Von Mises equivalent stress, time of analysis 0.2 ms – Model 4

Рис. 28 – Von Mises эквивалентное напряжение, время анализа 0.2 ms – Модель 4

Слика 28 – Von Mises-ов еквивалентни напон, време анализе 0,2 ms – модел 4

As it can be seen from the previous figures, for the case when the thickness of the armor plate is 18 mm, the armor plate is splitting but the penetration of the projectile does not occur.

The projectile velocity after the impact and semi penetration is shown on the diagram in Figure 29.

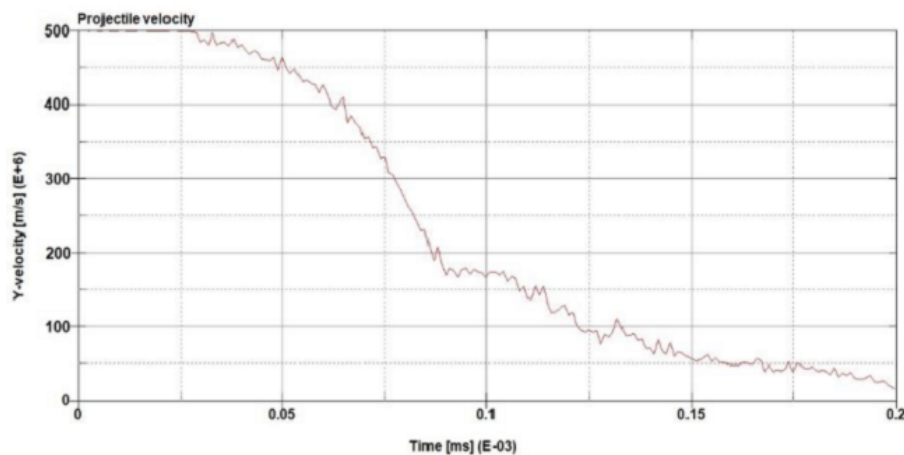


FIGURE 29

Velocity of the projectile in relation to time

Рис. 29 – Скорость снаряда в зависимости от времени

Слика 29 – Брзина пројектила у зависности од времена

From the diagram in Figure 29, it can be seen that semi-penetration occurs. It can also be noticed that the 18 mm thickness of the armor plate does not provide complete ballistic protection.

The displacement of the armor plate after the impact and semi-penetration is shown on the diagram in Figure 30. The first displacements occur after 0.03 ms. After 0.2 ms of the analysis, the maximum values of the displacements are achieved.

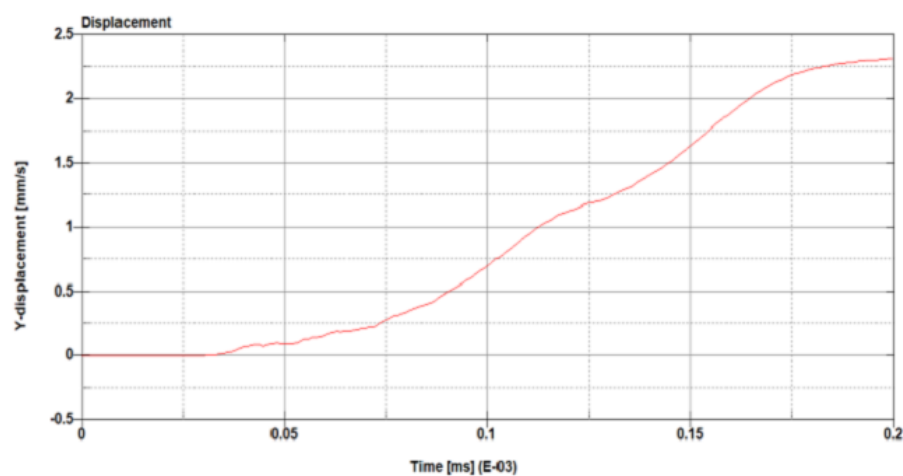


FIGURE 30

Displacement of the armor plate in relation to time

Рис. 30 – Смещение в зависимости от времени

Слика 30 – Померање у зависности од времена

CONCLUSION

Armored projectiles are intended to destroy armored targets. They penetrate armor plates thanks to enormous kinetic energy they have at the moment of collision with an obstacle and the great endurance of their body. Impact modeling for armor obstacles is very complex, extensive, and demanding, and the formed models in a very successful way approximate the real problem of projectile penetration.

It was determined that dynamic phenomena that occur during the process of ballistic penetration largely depend on deformation, strain rate, temperature, and pressure. In order to describe these phenomena in a correct way, it is necessary to define the models of material behavior. The Johnson-Cook material model and the material damage model proved to be the most suitable models for this study.

In this paper, a numerical simulation of the process of a 12.7 mm projectile penetration into armored plates of different thicknesses made of AISI 4340 alloy was performed. In all 4 models, there is a contact between the bullet and the armor plate after 0.03 ms of the analysis. It is clear that when the thickness of the armor plate is 10 mm, there is perforation, and when the armor plate is 23 mm thick, there is semi-penetration.

In models 1 and 3, the armor plate destruction occurs. The velocity of the bullet after perforation through the armored plate in model 1 is 350 m/s, while in model 3 the velocity of the bullet fragments is 140 m/s.

In models 2 and 4, there is no destruction of the armored plate. In model 2, the semi-penetration of the bullet is after 0.13 ms, and in model 4 after 0.2 ms.

In all 4 models, the first displacements occur after 0.03 ms of the analysis.

However, what was also very important in this paper is to determine the limit values of the thickness of obstacles/armor plates in which penetration occurs.

The semi thickness of the armor plate at which the limit penetration occurs is 18mm. With a thickness of 23 mm, the armor plate deforms but withstands the impact of projectiles without splitting, which provides complete ballistic protection.

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