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PROTAC 500 – ARMORED STEEL OF NEW GENERATION

PROTAC 500 – TENKOVSKI ČELIK NOVE GENERACIJE

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ABSTRACT

In this work we studied the response of newly developed armored steel plates PROTAC 500 to the ballistic testing with armored piercing bullets with a core of tungsten carbide, charge 7.62 mm. Interactions between the bullets and the steel plate was investigated by standard metallographic and mechanical testing methods.

We were interested in the geometric features of interaction, the phenomenon of adiabatic shear bands (ASB), cracks and local failure, local melting and interaction of the components and plate with metal balls fragments in the melt, rate of deformation and the steel hardening.

Keywords: armored steel plate, bullet, adiabatic shear band (ASB)

SAŽETAK

U ovom radu proučavan je odgovor novorazvijenih oklopnih limova PROTAC 500 na balističkih testiranja s oklopnim pancirnim mecima s jezgrom od tungsten karbida kalibra 7,62 mm. Interakcija između metaka i čelične ploče ispitivana je standardnim metalografskim i mehaničkim metodama testiranja. Praćene su geometrijske karakteristike interakcije, fenomen adijabatskog savojnog smicanja (ASB), pukotine, lokalne greške, lokalno topljenje i interakcije komponenti i ploče s metalnim fragmenata u talini, stepen deformacije i ojačavanje čelika.

Ključne riječi: tenkovski čelik, metak, adijabatsko savojno smicanje (ASB)

1. INTRODUCTION

The selection of the appropriate armored material is crucial to ensure the adequate safety and mobility transport systems. When selecting or developing the appropriate materials for the armor it is necessary to achieve the best possible compromise between the required mechanical properties of materials, minimizing the density and the final price of the product [1]. With the appropriate production technology, which includes synthesis, hot forming, heat treatment, etc.. High strength low alloy steel of good functional properties at affordable prices can be produced. By improving the strength and toughness of the steel the required thickness and the weight of the steel shell is reduced. Such steels are competitive to other materials for the armor [2]. In the context of this study, we carried out a test of a ballistic of high strengths low alloy steel PROTAC 500, whose mechanical properties are shown in Table 1 [3].

Table 1. Mechanical properties of steel PROTAC 500

TENSILE STRENGHT			*IMPACT PROPERTIES*		*HARDNESS*
Yeald strenght $R_{P0,2}$ [MPa]	*Tensile strenght Rm [MPa]*	*Elongation A5 [%]*	*Test temperature [°C]*	*Impact toughness [J]*	*HB*
1200	*1600*	*8*	*-40*	*20*	*480 - 530*

Steel PROTAC 500 belongs to a group of high-strength low-alloy steels (HSLA). It is made in Slovenian steelwork ACRONI by the standard procedures, the relevant mechanical properties are achieved by quenching and tempering [4].

Preliminary tests of the mechanical properties of the steel have indicated the possibility of using this steel for light armored vehicles. Ballistic testing was performed by using 7.62 mm armored-piercing bullets of the Swedish manufacturer Nammo (German standard VPAM, level 11, and the American standard STANAG 4569, Level 3), and to examine the interaction between a bullet and a steel plate [5]. Armored-piercing bullets, containing the rigid core (generally of high strength steel), which results in the conversion of the total kinetic energy of the bullets to the deformation of the target. The peculiarity of this bullet is the core of tungsten carbide (WC-Co). When the bullet hits its target, first the formation of pressure waves (cyclic stress) are formed, that spread through the target material and shall be deducted from the back side of the target as tensile waves. These waves reinforce the material, at a certain intensity of interaction between the

waves of pressure or tension and can lead to the formation of adiabatic shear bands, cracks and crack growth.
The material resistance to compressive and tensile waves is improved by increasing the strength and toughness of the. The deformation mechanisms at low strain rate are relatively homogeneous, while they are at extremely high speeds more complex. Here it comes to an extreme strain localization in narrow bands called adiabatic shear bands (ASB) [6]. The belt is during the deformation very hot (in some cases even to the melting point), whereby there a transformation of the austenite phase originates, after the load it is rapidly cooled, which results in the transformation to martensite, and thus a high hardness and brittleness of the steel in the ASP. The shear zones are so weak areas in the steel.

2. EXPERIMENTAL WORK

For the ballistics test a steel PROTAC 500 testing plate dimensions of 500 x 500 x 20.8 mm was used. We conducted six shots under the terms of the standard VPAM and STANAG 4569 (Table 2).

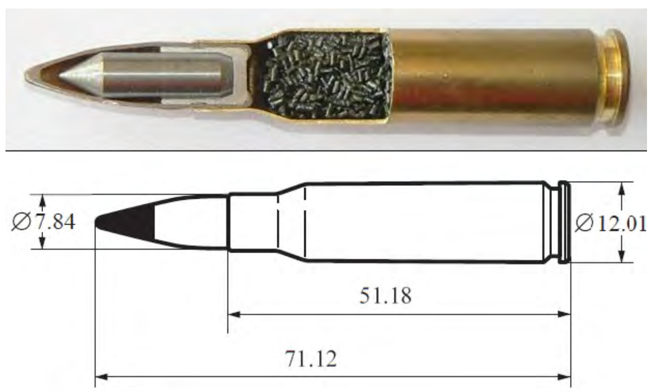
Table 2. Terms of ballistic test.

Standard	*Caliber*	*Cartridge*	*Bullet mass [g]*	*Producer*	*Bullet speed [m/s]*	*Distance from target [m]*	*Bullet energy [J]*
VPAM – level 11	*.308 Win*	*FMJ/PB/ WC*	*8.4 ± 0.1*	*Nammo AP8*	*930 ± 10*	*10 ± 0.5*	*3633*

Nammo AP8 is the cartridge of an armored-penetrating bullet caliber 7.62 X51 mm (.308 Winchester). American label of the cartridge is the M993. It tends to be used against targets with light armor. Bullet is capable of destroying such targets by 2 to 3 times the distance from the armored-piercing of bullets with steel cores. The bullet is made up of a core of tungsten carbide, mounted in an aluminum cup shell is made of steel coated with brass.
In Table 3 the properties of the bullet Nammo AP8 and image of transected cartridge and the cartridge sketch with dimensions [5].

Table 3. Characteristics and file of charges Nammo AP8 [5].

Bullet mass [g]	*8.3*
Core mass [g]	*5.9*
Core diameter [mm]	*5.5*
Core point angle [°]	*58*
Bullit cover material	*Steel and brass*
Bullit core material	*WC-Co*
Core hardness [HV]	*1450*



After the ballistics test was excluded from the test panel four samples were cut. One sample was then cut in several planes perpendicular to the direction of the shot, 3 samples were cut through the penetration of bullets in a plane parallel to the direction of the shot.

Surface analysis were etched with an aqueous solution of ferric chloride. Prepared in this way the analytical surface were examined by metallographic methods. Analysis of macro- and microstructure were performed on an optical microscope Olympus BX61. We were interested in particular areas with a different microstructure of the base and the places where the cracks and adiabatic shear bands ASB are [7,8]. This was followed by analysis of the scanning electron microscope JEOL-5610, which allows the observation of microstructure and qualitative and quantitative chemical analysis [9]. The images were recorded at various magnifications, especially the areas where had been adiabatic shear bands, cracks, pores, and where they were traces of melting and mixing of materials. Hardening of the steel sheet after penetrating bullets were determined by measuring the Vickers hardness. We have also made the fractographic analysis of cracks that have occurred during the ballistic test, for which it was necessary to break down the samples. To determine the mechanism of formation and spreading of the cracks and localized the nature of the fractured surfaces were ignoring and destroying extracts of the errors and faults at liquid nitrogen temperature.

3. RESULTS AND DISCUSSION

In Figure 1 there is the microstructure of the steel PROTAC 500 before the ballistic test. The microstructure consists of tempered martensite. In Figure 1c there are the lighter particles of cementite, which is eliminated during the tempering. The hardness of such steel is 540 HV.

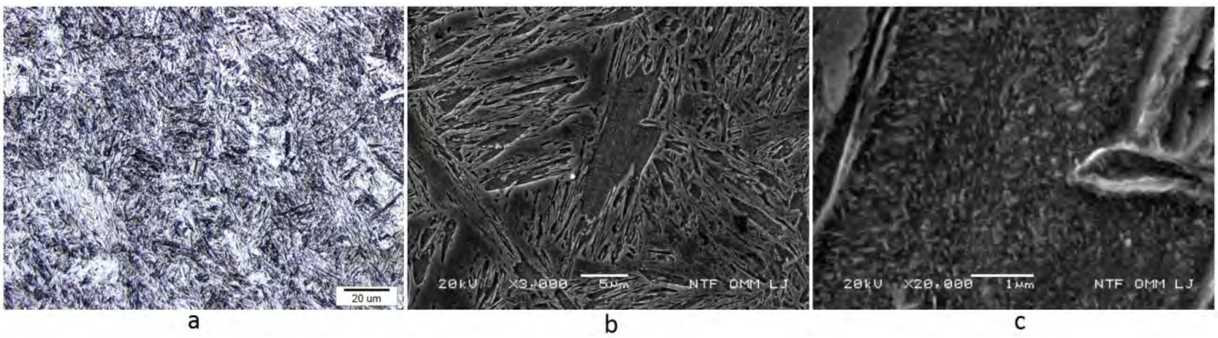


Figure 1. The microstructure of steel PROTAC 500 (a - tempered martensite (OM), b and c - tempered martensite (SEM)).

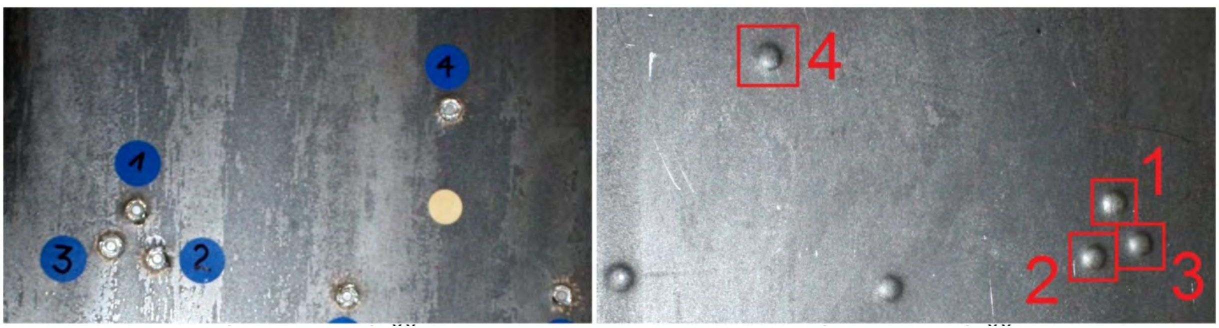


Figure 2. Front (left) and back (right) side of the steel plate after ballistic test.

On the left side of Figure 2 there is a front side of the panels PROTAC 500 after ballistics testing with the markings of four samples were have cut and prepared for further analysis. All armored-piercing bullets are stopped in the plate. In interpreting the results of ballistic tests is the most important information if a bullet penetrates the target. On the right side of Figure 2 there is the back side of the panel after ballistic test. In none of the 6 shots no perforation of the panel occurred.

The parameters of the test results and descriptions of the standard VPAM are in Table 4. By the shot to the sample 1 the bulge with a crack (BmRoL) was formed, that does not transmit light by other shots, but it was smaller bulge without cracks (Ibori). Code SS in the description of the result means that the ball remains in the target, and consequently, cast the whole kinetic energy of the target.

Table 4. Parameters of the test and the description of the results of the ballistic tests.

Sample	*Distance [m]*	*Shot angle[°]*	*Impact velocity [m/s]*	*Bullet energy[J]*	*Break trough*	*Resault description*
1	*10*	*90*	*929*	*3624.77*	*No*	*BmRoL, SS*
2	*10*	*90*	*931*	*3640.40*	*No*	*lBoR, SS*
3	*10*	*90*	*937*	*3687.47*	*No*	*lBoR, SS*
4	*10*	*90*	*931*	*3640.40*	*No*	*lBoR, SS*

For a more detailed picture of the interactions between bullets and plate the samples for metallographic analysis were prepared. Figure 3 consists of a macro picture of sample 1 cross-sections. In Figure 3 there is a cross-sectional view of the upper level of the sample, where there are a significant number of cracks, and branched adiabatic shear bands (ASB) which extend from the border between the envelope bullets (bright narrow band around the circumference of the core) and the base material towards the interior of the target. In Figure 4 is represents the scanning electron microstrucrograph of fractured surface of armored steel plate.

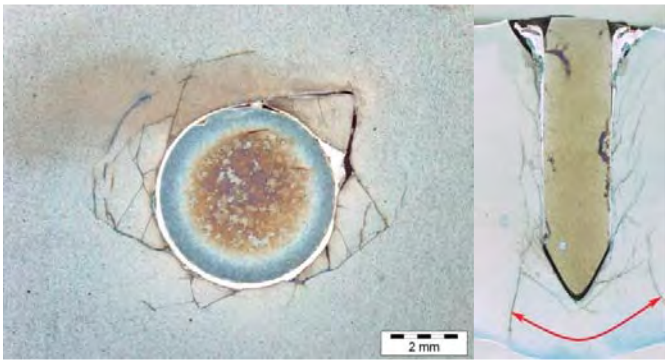


Figure 3. Macroscopic cross-sectional images of the sample 1.

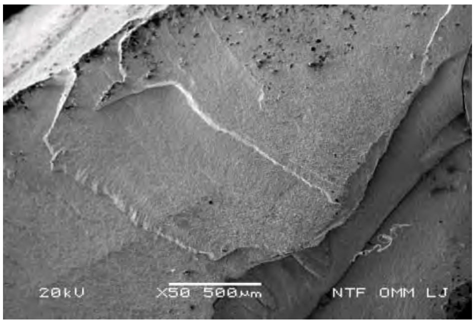


Figure 4. The fractured surface of steel plate PROTAC 500 (SEM).

4. CONCLUSIONS

The research analyzed the ballistic properties of armor plate PROTAC 500 against armored piercing bullets caliber 7.62 mm.

From the ballistic test follows that steel PROTAC 500 corresponds to the safety level of 11 standard VPAM and security level 3 standard STANAG 4569.

The most obvious and significant phenomena in penetrating of the bullets Nammo AP8 in steel target PROTAC 500 are:

1. strain hardening of steels,
2. the appearance of cracks and local failure,
3. adiabatic shear bands (ASB) and related phase transformations: austenitic, martensitic, melting, solidification, and
4. melting and alloying at the border of the bullet - the steel of the target.

5. REFERENCES

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