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DEGRADATION OF ARMOURED STEELS STRENGTH CHARACTERISTICS AFTER THEIR CUTTING BY WATER, PLASMA AND LASER BEAM

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Abstract

The paper deals with changes in mechanical properties of selected ARMOX steels after their cutting with using of non-conventional cutting methods as are plasma, laser and water jet cutting. Three variants of ARMOX steels (440, 500 and 600) were tested by tensile strength test in order to acquire yield strength, tensile strength and elongation. Finally, the results are compared and evaluated to formulate conclusions.

Key words: *armour steels, ARMOX, plasma cutting, laser cutting, water jet cutting, mechanical properties, tensile strength, yield strength*

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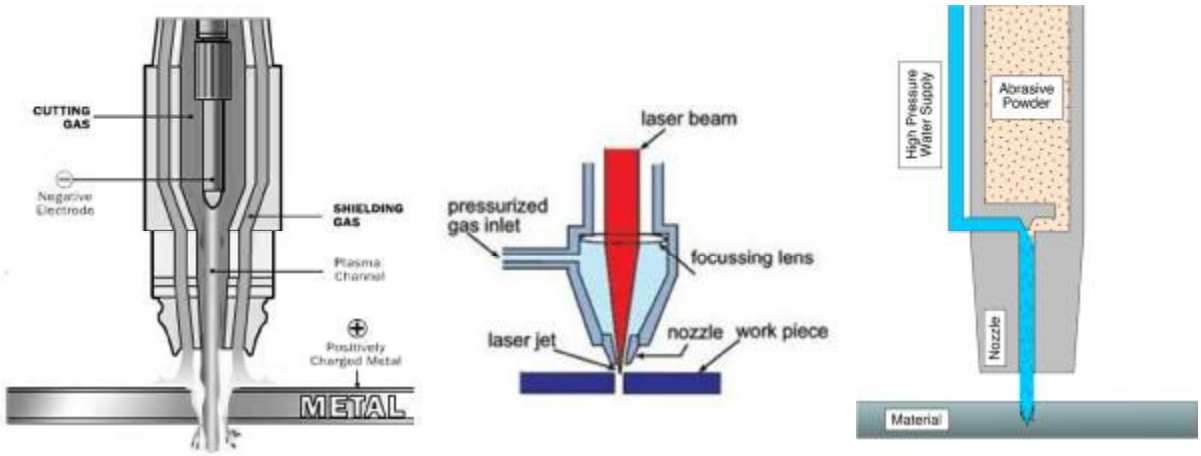
requiring a simpler blower, while slab or diffusion cooled resonators have a static gas field that requires no pressurization or glassware for protection. The principle of the plasma cutting is presented in fig.1b [3, 4].

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

4. REALIZATION OF EXPERIMENT AND EXPERIMENTAL RESULTS

All experimental samples were examined by tensile strength test (STN EN ISO 10002-1). Testing device Instron 5500R with automatic evaluation of mechanical characteristics (Tensile and Yield strength) is used. Elongation is evaluated manually.

Results of tensile strength test are presented in Table 5, Table 6 and Table 7.

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Table 5 Experimental results of tensile strength R_m [MPa]

Type of steel	Technology	Thickness		
		4 mm	5 mm	8 mm
440	Laser	1360,06	1383,54	1255,43
	Plasma	1290,22	1340,51	1151,20
	Water Jet	1358,35	1413,10	1372,92
500	Laser	1579,15	1598,99	1404,65
	Plasma	1539,89	1579,61	1288,00
	Water Jet	1614,32	1638,05	1620,13
600	Laser	1956,49	1811,13	1672,45
	Plasma	1895,28	1710,13	1489,44
	Water Jet	2094,37	1967,90	2020,81

Table 6 Experimental results of Yield strength $R_{p0,2}$ [MPa]

Type of steel	Technology	Thickness		
		4 mm	5 mm	8 mm
440	Laser	1227,64	1255,19	1134,35
	Plasma	1163,19	1278,25	1054,80
	Water Jet	1226,76	1310,90	1277,25
500	Laser	1392,68	1391,31	1236,19
	Plasma	1359,60	1389,70	1152,33
	Water Jet	1422,08	1414,98	1409,37
600	Laser	1556,29	1477,66	1342,35
	Plasma	1529,79	1412,10	1251,12
	Water Jet	1562,11	1605,42	1630,44

Table 7 Experimental results of Contraction A [%]

Type of steel	Technology	Thickness		
		4 mm	5 mm	8 mm
440	Laser	10,00	13,75	14,69
	Plasma	14,38	11,88	12,50
	Water Jet	13,13	11,25	14,06
500	Laser	9,69	12,19	12,19
	Plasma	9,38	10,31	12,50
	Water Jet	14,38	10,94	13,44
600	Laser	4,38	4,69	5,31
	Plasma	8,75	9,06	8,44
	Water Jet	13,44	10,63	10,94

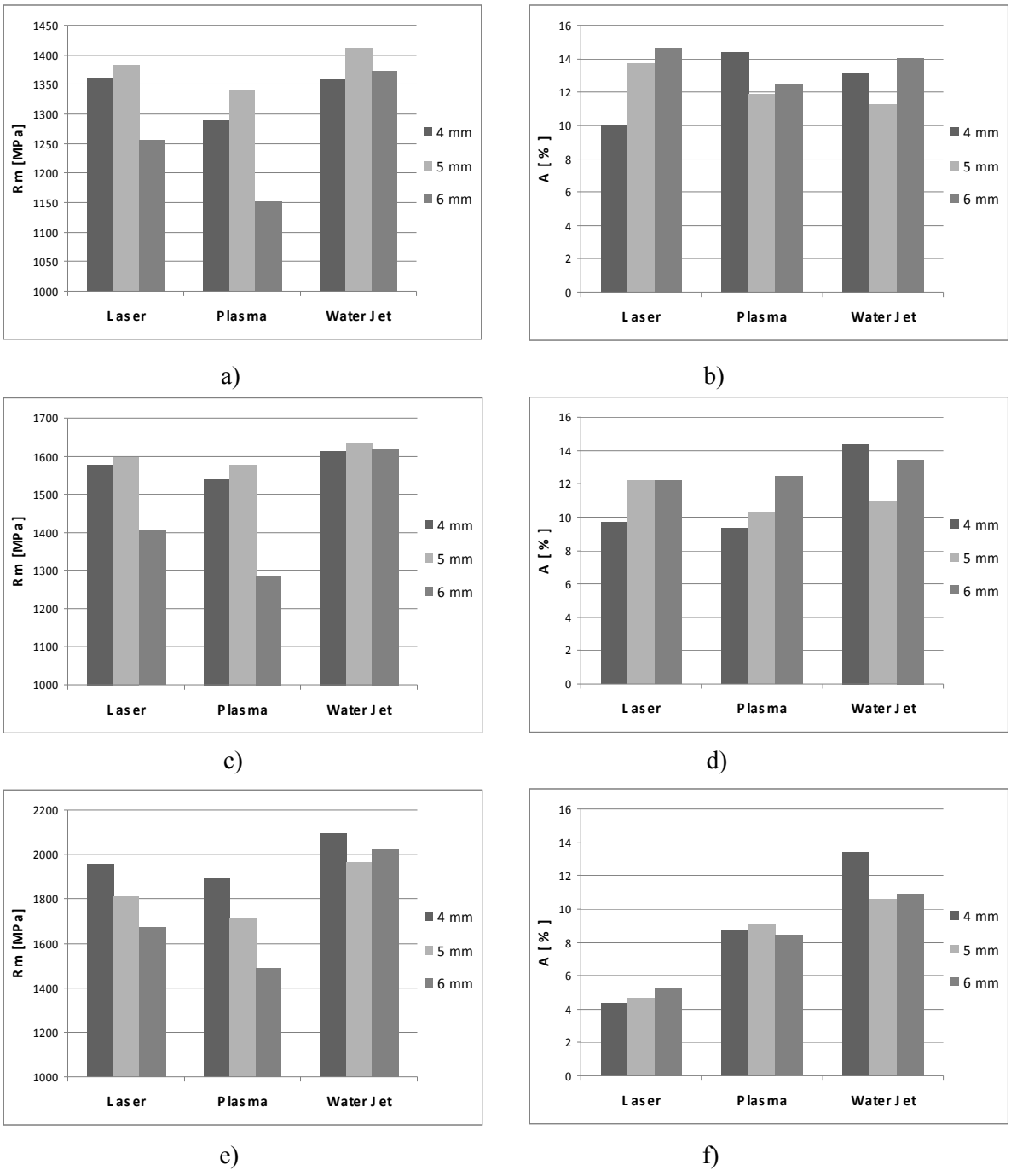

Fig. 2 Results of tensile strength and contraction

a, b - Armox 440; c, d – Armox 500; e, f – Armox 600

More effective interpretation of experimental result provides bar graphs on figure 2 where results of tensile strength Rm and contraction A are shown for all tested steels.

The graphs indicated the decrease of mechanical properties level for all materials cut by plasma and laser against materials cut by water jet. In a case of Armox 450 and 500 with thickness 4 and 8 mm is the decrease about 2% for laser cut samples and about 5 % for plasma cut samples. In a case of thickness 8 mm of these steels is the decrease about 15%.

Armox 600 has more noticeable decrease of mechanical properties. Samples with thickness 4 and 5 mm have decrease about 9-13% and samples with thickness 8 mm have decrease up-to 26%.

The changes of Rp0,2 values traces the changes of tensile strength values what results form method for evaluating of the conventional yield strength Rp0,2.

CONCLUSIONS

Experimental results clearly provide the degradation of mechanical properties on samples affected by heat during their cutting by plasma and laser. 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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