

# Numerical analysis of the penetration process of a 30mm armor-piercing fin-stabilized discarding sabot projectile

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## Abstract:

*Introduction/purpose: In recent times, with the tendency to develop new types of armor-piercing ammunition, constant investments in the development of new types of armored obstacles is necessary. Obstacles made of high-alloy steel plates are still the best form of protection against larger caliber ammunition. There are a number of factors to consider when selecting an alloy, including the weight, dimensions, intended use, desired ballistic performance, and costs. According to that, a numerical analysis of penetration of a 30mm armor-piercing fin-stabilized discarding sabot projectile into the steel alloy Weldox 460 plates of different thicknesses at a distance of 1000m with a velocity of 1300m/s is presented in this paper.*

*Methods: The stresses and deformations of the penetration effect were calculated through numerical analysis and finite element modeling. To specify material characteristics, the Johnson-Cook material model and the*

*fracture of materials model have been utilized. In order to define models and carry out numerical calculations, the software packages FEMAP and LS Dyna have been used in this paper.*

*Results: For a numerical analysis of the penetration process of this projectile type against armor obstacle, four different armor plate thicknesses are calculated: 10mm, 50mm, 100mm, and 110mm. For each of them, the results are shown in a form of stress and displacement, so that the interaction phenomena between the sub-projectile and the armor plate can be described.*

*Conclusion: Modeling the impact on armor-piercing obstacles is extremely difficult, time-consuming, and complex, and the resulting models very successfully (or with some deviation) approximate the real problem of projectile penetration. One of the most effective methods for solving problems of this kind and others of a similar nature in recent times is the finite element method analysis. The material and the target dimensions, as well as the ballistic parameters and the material of the projectile have the biggest influence on projectile penetration. The target's resistance to penetration increases when all input parameters are maintained at the same level and its thickness is increased, and vice versa.*

*Keywords: armor, projectile, penetration, W尔多x 460, numerical analysis.*

## Introduction

Armor-piercing ammunition is designed to penetrate high-strength obstacles. In modern times, in addition to improving the geometric and ballistic characteristics of the projectile body, high efforts are invested in the development of new types of ammunition and new types of materials.

The projectile shape has the biggest influence on velocity and by optimizing its geometry, it is possible to decrease aerodynamic drag and to keep a high level of projectile velocity until it reaches the target.

One of the most effective types of large-caliber armor-piercing ammunition is sub-caliber ammunition which is mostly used for tank cannons. Recently, there has been a development of this type of ammunition for medium caliber cannons, e.g., 30mm.

This type of ammunition is made of tungsten heavy metal alloy (WHA). Due to the specific characteristics of the heavy metal alloy, during the process of penetration into the armor, certain phenomena occur, not characteristic of the classic armor-piercing ammunition, which will be discussed in more detail later. The high-density tungsten alloy increases weight of sub-projectile more than 2.2 times compared to steel and this increases the total kinetic energy of the moving projectile.

The mechanical properties of tungsten heavy metal alloy are adjustable via changes to the composition, sintering cycle, or post-sintering treatment. Increased strength, with a loss of ductility, comes with post-sintering deformation and aging treatments (German, 2022).

According to all mentioned, a numerical simulation of the penetration process of a 30mm caliber armor-piercing fin-stabilized discarding sabot projectile with a heavy metal alloy core into plates of various thicknesses made of Weldox 460 alloy is performed in this paper. The sub-projectile simplified drawing used in this analysis is shown in Figure 1.

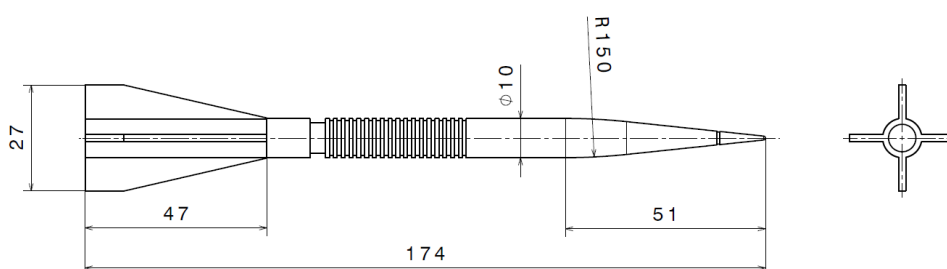


Figure 1 – 30mm sub-projectile, drawing

The armor-piercing fin-stabilized discarding sabot (APFSDS) projectile is made of several subparts: core, fins, carrier, plastic cap, and driving band. If it has a tracer implemented, it is labelled APFSDS-T.

Due to the specificity of the sub-caliber design compared to other types of projectiles, it should be emphasized that the effect on the target is achieved only by the core made of heavy metal and a negligibly small part of the fins whose role is to ensure the stability of the core on the trajectory from the muzzle to the drop point. The other parts (carrier, plastic cap and driving band) have the function of guiding the projectile in the barrel, and after that they are separated from the rest. This is ensured by the construction. In Figure 2, a projectile with a cartridge case is shown in the cross section view and it represent one design solution of this special ammunition type (Sturgeon's House, 2018).

The sub-projectile body is made of two materials:

- Heavy metal alloy Wi-Ni-Fe – core, and
- Aluminium alloy ASTM 7075-T6 – fins.

For the analysis of the penetration effect, the plate made of armor steel Weldox 460 is used. A 3D model of the sub-projectile design used in analysis is shown in Figure 3.



Figure 2 – 30mm x 173 cartridge, APFSDS-T



Figure 3 – 30mm sub-projectile, APFSDS, 3D model

The projectile ballistic characteristics are presented in Table 1.

Table 1 – Ballistic characteristics of the 30mm projectile

Caliber	d x l	30 x 173	mm
Projectile weight	m	0.23	kg
Sub-projectile weight	m	0.15	kg
Sub-projectile muzzle velocity	$V_0$	1430	m/s
Sub-projectile velocity at a distance of 1000 m	$V_{1000}$	1300	m/s

## Material characteristics

The penetration represents one of the typical examples of explicit nonlinear analysis, which is characterized by large deformations, deformation rates, as well as material failure.

In order to define the material properties of a high-strength steel target and a heavy metal alloy sub-projectile, it is necessary to define an appropriate material model that will describe the properties and the behavior of the material.

Pantović et al (2023) analyzed the penetration ability of a 30mm armor-piercing projectile and defined Johnson-Cook's constitutive material model (Wang & Shi, 2013; Liu et al, 2012) for metals characterized by high stresses, high strain rates and high temperatures. Each of the phenomena

(strain hardening, strain hardening rate and thermal softening) is represented by an independent factor. To determine the pressure in solids exposed to high pressure for a short period of time, the Mie-Grüneisen equation of state is defined which represents the relationship between pressure and volume of a solid at a given temperature (Heuzé, 2012; Wilkins, 1999).

Table 2 defines the Johnson-Cook parameters for various materials used in the numerical simulation of a 30mm APFSDS projectile penetration, and Table 3 provides the temperature parameters. The damage parameters for the same materials are defined in Table 4. These parameters are defining the Johnson-Cook material model used in numerical simulations (Sun et al, 2021; Flores-Johnson et al, 2014; Rezasefat et al, 2018).

*Table 2 – Johnson-Cook parameters for different materials*

Material	A [MPa]	B [MPa]	n	C	m
Wi-Ni-Fe alloy	1506	177	0.12	0.016	1.0
ASTM 7075-T6	520	477	0.52	0.001	1.0
Weldox 460	490	807	0.73	0.0114	0.94

*Table 3 – Thermal characteristics for different materials*

Material	T <sub>melt</sub> [K]	c <sub>p</sub> [J/kgK]
Wi-Ni-Fe alloy	1723	250
ASTM 7075-T6	893	910
Weldox 460	1800	452

*Table 4 – Damage parameters for different materials*

Material	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>	D <sub>5</sub>
Wi-Ni-Fe alloy	0	0.33	-1.5	0	0
ASTM 7075-T6	0.096	0.049	-3.465	0.016	1.1
Weldox 460	0.0705	1.732	-0.54	-0.015	0

Table 5 defines the parameters of the equation of state for different materials used in the numerical simulation.

Table 5 – Equation of the state parameters for different materials

Material	$C_0$ [mm/s]	s	$\Gamma_0$
Wi-Ni-Fe alloy	$4.029 \cdot 10^6$	1.237	1.54
ASTM 7075-T6	$5.452 \cdot 10^6$	1.259	2.14
Weldox 460	$3.574 \cdot 10^6$	1.920	1.69

### Finite element modeling

For the purpose of defining the geometry of the projectile and plate, due to the existence of two symmetry planes, a quarter model is created using the finite element method. By simplifying the model, it is possible to save time and obtain calculation results many times faster. In order to obtain more accurate calculation results, the projectile and the plate model are created using a 3D element hexa.

The sub-projectile and plate models are shown in Figures 4, 5 and 6. The sub-projectile geometry is modeled using 162000 nodes and 122000 elements, while the 10mm thick plate is modeled using 108000 nodes and 96000 elements. The average size of the elements is 0.5mm.

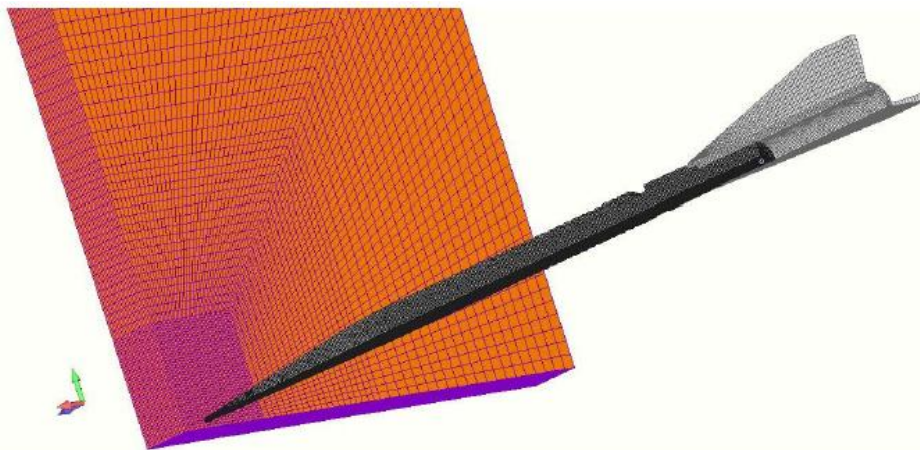


Figure 4 – FEM model of the sub-projectile and the plate, isometry

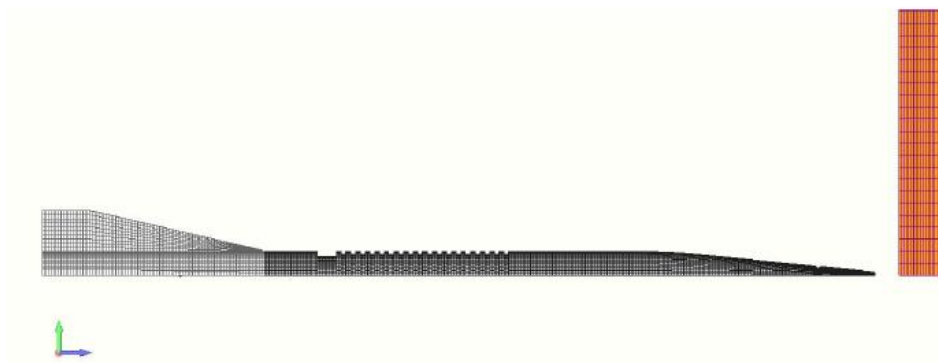


Figure 5 – FEM model of the sub-projectile and the plate, side view

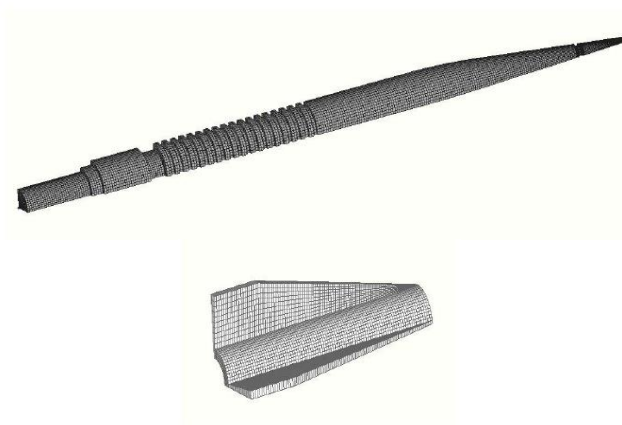


Figure 6 – FEM model of the sub-projectile elements

## Results and discussion

The chapter on the results presents the numerical simulation output results for different cases. As it is mentioned, four different plate thicknesses are analysed: 10mm, 50mm, 100mm, and 110mm.

The 30mm APFSDS projectile muzzle velocity is 1430m/s, but due to the aerodynamic resistance that occurs during the projectile motion until it reaches the target, it loses some amount of its kinetic energy. At a distance of 1000m from the barrel muzzle, the sub-projectile has a velocity of 1300m/s and that is the value which is used as an impact velocity in the performed numerical simulations.

It is determined that the penetration ability of the projectile decreases with the increase of the target plate thickness, and vice versa.

### Case 1 – 10mm thick plate

The Von Misses equivalent stress and penetration effect of the armor plate Weldox 460 with thickness of 10mm are shown in Figures 7-12.

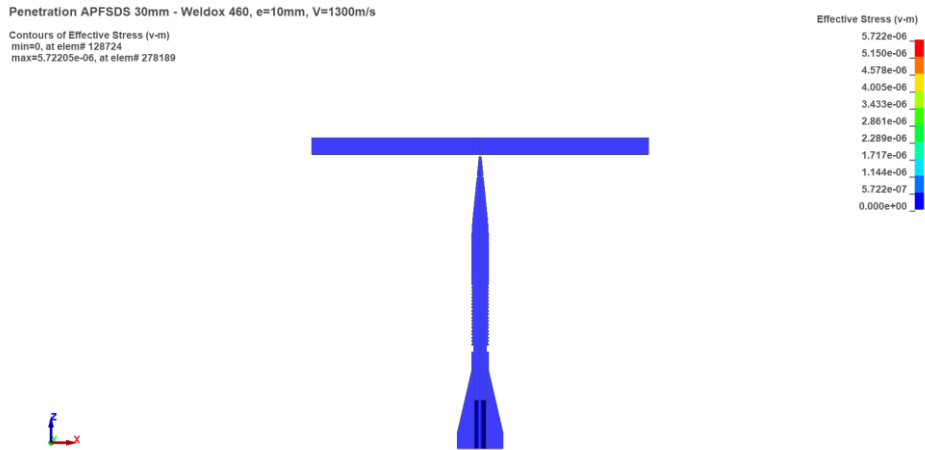


Figure 7 – Von Misses equivalent stress, step 1 – case 1

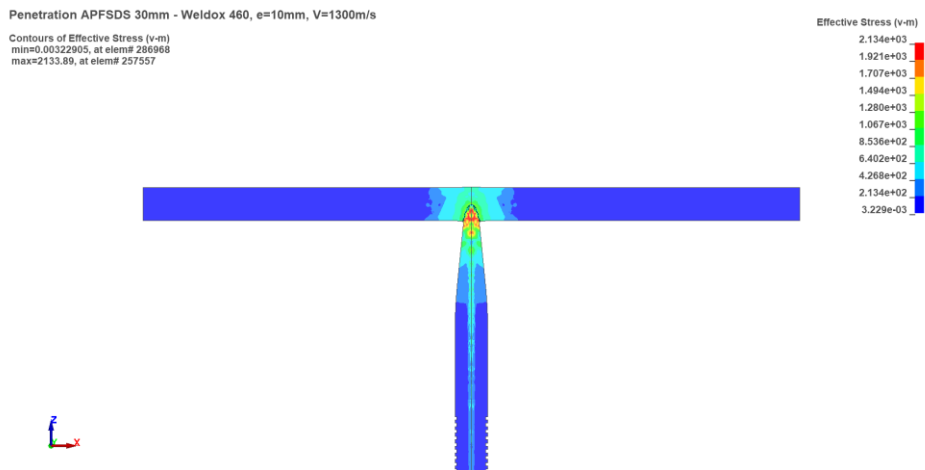


Figure 8 – Von Misses equivalent stress, step 2 – case 1



Penetration APFSDS 30mm - Weldox 460, e=10mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=0.28245, at elem# 397134  
max=2115.69, at elem# 274255

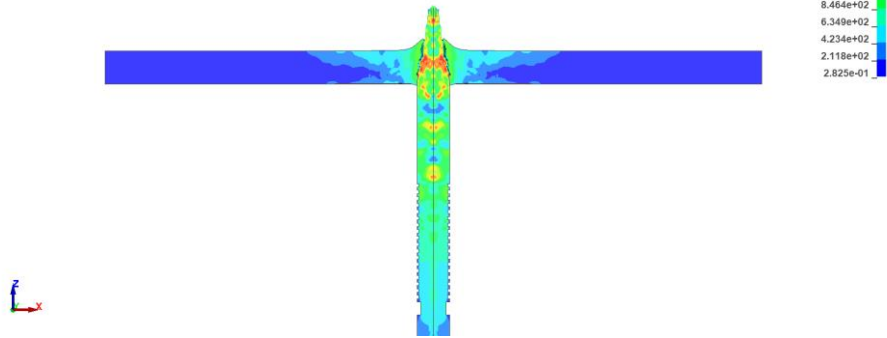


Figure 9 – Von Mises equivalent stress, step 3 – case 1

Penetration APFSDS 30mm - Weldox 460, e=10mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=4.92898, at elem# 372009  
max=2097.52, at elem# 235334

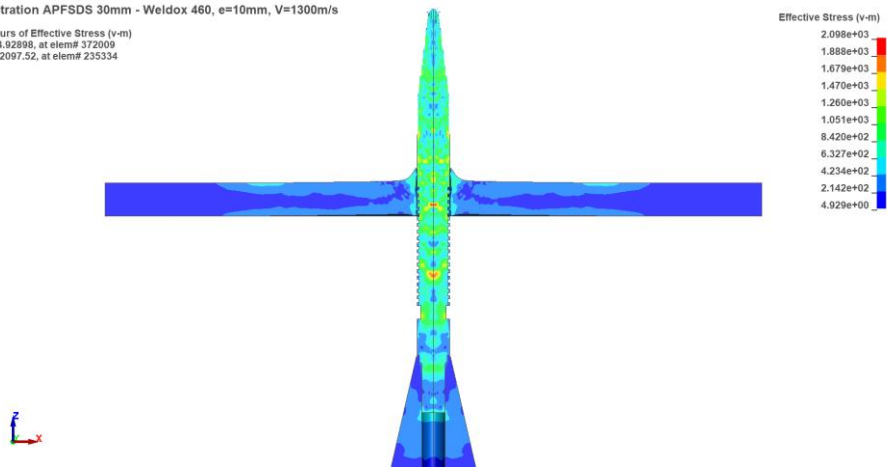


Figure 10 – Von Mises equivalent stress, step 4 – case 1

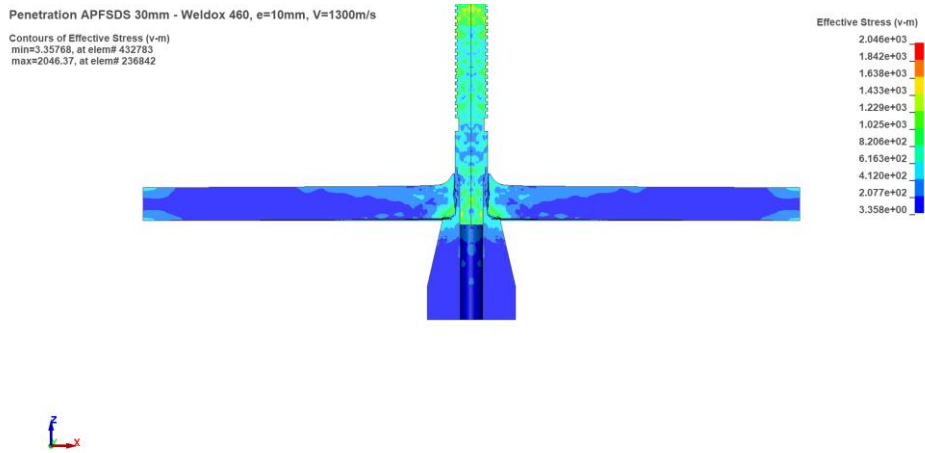


Figure 11 – Von Misses equivalent stress, step 5 – case 1

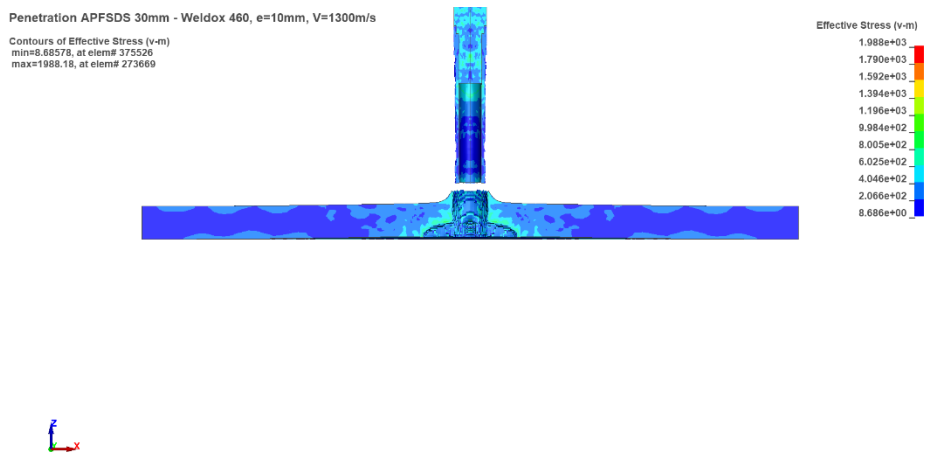


Figure 12 – Von Misses equivalent stress, step 6 – case 1

As the presented results show, the sub-projectile has enough kinetic energy to achieve the full penetration effect into the 10mm thick plate. The core of the projectile retains its structure, while the main part of the fins is welded to the structure of the plate and the cylindrical part of the fins fragments behind the plate due to stress relief.

The sub-projectile velocity is shown in Figure 13 and it represents the velocity value from the moment of leaving the barrel, until the moment it penetrates through the target plate. As it can be seen, the sub-projectile velocity after penetration is still high and has the value of 1280m/s.

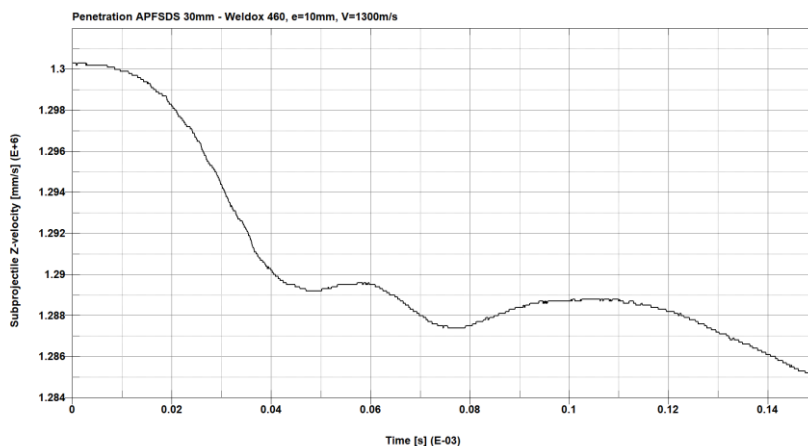


Figure 13 – Projectile velocity as a function of time – case 1

The plate displacement is shown in Figure 14. The first movement of target plate occurs after 0.1ms, and the maximum displacement is 0.3mm.

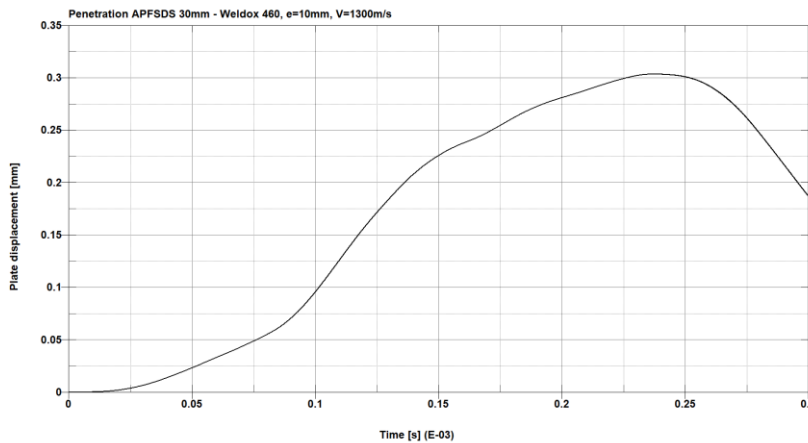


Figure 14 – Plate displacement in function of time – case 1

### Case 2 – 50mm thick plate

The Von Mises equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 50mm are shown in Figures 15-20.

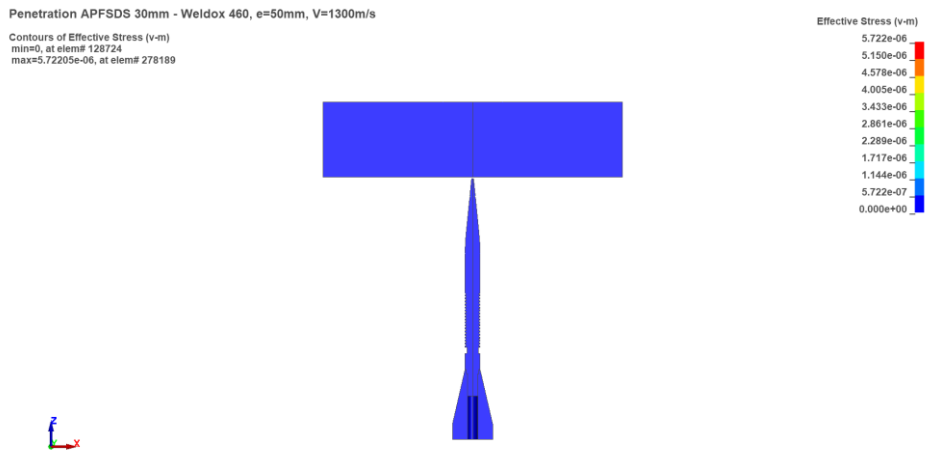


Figure 15 – Von Mises equivalent stress, step 1 – case 2

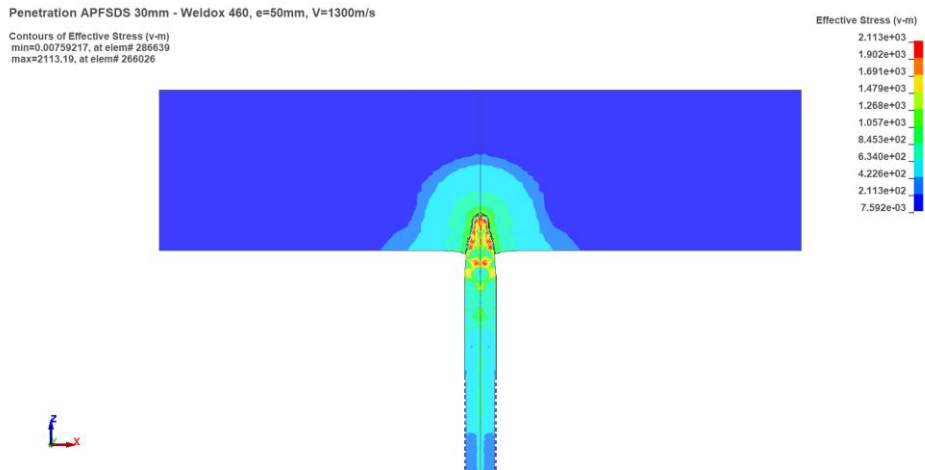


Figure 16 – Von Mises equivalent stress, step 2 – case 2

Penetration APFSDS 30mm - Wieldox 460, e=50mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=2.45157, at elem# 823383  
max=2114.81, at elem# 237824

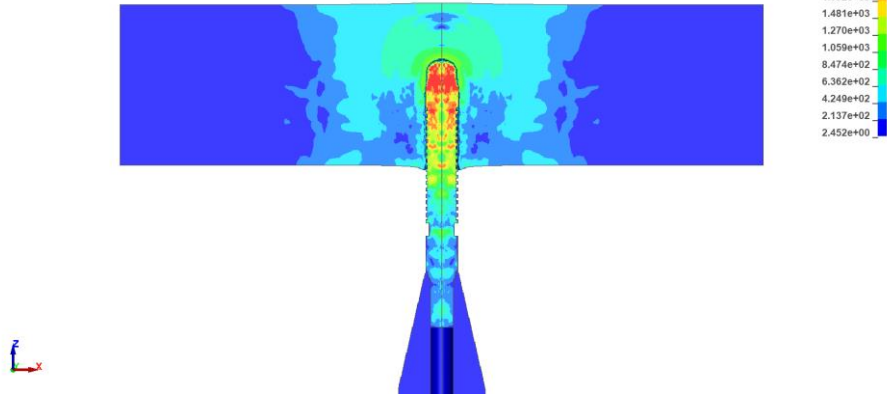


Figure 17 – Von Mises equivalent stress, step 3 – case 2

Penetration APFSDS 30mm - Wieldox 460, e=50mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=5.31398, at elem# 770479  
max=2101.57, at elem# 225791

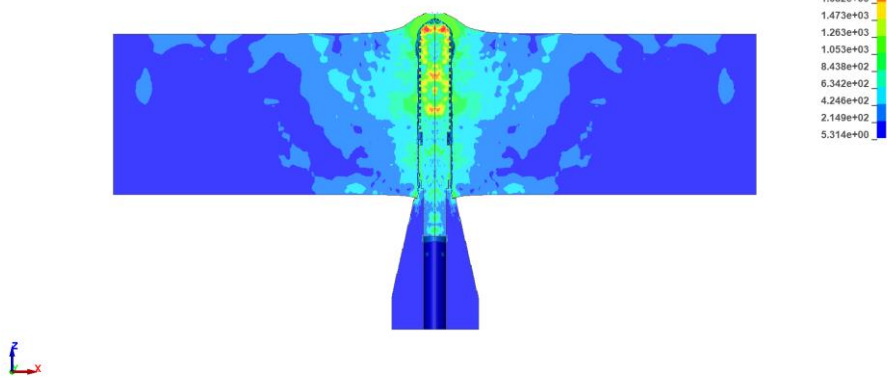


Figure 18 – Von Mises equivalent stress, step 4 – case 2

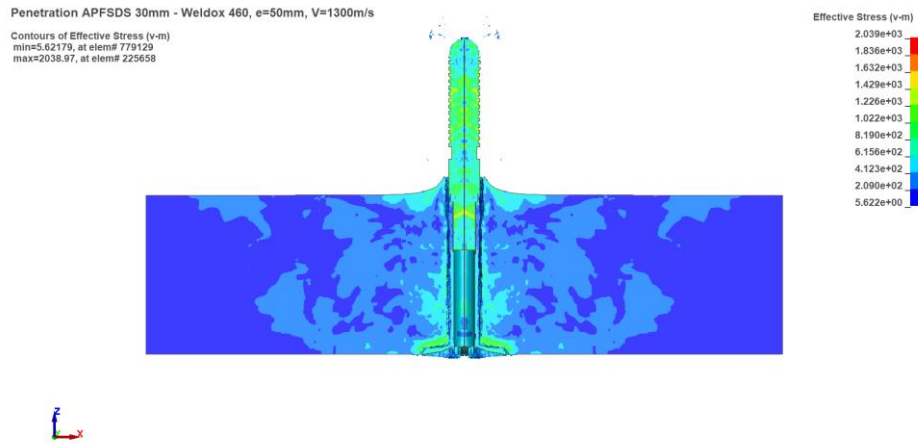


Figure 19 – Von Mises equivalent stress, step 5 – case 2

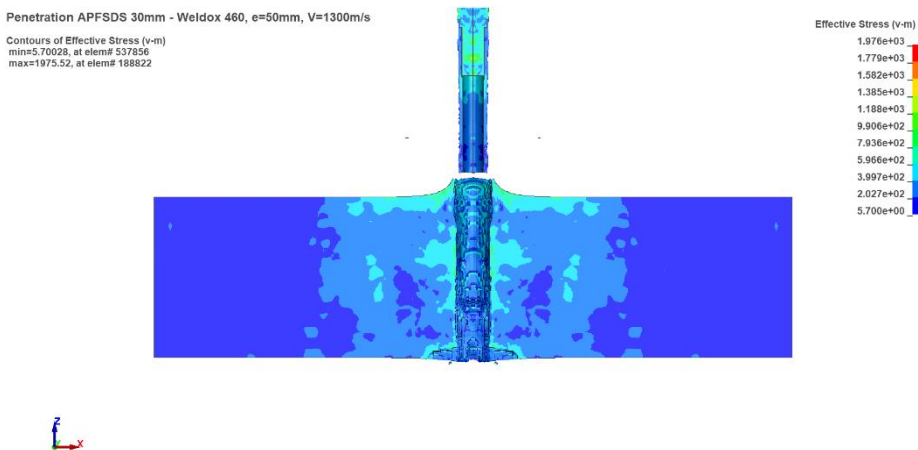


Figure 20 – Von Mises equivalent stress, step 6 – case 2

As the results show, the sub-projectile still has sufficient kinetic energy to achieve a full penetration effect in the plate of a thickness of 50mm. It is interesting to mention that compared to the standard armor-piercing (AP) ammunition type, the APFSDS projectile has a different penetration effect. This effect will be described in more detail later in the paper. Figure 21 shows the sub-projectile velocity which is still on high level after penetrating 50mm of steel and it has a value of 1210m/s.

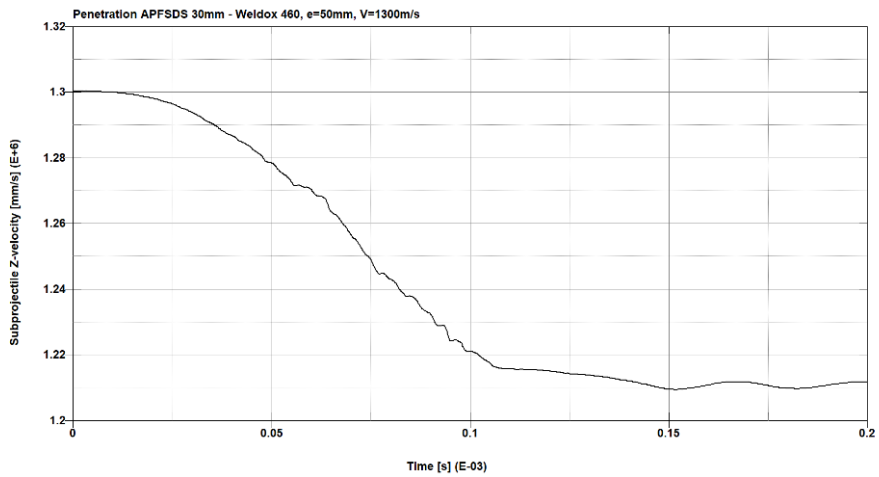


Figure 21 – Projectile velocity as a function of time – case 2

The plate displacement is shown in Figure 22. The maximum plate displacement is low, 0.06mm. It is lower than in case 1 because the plate thickness in the case 2 is much higher.

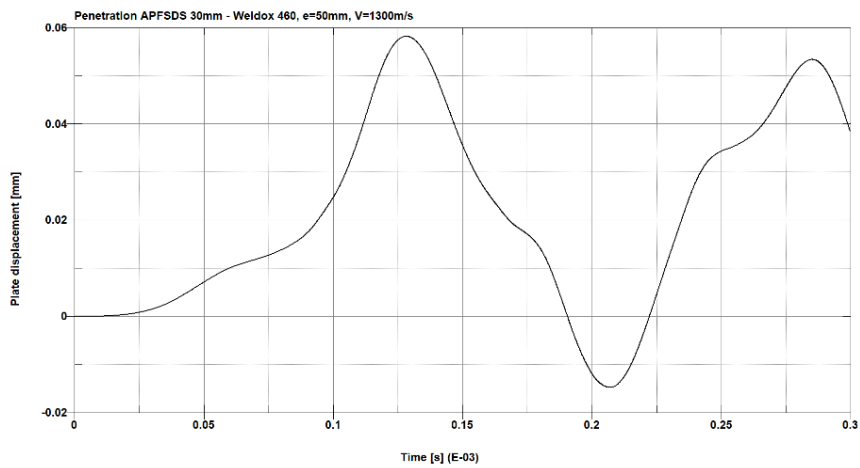


Figure 22 – Plate displacement as a function of time – case 2

### Case 3 – 100mm thick plate

The Von Mises equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 100mm are shown in Figures 23-28.

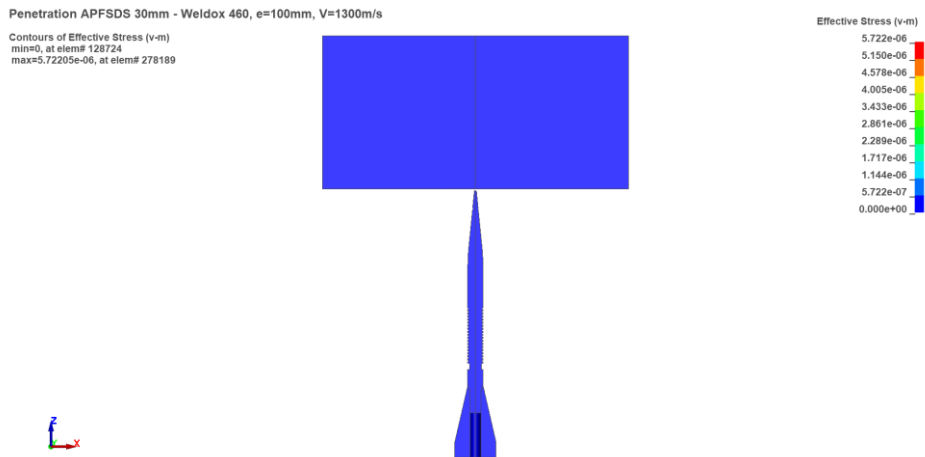


Figure 23 – Von Mises equivalent stress, step 1 – case 3

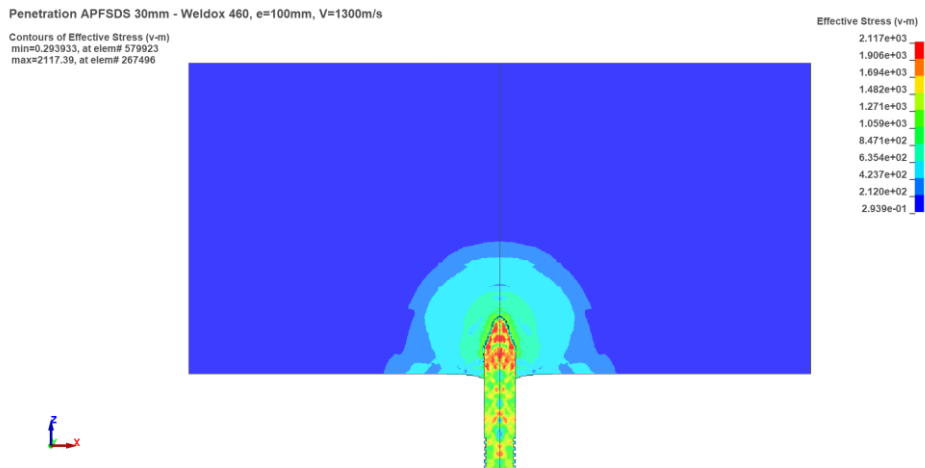


Figure 24 – Von Mises equivalent stress, step 2 – case 3



Penetration APFSDS 30mm - Weldox 460, e=100mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=2.19249, at elem# 1155964  
max=2110.23, at elem# 155244

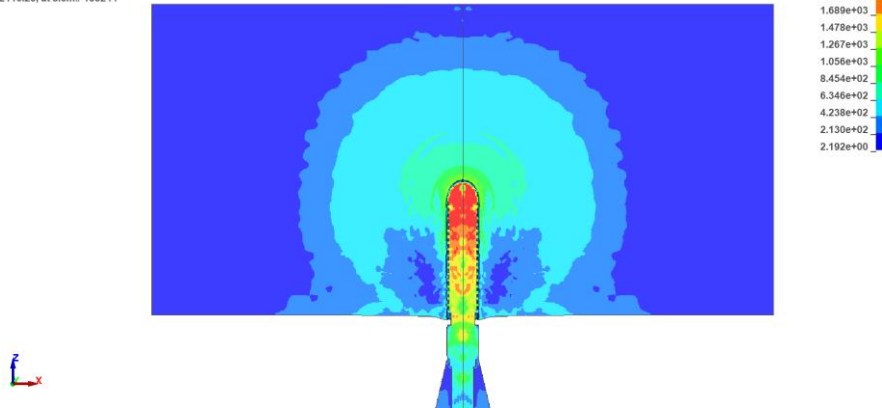


Figure 25 – Von Mises equivalent stress, step 3 – case 3

Penetration APFSDS 30mm - Weldox 460, e=100mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=5.1382, at elem# 767925  
max=2085.19, at elem# 193273

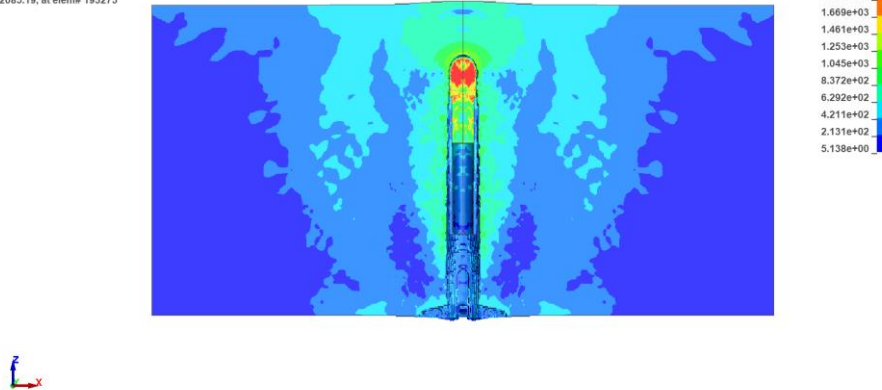


Figure 26 – Von Mises equivalent stress, step 4 – case 3

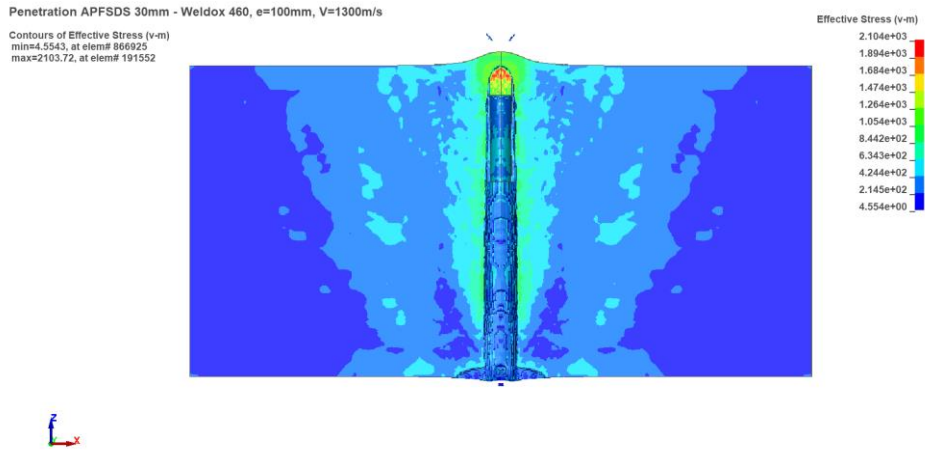


Figure 27 – Von Misses equivalent stress, step 5 – case 3

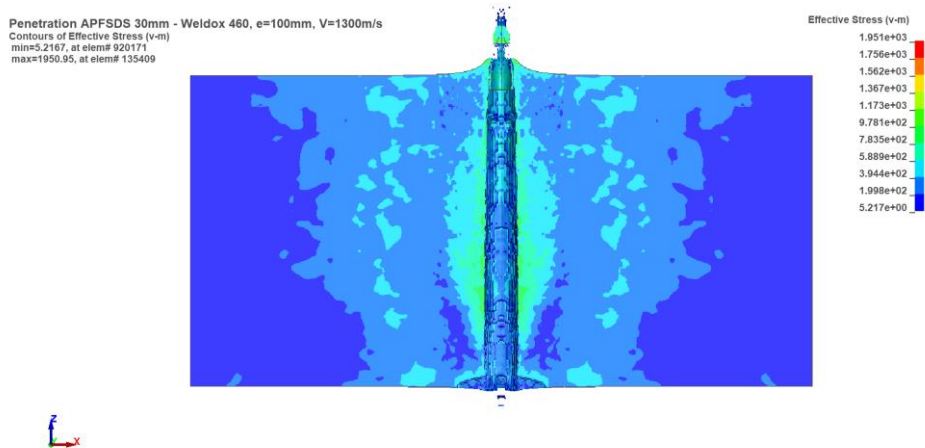


Figure 28 – Von Misses equivalent stress, step 6 – case 3

As the results show, the sub-projectile has a sufficiently high kinetic energy to achieve the full penetration effect in the 100mm thick plate. Because it loses too much of energy during penetration, its length behind the plate is short and therefore does not have a large number of fragments behind the plate (Figure 28). That reduces its effect behind the target, but in any case, it still has a high penetration ability.

The sub-projectile velocity is shown in Figure 29. The fragments velocity after penetration is around 470m/s.

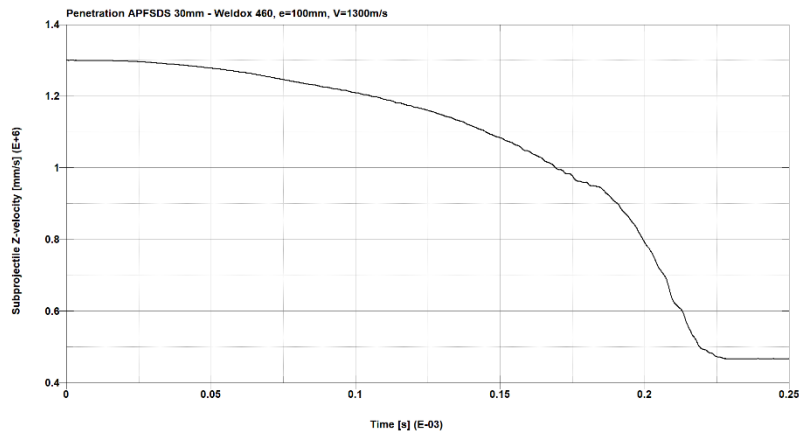


Figure 29 – Projectile velocity as a function of time – case 3

The plate displacement as a function of time is shown in Figure 30. The maximum plate displacement is 0.04mm and the first plate movement occurs after 0.05ms.

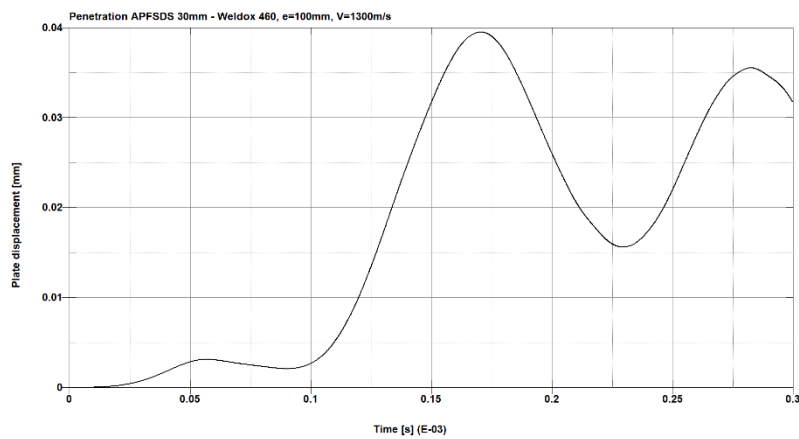


Figure 30 – Plate displacement as a function of time – case 3

### Case 4 – 110mm thick plate

The Von Misses equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 110mm are shown in Figures 31-36.

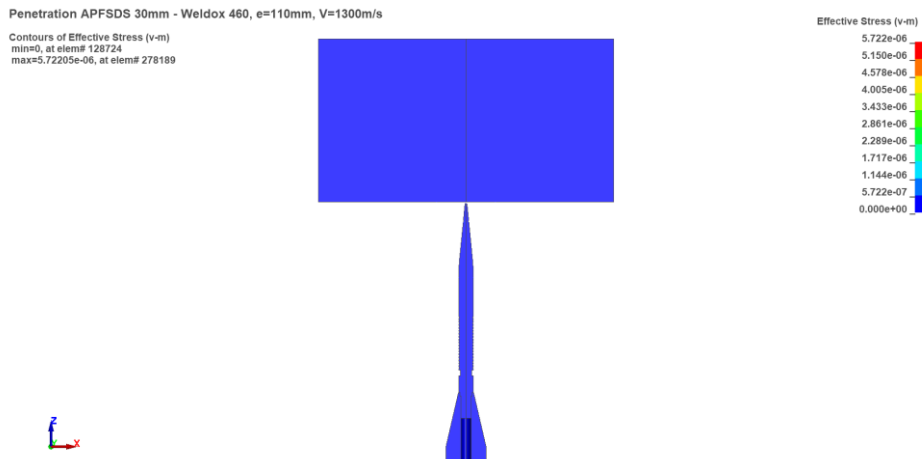


Figure 31 – Von Misses equivalent stress, step 1 – case 4

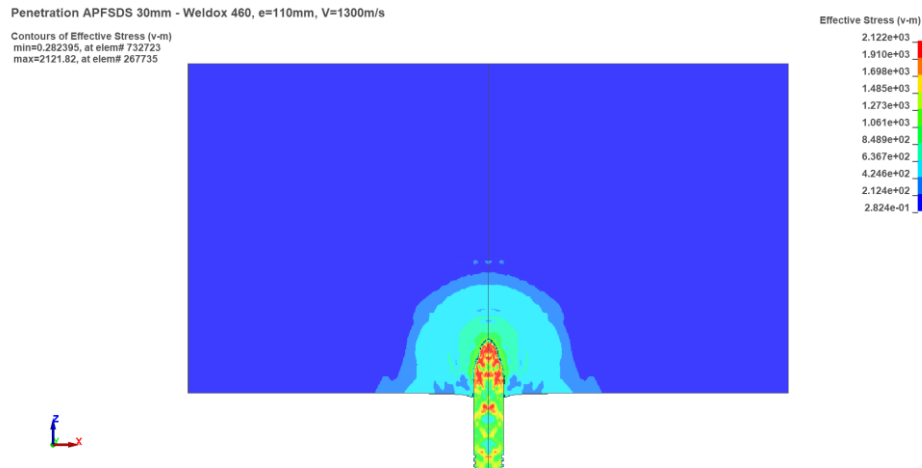


Figure 32 – Von Misses equivalent stress, step 2 – case 4

Penetration APFSDS 30mm - Weldox 460, e=110mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=1.45051, at elem# 1257963  
max=2089.92, at elem# 226111

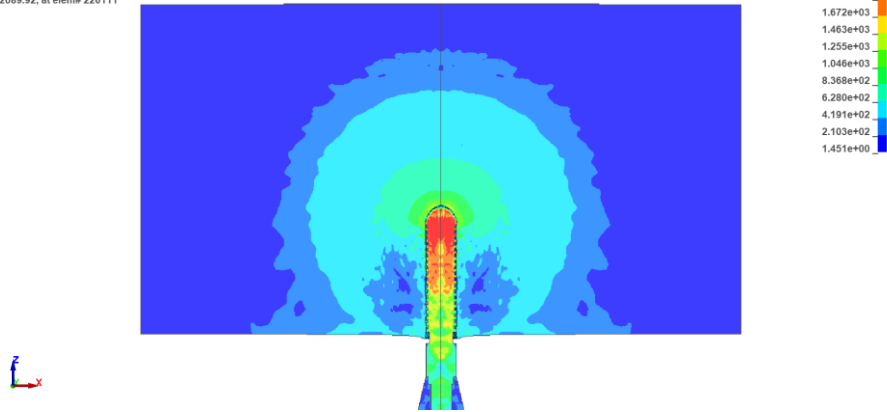


Figure 33 – Von Mises equivalent stress, step 3 – case 4

Penetration APFSDS 30mm - Weldox 460, e=110mm, V=1300m/s

Contours of Effective Stress (v-m)  
min=4.14975, at elem# 1262324  
max=2120.32, at elem# 225471

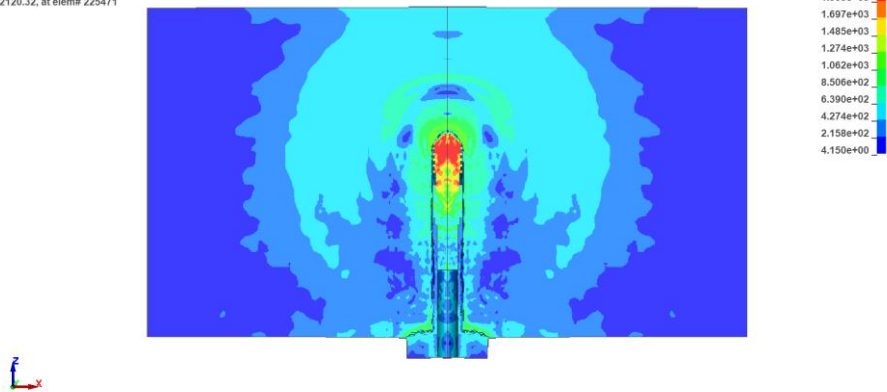


Figure 34 – Von Mises equivalent stress, step 4 – case 4

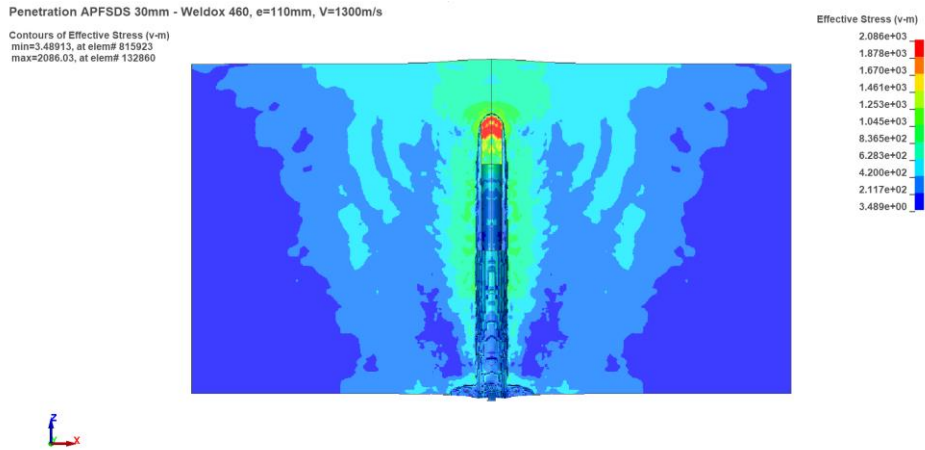


Figure 35 – Von Mises equivalent stress, step 5 – case 4

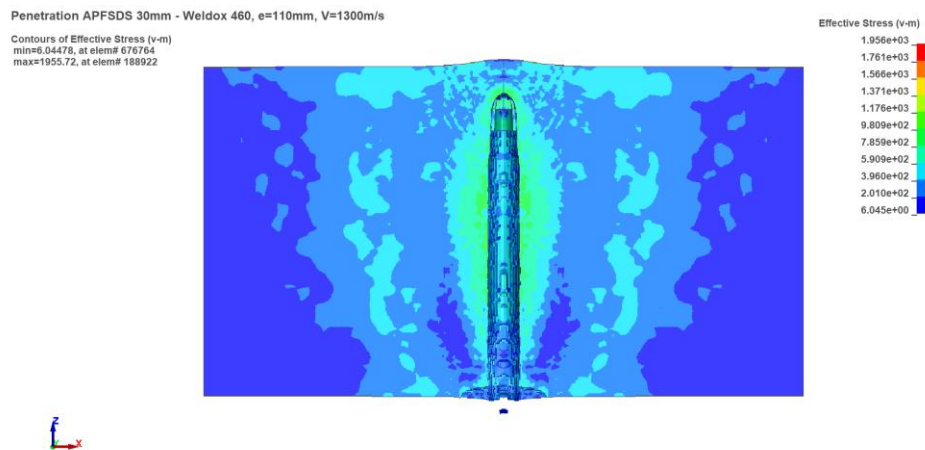


Figure 36 – Von Mises equivalent stress, step 6 – case 4

As the results show, in this case the sub-projectile does not have enough kinetic energy to achieve full penetration into the 110mm thick plate. After the impact with the plate, the sub-projectile core penetrates to the point it loses its length, weight and velocity and its kinetic energy. After that, the remained particles get jammed into the armor steel plate structure and behind the plate there are no fragments.

In Figure 37, the sub-projectile velocity is shown from the moment the projectile leaves the barrel until the moment it jams into the plate after 0.23ms.

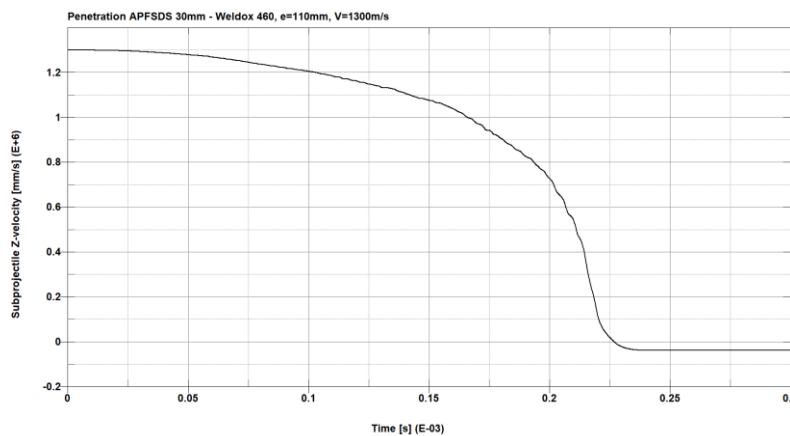


Figure 37 – Projectile velocity as a function of time – case 4

The plate displacement is shown in Figure 38. The maximum plate displacement is 0.043mm.

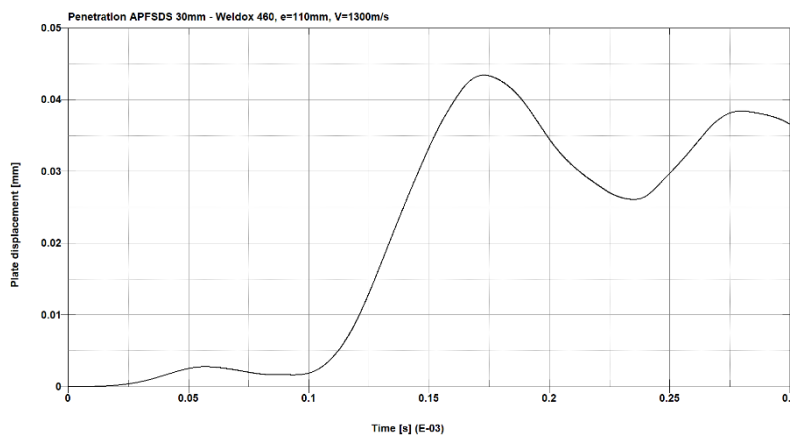


Figure 38 – Plate displacement as a function of time – case 4

The comparative overview of the analysis results is given in Table 6.

Table 6 – Comparative overview of the analysis results

Plate thickness [mm]	Penetration	Output velocity behind plate [m/s]	Plate displacement [mm]
10	yes	1280	0.3
50	yes	1210	0.06
100	yes (limited)	470	0.04
110	no	n/a	0.043

As it is already mentioned in this paper, compared to the classic armor-piercing (AP) ammunition type, the APFSDS sub-projectile has a different penetration effect. It penetrates through a steel plate without energy dissipation and “digs” the steel plate structure; while penetrating, its length becomes shorter. This effect resembles the penetration of a cumulative jet of HEAT (High-explosive anti-tank) ammunition, because of high temperatures and effect of material melting.

Magier, M. (2010) also demonstrated this specific penetration effect of APFSDS ammunition while analyzing the penetration capability of kinetic energy projectile with a tungsten alloy core for 120mm tank guns. This effect which M. Magier analyzed is shown in Figure 39.

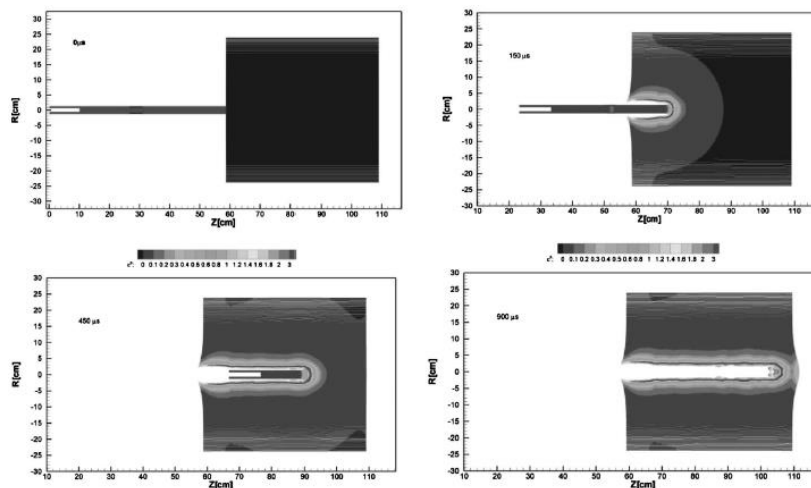


Figure 39 – The time sequence of equivalent plastic strain

The concurrence between the phenomenon shown in Figure 39 and the calculation results shown in figures in the previous part of the paper is



the confirmation of the accuracy of the claims and the applied methods and parameters used in this paper.

Table 7 shows a comparison of the penetration capabilities of 30mm APFSDS and 30mm AP projectiles (Pantović et al, 2023).

*Table 7 – Comparison of the penetrating capabilities of different types of projectiles*

Projectile type	Muzzle velocity [m/s]	Impact velocity at 1000m [m/s]	Penetration at 1000m [mm]
30mm APFSDS	1430	1300	100
30mm AP	970	750	33

The APFSDS sub-projectile with the defined material and ballistic characteristics has the ability to fully penetrate the Weldox 460 plate with a maximum thickness of 100mm.

Different manufacturers provide similar information on maximum penetration capability for this type of ammunition. For example, *Nammo* (Norway) in its catalogue gives a penetration value of 100mm at a distance of 1000m (Nammo, 2023).

Other manufacturers, such as *Mecar* (Belgium), give a penetration value of 50mm at 60° obliquity angle, which is similar to 100mm at 0°, due to a cosine of the angle and specific effect of penetration at a low angle of attack (Gyürösi, 2019).

## Conclusion

Armor-piercing ammunition is intended to penetrate ballistic armor and different protective shields designed to protect certain defended objects. This ammunition type achieves an effect on the target thanks to its high material properties, velocity and a specially designed shape.

Representation of the effects that occur during the penetration process is extremely complex, but by using special material and geometric models it is possible to describe the real problem of armor-piercing projectile penetration. For this purpose, different calculation approaches are available in the modern times, but one of the most successful which provides the most accurate results is the finite element method.

Accordingly, a numerical analysis of the penetration of a 30mm armor-piercing fin-stabilized discarding sabot projectile into the steel alloy Weldox 460 plates of different thicknesses at a distance of 1000m with a velocity of 1300m/s is presented in this paper.

In accordance with the penetration theoretical principles, the key factors which have the greatest influence on the penetration process are deformation, strain rate, temperature, and pressure.

For the purposes of defining the phenomenon of penetration, it is necessary to define initial and boundary conditions, material characteristics, and contact conditions.

For the analysis of a 30mm armor-piercing (AP) projectile on the same type of armor steel plate, Pantović et al (2023) used the Johnson-Cook material model and the Mie-Grüneisen equation of state to describe material behavior. The maximum armor plate thickness which a 30mm armor-piercing projectile can penetrate, according to the numerical calculation result, is 33mm.

To establish the penetration ability of a 30mm APFSDS projectile, four different cases were performed in this analysis.

The 30mm APFSDS sub-projectile with defined ballistic and material characteristics had a full penetration effect into the 10mm and 50mm thick armor plates (case 1 and case 2), because its impact velocity and kinetic energy were higher than needed for the full penetration effect. The projectile velocity behind the plate, after penetration, in case 1 was 1280m/s, and in case 2, the velocity was 1210m/s.

In case 3, the sub-projectile had a limited penetration because only small particles of the core and fins went through the whole plate thickness, and the hole outer diameter was smaller than the sub-projectile core diameter. The fragments velocity behind the plate after penetration was around 470m/s.

In case 4, the sub-projectile did not have sufficient kinetic energy to achieve penetration into the 110mm thick plate. After collision with the plate, the sub-projectile core penetrates till the point it loses its kinetic energy. After that, remained particles get jammed into the steel plate structure and there were no fragments behind the plate.

By performing a penetration analysis of the sub-caliber armor-piercing ammunition with a core made of tungsten heavy metal alloy, a specific penetration effect was established and described. The appearance of such an effect is a function of a large number of different factors - the type of material, very high values of the collision speeds and the projectile and obstacles deformation speed, which together, interpenetrating, lead to a large destruction of the material structure and a high level of penetration.

The 30mm APFSDS sub-projectile with the defined material and ballistic characteristics has the ability to fully penetrate the Weldox 460 plate with a maximum thickness of 100mm.

The shown numerical results are confirmed with catalogue data given by various ammunition manufacturers, as listed in the paper.

Depending on the armor barrier design, the thickness of 100mm can be achieved in different ways – as a monoblock or as a sandwich armor with several thicker and thinner plates (e.g., 10, 20, 50mm). In the sandwich armor case, the sub-projectile penetration effect would be different because that structure would represent a sandwich barrier with different cross-sectional densities, which would give different output results.

From the aspect of ballistic protection, it is necessary to design an armored barrier in such a way that the personnel behind it is safe. For a safe protection from this projectile type, it is necessary to use armor steel with a thickness greater than the calculated one. That would neutralize the potential effect of separate fragments from the other side of the plate.

The numerical and analytical methods of calculation can provide quality results and present certain phenomena, but it is desirable to carry out experimental tests on the training ground, and at the same time numerical calculations, which would give comparable or incomparable results, which in the end would be a confirmation of the quality of the applied methods.

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Análisis numérico del proceso de penetración de un proyectil de descarte sabot perforador de blindaje de 30 mm estabilizado por aletas

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CAMPO: ingeniería mecánica, materiales  
TIPO DE ARTÍCULO: artículo científico original

*Resumen:*

*Introducción/objetivo:* En los últimos tiempos, con la tendencia a desarrollar nuevos tipos de municiones perforantes, es necesaria una inversión constante en el desarrollo de nuevos tipos de obstáculos blindados. Los obstáculos fabricados con placas de acero de alta aleación siguen siendo la mejor forma de protección contra municiones de mayor calibre. Hay una serie de factores a considerar al seleccionar una aleación, incluido el peso, las dimensiones, el uso previsto, el rendimiento balístico deseado y los costos. De acuerdo con esto, en este artículo se presenta un análisis numérico de la penetración de un proyectil de descarte de sabot estabilizado con aletas perforador de armadura de 30 mm en placas de aleación de acero Weldox 460 de diferentes espesores a una distancia de 1000 m con una velocidad de 1300 m/s.

*Métodos:* Las tensiones y deformaciones del efecto de penetración se calcularon mediante análisis numérico y modelado de elementos finitos. Para especificar las características del material se ha utilizado el modelo de material de Johnson-Cook y el modelo de fractura de materiales. Para definir modelos y realizar cálculos numéricos se han utilizado en este trabajo los paquetes de software FEMAP y LS Dyna.

*Resultados:* Para un análisis numérico del proceso de penetración de este tipo de proyectil contra un obstáculo blindado, se calculan cuatro espesores diferentes de placas de blindaje: 10 mm, 50 mm, 100 mm y 110 mm. Para cada uno de ellos, los resultados se muestran en forma de tensión y desplazamiento, de modo que se puedan describir los fenómenos de interacción entre el subproyectil y la placa de blindaje.

*Conclusión:* Determinar el impacto sobre obstáculos perforantes es extremadamente difícil, requiere mucho tiempo y es complejo, y los modelos resultantes se aproximan con gran éxito (o con alguna desviación) al problema real de la penetración de proyectiles. Uno de los métodos más eficaces para resolver problemas de este tipo y otros de naturaleza similar en los últimos tiempos es el análisis por el método de elementos finitos. El material y las dimensiones del objetivo, así como los parámetros balísticos y el material del proyectil tienen la mayor influencia en la penetración del proyectil. La resistencia del objetivo a la penetración aumenta cuando todos los parámetros de entrada se mantienen al mismo nivel y se aumenta su espesor, y viceversa.

*Palabras clave:* blindaje, proyectil, penetración, Weldox 460, análisis numérico.

Численный анализ процесса проникновения 30-мм бронебойного снаряда

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ВИД СТАТЬИ: оригинальная научная статья

**Резюме:**

*Введение/цель:* В последнее время вследствие тенденции в проектировании новых видов бронебойных боеприпасов требуются постоянные капиталовложения в разработку новых видов бронебойных препятствий. Бронепреграды из листов высоколегированной стали по-прежнему являются лучшей защитой от боеприпасов крупного калибра. При выборе сплава следует учитывать ряд факторов, включая вес, размеры, предполагаемое использование, соответствующие баллистические характеристики и стоимость. В соответствии с вышеперечисленным в статье представлен численный анализ проникновения 30-мм бронебойно-оперенного подкалиберного снаряда в пластины стального сплава Weldox 460 различной толщины на расстоянии 1000 м со скоростью 1300 м/с.

*Методы:* Напряжение и деформации эффекта проникновения были рассчитаны путем численного анализа и моделирования методом конечных элементов. При определении характеристик материала использовались: модель материала Джонсона-Кука и модель разрушения материалов. Для определения моделей и проведения численных расчетов в данной статье использовались пакеты программного обеспечения FEMAP и LS Dyna.

*Результаты:* При численном анализе процесса проникновения такого вида снаряда в броневую преграду рассчитаны четыре различных толщины бронелистов: 10 мм, 50 мм, 100 мм и 110 мм. По каждой из них представлены результаты в виде напряжений и деформаций, а также описано взаимодействие подкалиберного снаряда с бронелистом.

*Выводы:* Моделирование удара на бронебойные препятствия является чрезвычайно сложным и трудоемким процессом, однако полученные модели весьма успешно (или с некоторым отклонением) аппроксимируют реальную задачу проникновения

снаряда. В последнее время анализ с использованием метода конечных элементов является одним из наиболее эффективных подходов к решению подобных задач.

**Ключевые слова:** броня, снаряд, проникновение, Weldox 460, численный анализ.

Нумеричка анализа процеса пенетрације панцирног поткалибарног пројектила калибра 30 mm

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ОБЛАСТ: машинско инжењерство, материјали

КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

**Сажетак:**

*Увод/циљ:* У новије време, са тенденцијом развоја нових типова оклопне муниције, неопходна су стална улагања у развој нових типова оклопних препрека. Препреке од високолегираних челичних плоча и даље су најбољи вид заштите од муниције већег калибра. Постоји низ фактора које треба узети у обзир при одабиру легуре, укључујући тежину, димензије, предвиђену употребу, жељене балистичке перформансе и цену. У складу с тим, у овом раду је приказана нумеричка анализа продора поткалибарног пројектила калибра 30 mm, брзине 1300 m/s, у челичне плоче различитих дебљина, израђене од легуре Weldox 460, на удаљености од 1000 m.

*Метод:* Нумеричком анализом и моделирањем коначних елемената израчунати су напони и деформације ефекта пенетрације. За дефинисање карактеристика материјала коришћени су Џонсон-Куков материјални модел и модел лома материјала, а за дефинисање модела и извођење нумеричких прорачуна – софтверски пакети FEMAP и LS Dyna.

*Резултати:* За потребе нумеричке анализе процеса продирања овог типа пројектила у оклопне препреке, израчунате су четири различите дебљине оклопних плоча: 10 mm, 50 mm, 100 mm и 110 mm. За сваку од њих приказани су резултати у облику напрезања и померања, а описан је и феномен интеракције између поткалибарног пројектила и оклопне плоче.

*Закључак: Моделирање удара на оклопне препреке је изузетно тешко, дуготрајно и сложено, а дефинисани модели веома успешно (или уз извесно одступање) одређују прави проблем пробијања пројектила. Једна од најефикаснијих метода за решавање проблема ове врсте, и других сличних, у новије време јесте анализа методом коначних елемената. Материјал и димензије мете, као и балистички параметри и материјал пројектила највише утичу на продор пројектила. Отпор мете на пробој се повећава када се сви улазни параметри одржавају на истом нивоу, а њена дебљина се повећава, и обрнуто.*

*Кључне речи: оклоп, пројектил, пробој, Weldox 460, нумеричка анализа.*

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