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INFLUENCE OF THE WELDING JOINT TYPE ON SAFETY PROPERTIES OF THE ARMOR STEEL ARMOX 500T

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Abstract: Steels of the ARMOX class belong into a group of the fine-grained, increased strength steels, which are manufactured by the quenching and low-tempering procedure, with intensive thermo-mechanical treatment at high temperatures. Combination of the heat and mechanical treatments provides for the fine grains and exceptionally good properties of these steels, while the low-tempering enables relatively high hardness and good ballistic properties. This is why the welding of these steels can negatively affect the material properties in individual zones of the welded joint, what could lead to worsening of the material's ballistic properties, as well. The model plates were welded with the specially prescribed technology; the joints were the but-joint, corner joint and the joint with the shielding plate. In this paper are presented results obtained from the ballistic tests of the plates welded by the prescribed technology; tests consisted of shooting with three types of live ammunition at different types of the welded joints.
Keywords: ARMOX 500T, safety properties, ballistic properties, welding, heat affected zone

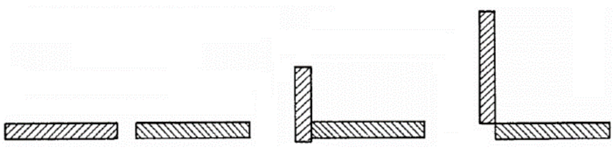
1. INTRODUCTION

The combat vehicles for the infantry were created from the tendency to increase the efficiency of the tanks and possibilities for their survival on the combat field. The problem that appeared was how to develop the armor, which would guarantee the safety to the personnel by preventing the penetration of the projectile from the anti-armor ammunition into the vehicle, while simultaneously realizing as good as possible its tactical-technical and combat-exploitation characteristics. Taking into account

these requirements, it was inevitable to develop the special group of the high-strength steels, known as the armor steels that are being improved (Arsić et al., 2014).
The Swedish company SSAB Oxelösund (www.ssab.com)has the high-strength steels in its production program, where the especially interesting is a group of armor steels, known under the commercial brand ARMOX, which are produced according to the strictly defined manufacturing procedures (Lazić et al., 2017). Their excellent properties are resulting from the manufacturing process. They possess a very low content of carbon what positively affects their weldability, while the strength is being achieved by application of the thermo-mechanical processing (TMP) (Arsić et al., 2014, Lazić et al., 2017). However, despite their exceptional properties, when the armor is being welded, the worsening of those properties occurs, locally, due to the entered heat. Such spots represent the critical places on the structure and the objective of this paper is to show how those places (various types of the welded joints) behave in the conditions when being hit by the projectiles of different types.

2. WELDING OF PLATES FOR PREPARATION OF SAMPLES

The welded joints on combat vehicles, made of this or some other steel, represent the most vulnerable places of the whole structure. The reason for that is the fact that in welding of the armor steels the filler metals must be applied, which produce the weld metal of the significantly lower strength with respect to the base metal. Thus, the appearance of the cold cracks can happen, since the armor steels are very prone to hardening. Besides that, this steel belongs into a group of the conditionally weldable steels, which implies that adequate measures must be taken during the welding. One of the most important measures is to control the heat input, what is explicitly presented by *SSAB* in specifications of this steel. The heat input is limited to 200 °C, since at the higher temperatures the excessive annealing occurs and thus the loss of all the positive properties induced by the TMP. In this paper are given recommendations that are mandatory to be followed in order to obtain as high quality welded joints as possible. The welding technologies are also proposed, all based on recommendations by the steel manufacturer, as well as the experts that have already dealt with this problem.
The experimental samples, needed for the ballistic tests of the basic zones of the welded joint, were made in the form of the butt, corner and corner-edge joints (Figure 1). The plates' dimensions of the ARMOX 500T steel were 200×200×8.6 *mm* and they were cut by the laser, Figure 2.
The MMA welding procedure was used, whose parameters are presented in Table 1 and in Figure 3 are shown the plates' appearances after the welding, for all the three cases.



a) b) c)

Fig. 1. Schematic presentation of the welded joint: a) butt, b) corner and c) corner-edge

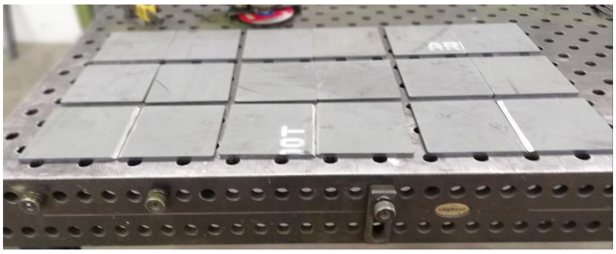
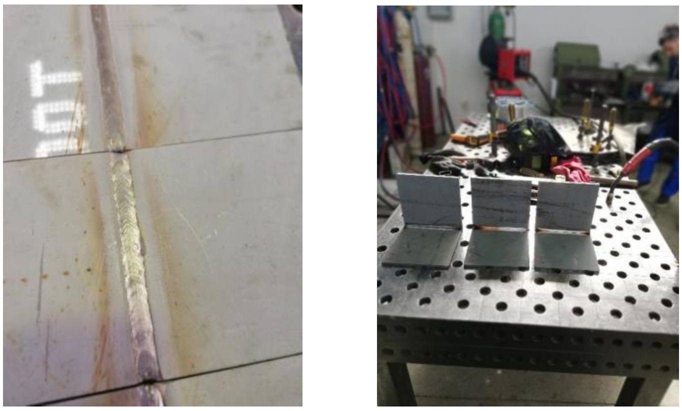


Fig. 2. Plates prepared for welding

Table 1
The plates' welding parameters

1.	Groove type	V
	Way of preparation	grinding
2.	Wire diameter	1.0 *mm*
	Type	
	Protective gas type	Ar + 2.5
3.	Preheating temperature	125-175ºC
	Interpass temperature	150-175ºC
	Measurement procedure	Thermo-chalks
	Preheating device	Gas flame
4.	Welding procedure	135 (MMA)
	Welding position	PA
	Welding technology	To the left/75º
	Power	190-210 *A*
	Arc voltage	24.5 *V*
	Current type	DC
	Polarity	+
	Wire feeding rate	6 *m/min*
	Welding rate	21 *cm/min*
	Gas flow	18 *l/min*
	Number of passes	2
	Driving energy	≈ 11000 *J/cm*

Presented welding parameters were, with small variations used for making all the types of joints.



a) b)

c)

Fig. 3. Welded plates: a) butt, b) corner and c) corner-edge joint

3. TESTING OF THE WELDED JOINT BASIC ZONES BALLISTIC RESISTANCE

Many countries have prescribed standards regarding the levels of the ballistic protection; the most used by the ARMOX manufacturers are STANAG 4569 (Table 2) prescribed by the NATO and EN 1522, prescribed by the UN, primarily due to the customers' requests, (Rakičević, 2018). The STANAG 4569 standard refers to degrees of the protection for logistic and light armored vehicles.

The standard includes threats by the ballistic projectiles, of the small and medium caliber, as well as the fragments simulating the penetrators, in order to simulate the artillery actions. It is aimed for the repeatable testing procedures for estimate of the ballistic protection of the armored vehicles' parts and for determination of the critical zones on those vehicles. The threats are divided into five levels, where the first level is related to civilian threats, while the other levels are related for various military threats.

Table 2

Standard STANAG 4569 NATO

Level	Weapon type	Caliber	Distance, *m*	Velocity , *m/s*
I	Rifle	7.62×51 - NATO Ball	30	833
		5.56×45 - NATO SS109		900
		5.56×45 - M193		937
II	Infantry rifle	7.62×39 - API BZ	30	695
III	Sniper rifle	7.62×51 - AP (WC core)	30	930
		7.62×54R - B32 API		854
IV	Machine gun	14.5×114AP - /B32	200	911
V	Automatic cannon	25 mm APDS-TM-791	500	1258

4. RESULTS OF THE BALLISTIC TEST

Though the three samples were made for each type of joints (the butt, corner and corner-edge), the ballistic tests were done at one sample from each group, only. That was done primarily due to the complexity of the experiment and since the obtained data were sufficient to estimate the ballistic resistance. The objective of the experiment was to estimate the degree of damage, namely the type of penetration of the basic zones of the welded joint (the base metal – BM, the heat affected zone – HAZ, the joining zone – JZ and the weld metal – WM) by ammunition of the 7.62× 39 type: M67 Ball, 7.62 × 51 NATO Ball (Ball M80) and armor bullet 7.62 × 54R B32 API (Dragoon's). The 7.62 × 39 M67 Ball bullet is not prescribed by the NATO standards, but by the Russian standards of the ballistic protection, which is not guaranteed by the *SSAB*.

The experiment was performed on the test field of the "Prvi Partizan DOO" company in Užice, Serbia, which has decades' long experience in producing the ammunition and the tests of this kind. The finishing, verification and homologation (approval) tests of ammunition are being conducted on this test field. The experiment was executed by the expert staff, according to adequate safety standards. The testing equipment included:

- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 39 *mm*,
- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 51 *mm*,
- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 54 *mm*,
- Stand for the test barrel
- Ammunition 7.62 x 39 M67 Ball, velocity at v_{25} = 725 *m/s*,
- Ammunition 7.62 x 51 NATO Ball (Ball M80), velocity at v_{25} = 830 *m/s*,
- Ammunition 7.62 x 54R B32 API, velocity at v25 = 790 *m/s*, Figure 4.

a) 7.62×39 M67 Ball

b) 7.62×51 NATO Ball (Ball M80)

c) 7.62×54R B32 API

Fig. 4. Appearance of the used ammunition
Source: (Rakičević, 2018).

The samples of the armor steel, prior to the commencing of the experiment, were firmly positioned in the wooden frames, to prevent the loss of energy due to motion of the plates when hit by the bullet. The distance from the exit hole of the test barrel to the sample was 10 *m*. According to the experimental plan, the welded joints were positioned in such a way that the weldment was perpendicular to the bullet motion direction, what at the corner and corner-edge joints should present the behavior of the base metal and the heat affected zone at the bullet impact at an angle.
Appearance of the butt joint after the bullet impacts is presented in Figure 5. Total of 10 projectiles were fired of the three calibers (Rakičević, 2018).

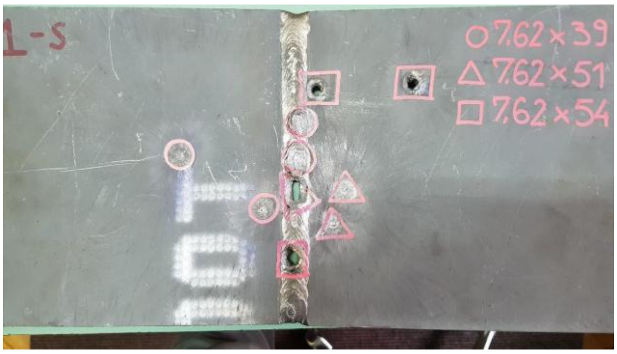


Fig. 5. Appearance of the tested sample of the butt joint from the entrance side

After the tests on the butt joint, the tests of the corner joint were performed, with the samples fixed as described earlier. The total of 9 bullets was fired of the three calibers. The entrance side of the corner joint is presented in Figure 6 (Rakičević, 2018).
The penetrated spots – perforations were of the type characteristic for an impact by the sharp pointed projectiles into the armors of the small thickness. In some cases they also appear for the flat bullets' impacts at velocities that are close to the limiting velocities of penetration. Consequences of penetrations of this type are characteristic since the shape of the hole at the exit side resembles the flower petals.

Fig. 6. Appearance of the tested sample of the corner joint from the entrance side

At the end, the corner-edge joint was tested, which on the inside has little platelets made of the same material. The idea is that they should act as a protection in the case that the weld metal and its vicinity have been penetrated. Total of 8 bullets were fired of the three different calibers, into the characteristic zones of the welded joint. Results are presented in Figure 7, (Rakičević, 2018).

a)

b)

Fig. 7. Appearance of the corner-edge joint with protection: a) at the entrance side, b) at the exit side

5. CONCLUSIONS

The welding technology for the ARMOX 500T steel sample plates is given in this paper. The ballistic tests to check the penetration resistance of three types of welded joints' zones were performed.

Obtained results led to the following conclusions:

- The base metal, the heat affected zone and the weld metal are all bullet proof for the caliber 7.62×39.
- Test by the 7.62×51 caliber bullets showed that only the base metal is resistant to penetration.
- For the armor ammunition of the 7.62×54R caliber there are no obstacles, i.e. all the zones of the welded joint are threaten, even the protective plates in the corner-edge joint case.

Based on these results, one must recommend that vehicles constructions made of this steel must be so designed that all the zones of the welded joint should be well protected against penetration by any caliber projectiles. The weld metal should be hidden whenever possible, while the butt joints should be strictly avoided in any case. If these recommendations were not followed to the letter, the safety of the personnel in the vehicle, against the projectile penetrating the armor, cannot be guaranteed.

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