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CHANGES IN MICROSTRUCTURE AND MICROHARDNESS AFTER APPLICATION OF UNCONVENTIONAL CUTTING TECHNOLOGIES ON ARMOURED STEELS

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Abstract

The paper describes changes appeared in microstructure and microhardness of selected Armox steels after their cutting by unconventional technologies as are plasma, laser and water jet cutting. Three variants of ARMOX steels (440, 500 and 600) were cut with using of stated methods and then tested by Vickers microhardness test and examined their micro structure. Finally, the results are compared and evaluated to formulate conclusions.

Key words: *armour steels, ARMOX, plasma cutting, laser cutting, water jet cutting, microhardness, optical microscopy, metallographic examination*

1. INTRODUCTION

The most known and most widely used steel armory plates are ARMOX steels by Swedish company SSAB Oxelosund. Armox steels have high strength, hardness and good toughness. The steels acquire these specific properties by application of thermo-mechanical treatment (TMT) and therefore the producer recommends do not exceed the temperature circa 200°C during their secondary processing. In a case of violation of this recommendation TMT effect will be eliminated by un-controlled tempering and degradations of mechanical properties level occur.

Describing effect of armoured steels heat affection also occur at their cutting by un-conventional technologies as are plasma, laser and water jet cutting.

2. CUTTING TECHNOLOGIES USED FOR EXPERIMENTS AND THEIR PARAMETERS

The plasma cutting process is based on the superheated gas plasma jet created via a controlled electrical arc between the work head and the part to be processed. Inside the plasma arc temperatures of 30,000 °C can arise, that realize in connection with the high kinetic energy of the plasma beam and depending on the material thickness cutting speeds reaches 6000 m.s-1. These conditions are adequate to easily cut through a variety of metals, with part accuracies better than 0.3 mm attainable with the high density torch designs. Cutting material must be electrically conductive. The principle of the plasma cutting is presented in fig. 1a. [1, 2]

Laser cutting is a technology that uses a focused beam of high energy laser light to cut material by selectively burning, vaporizing and/or melting a highly localized area, while an assist gas is used to remove the molten material from the resulting cut. It is one of the fastest and most accurate methods for cutting a variety of metals and non-metals. Both gaseous CO2 and solid-state Nd:YAG lasers can be used for cutting. In each case, several subvariants can be identified, such as fast axial flow, slow axial flow, transverse flow, and slab lasers for CO2 lasers. The type of gas flow can affect the cutting performance. For example, transverse flow lasers circulate the gas mix at a lower velocity,

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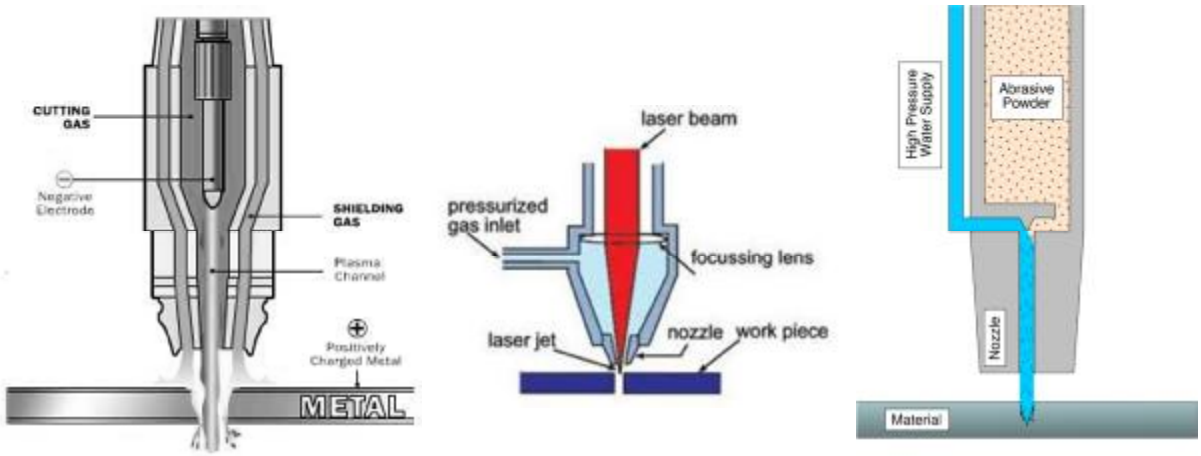
requiring a simpler blower, while slab or diffusion cooled resonators have a static gas field that requires no pressurization or glassware for protection. The principle of the plasma cutting is presented in fig.1b [3, 4].

Water Jet cutting uses transformation of high pressure water jet to high speed water jet (pressure of water: 380 MPa) as a force for material cutting. The addition of abrading agent increases cutting efficiency what widely enlarges a variety of materials that can be cut with using of this technology. The principle of the water jet cutting is presented in fig.1c [5, 6].

Technology of water jet cutting does not require high temperatures effect during its application and therefore does not affect cutting material. Due to this fact, the technology is used as a comparative standard to measure changes caused by laser and plasma cutting.



a) b) c)

Fig. 1 Principle of cutting technologies: a – plasma, b – laser, c - water jet [7, 8]

There are processes parameters used for cutting by plasma in the table 1, by laser in the table 2 and by water jet in the table 3. Parameters settings depend on cutting material thickness at every used technology.

Table. 1 Parameters of the plasma cutting process

Thickness [mm]	Voltage [V]	Current [A]	Cutting Speed [m/min]	Plasma gas: O_2
4	120	30	0.9	
5	125	45	0.85	Supplementary gas: O_2 / N_2
8	130	50	0.55	

Table 2 Parameters of the laser cutting process

Thickness [mm]	Laser Output [W]	Frequency [Hz]	Cutting Speed [m/min]
4	3200	10000	2,2
5	3200	10000	3,1
8	1900	10000	2,9

Table 3 Parameters of the water jet cutting process

Thickness [mm]	Water pressure [MPa]	Abrasive flow rate	Cutting Speed [mm/min]
4	350	0,25	15,3
5	350	0,25	12,7
8	350	0,25	10,16

3. ARMOX STEELS USED FOR EXPERIMENTS

Three types of ARMOX steel are used for experiment – ARMOX 440, 500, 600. Their basic characteristics are shown in the table 4. Steels are delivered in the metal plate shape obviously. The plates of selected steel of three different thickness (4, 5 and 8 mm) was cut with using plasma, laser and water jet cutting technology in order to made the experimental samples. The shape of experimental sample is designed according to STN EN ISO 6892 – 1 standard.

Table 4 Chemical composition and mechanical properties of examined steels [9]

ARMOX 440	Chemical composition [wt. %]	C	Si	Mn	P	S	Cr	Ni	Mo	B
		0.2	0.1-0.5	1.2	0.010	0.010	1.0	2.5	0.7	0.005
	Mechanical properties	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Toughness KCU [J]	Hardness HBW	Elongation A5 [%]				
		1250 - 1550	Min. 1100	35	420 - 480	10				
ARMOX 500	Chemical composition [wt. %]	C	Si	Mn	P	S	Cr	Ni	Mo	B
		0.32	0.1-0.4	1.2	0.015	0.010	1.0	1.8	0.7	0.005
	Mechanical properties	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Toughness KCU [J]	Hardness HBW	Elongation A5 [%]				
		1450 - 1750	Min. 1250	25	480 - 540	8				
ARMOX 600	Chemical composition [wt. %]	C	Si	Mn	P	S	Cr	Ni	Mo	B
		0.47	0.1-0.7	1.0	0.010	0.005	1.5	3.0	0.7	0.005
	Mechanical properties	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Toughness KCU [J]	Hardness HBW	Elongation A5 [%]				
		2000	1500	12	570 - 640	7				

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Cut experimental specimens were divided to smaller segments, subsequently moulded to bakelite mass. Thereafter conventional metallographic preparation was performed with the samples – grinding, polishing and surface etching by Nital.

The next step is evaluation of microhardness of surface layers with using Vickers hardness test according to STN EN ISO 6507-1 standard. The microhardness test is used in order to evaluate the deep of area affected by heat during cutting. The test was realized on Leco LM700 device with using load force 0,5 kp (4,9 N).

4. CHANGES IN MICROSTRUCTURE OF CUTTING ARMOX STEELS

Armox 440 comprises of non-heterogeneous sorbitic structure (fig. 2a). Armox 500 and 600 comprise of tempered martensite. From surface begins heat affected area whole comprised of martensite. There is micro layer of shapeless martensite on the surface.

There is visually observable affected area in cases of plasma and laser cutting (fig. 2a, 2b) which consist of three phases [5]:

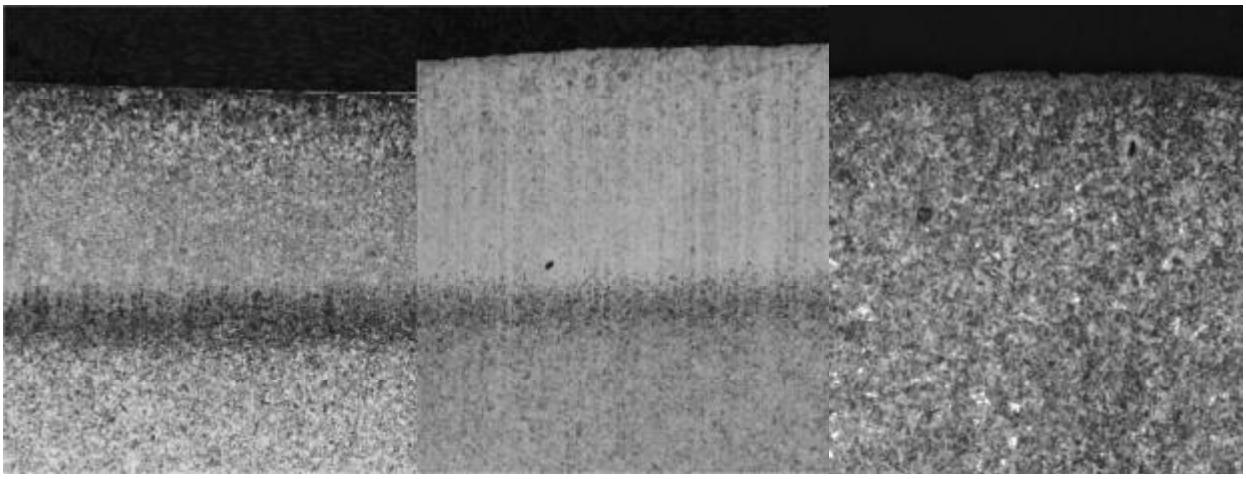
- Area of heating up over temperature A_3 (range of temperatures between A_{c3} + 150 ^{0}C and solidus). These conditions cause coarsening of austenitic grain as consequence of heating to high temperatures of steels which are predisposed to growth of austenitic grain. The result is coarse-grained feritic-perlitic structure. This little layer is on the surface of cutting area of sample cutting by plasma and laser.
- Area of heating up between temperatures from A_{c1} to A_{c3} (area of uncompleted transformation). These conditions lead to partial austenitization because the period of the heating is too short. Appropriate conditions of cooling cause creation of wispy-shaped perlite. Martensite transformation can take place with extreme conditions of cooling. This structure is placed tightly under surfaced layer.
- Area of heating up under temperature A_{c1} (area without recrystallization). There is a not radical microstructure change in this area. Processes occurred in range of these temperatures is known from steel tempering as disintegrating of residual austenite or cementite creation.

5. EXPERIMENTAL RESULTS OF MICROHARDNESS HV0.5

Experimental results of HV0.5 microhardness values are in the table 5. More effective interpretation of experimental result provides graphs on figure 3.

Microhardness HV0.5 is nearly constant in a case of samples cutting by water jet. In cases of samples cutting by plasma and laser occur the decrease of microhardness in layers near to the surface. The decrease is more intensive at samples with bigger thickness (figure 3b, 3d, 3f). There is micro layer with hardness greater than hardness of basic material.

The decrease of microhardness is more noticeable at samples cut by plasma than by laser.



a) b) c)

Fig. 2 Selected microstructure of ARMOX 440 after plasma (a), laser (b) and water jet cutting (c), magnification 50x

Table 5 Experimental results of microhardness HV0,5

Material	**Thickness** [mm]	Technology	Distance form surface [mm]											
			0,20	0,40	0,60	0,80	1,00	1,50	2,00	2,50	5,00	5,50	6,00	6,50
Armox 440	4	Laser	338	409	427	430	419	438	409	425	414	435	425	433
		Plasma	458	409	337	375	390	414	427	427	425	425	430	430
		Water Jet	461	473	492	489	486	464	492	479	489	492	486	499
	8	Laser	386	435	441	314	329	377	393	407	438	433	438	433
		Plasma	375	379	412	377	315	350	368	402	409	404	427	422
		Water Jet	364	435	438	427	441	438	430	433	427	444	433	433
Armox 500	4	Laser	516	397	452	492	489	499	492	489	486	489	486	486
		Plasma	541	381	358	397	414	446	476	482	482	486	489	492
		Water Jet	433	438	427	444	435	433	427	433	441	427	444	441
	8	Laser	561	553	577	298	340	388	430	458	489	512	492	502
		Plasma	476	519	526	455	322	383	417	444	502	509	516	519
		Water Jet	526	512	512	512	519	527	512	512	492	516	516	516
Armox 600	4	Laser	675	458	509	553	573	621	621	630	635	635	635	625
		Plasma	665	660	381	420	452	512	541	577	630	635	635	645
		Water Jet	670	654	660	640	675	665	675	670	625	612	630	635
	8	Laser	755	755	794	660	379	425	470	516	640	645	645	645
		Plasma	635	670	675	691	366	420	467	479	569	573	585	590
		Water Jet	649	612	635	616	635	635	625	635	621	621	645	621

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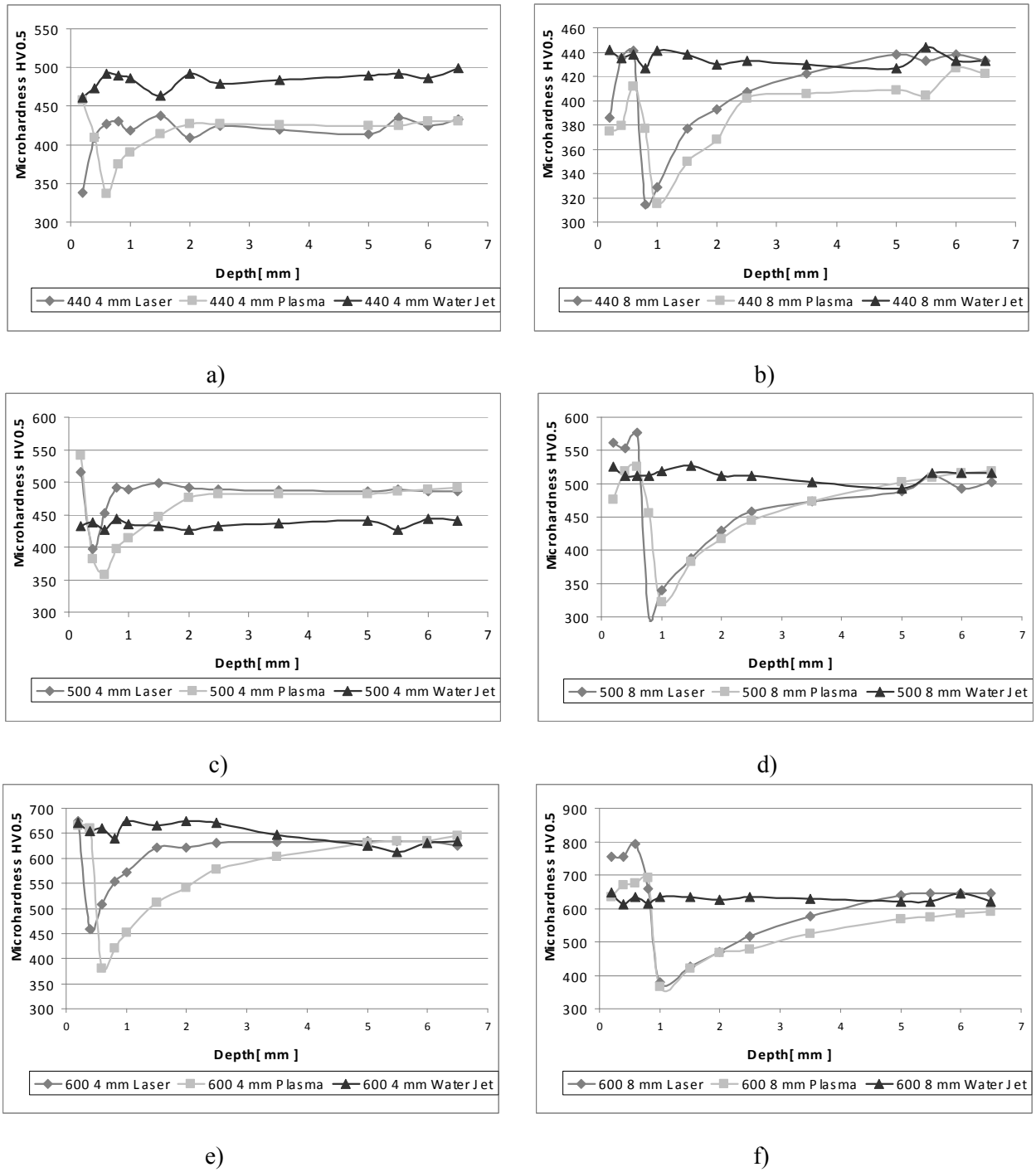

Fig. 3 Experimental results of microhardness HV0.5: a,b - Armox 440 thickness 4 and 8 mm; c,d – Armox 500 thickness 4 and 8 mm; e,f – Armox 600 thickness 4 and 8 mm

CONCLUSION

Water jet cutting do not require the heat to cut the materials, therefore samples of this kind do not show changes of microstructure or microhardness in surface layers. On the other hand, affection of samples cut by plasma or laser was confirmed from microstructure study as well as microhardness study. The affection is more significant with increasing of cutting material thickness. The plasma cutting affected mechanical properties more intensively than laser cutting.

Described influence may affect final quality of cutting product at smaller intersections mainly. Due to these reasons is advisable to cut Armox materials by using of the water jet where no treat of the heat affection is. Acceptance of this recommendation supports the increase of reliability and safety of products.

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