CHANGES IN MECHANICAL PROPERTIES OF SELECTED UHSS STEELS AFTER THEIR CUTTING BY LASER AND PLASMA

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Abstract

The paper deals with armoured martensitic ultra high strength steels of Armox type and changes of their mechanical properties after the application thermal cutting processes as are plasma or laser cutting. The paper consists of theoretical part with explanation of the principle of plasma and laser cutting as well as experimental part describing experiment and results of the influence of cutting heat on tensile strength and yield strength of studied steels

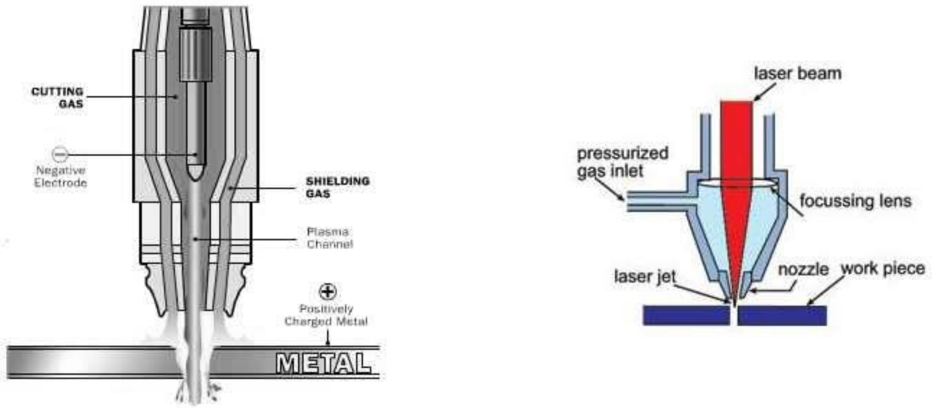
Keywords: armour steels, martensitic steel, ultra high strength steel, ARMOX, plasma cutting, laser cutting, mechanical properties, tensile strength

1 Introduction

Armox steels are good known and probably most widely used steel armoury plates in Europe. The steels are produced by Swedish company SSAB Oxelosund and their security and protection applications require having high strength, hardness and good toughness. The steels acquire these specific properties due to strict requirements on chemical purity (H, N, P or S content) and specific production process, finalized by very rapid quenching and tempering. The chemical purity in combination with very rapid cooling brings good toughness of material despite of tempering at very low temperatures. Due to these production process specifics, the producer recommends do not exceed the temperature circa 200°C during the secondary processing of Armox steels as are plasma or laser cutting. In a case of breach of this recommendation degradation of mechanical properties level occurs.

2 Used cutting technologies 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. and is described in more details in [1, 2].



a) b)

Fig.1 Principle of cutting technologies [3, 4]
a – plasma, b – laser

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 CO_2 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, 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 shown in fig. 1b and is described in more details in [5, 6].

The parameters used for experimental sample preparation is shown in table 1 and table 2. Samples of three different thicknesses (4, 5 and 8 mm) were cut and the parameters are changing in relation to material thickness.

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	0.90	
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

3 Characteristics of materials used for experiment

Three types of ARMOX steel were used for experiment – ARMOX 440, 500, 600. Their basic characteristics and chemical composition are described in the table 3. Steels are delivered in the metal plate shape with various thicknesses. Three different thickness (4, 5 and 8 mm) of selected steels 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. Cutting by water jet is not based on heat transfer, therefore does not affect cutting material and the samples cut by this technology were made in order to compare and evaluate the changes caused by plasma and laser cutting.

Table 3 Chemical composition and mechanical properties of examined steels [7]

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 6892-1). Testing device Instron 5500R with automatic evaluation of mechanical characteristics (Tensile and Yield strength) is used for testing. Results of tensile strength and yield point values evaluated by the test are presented in Table 4, and Table 5.

Table 4 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

More effective interpretation of experimental result provides bar graphs depicted in figures 2, 3 and 4 where the results of tensile strength R_m are shown for all tested steels and all their thicknesses variants.

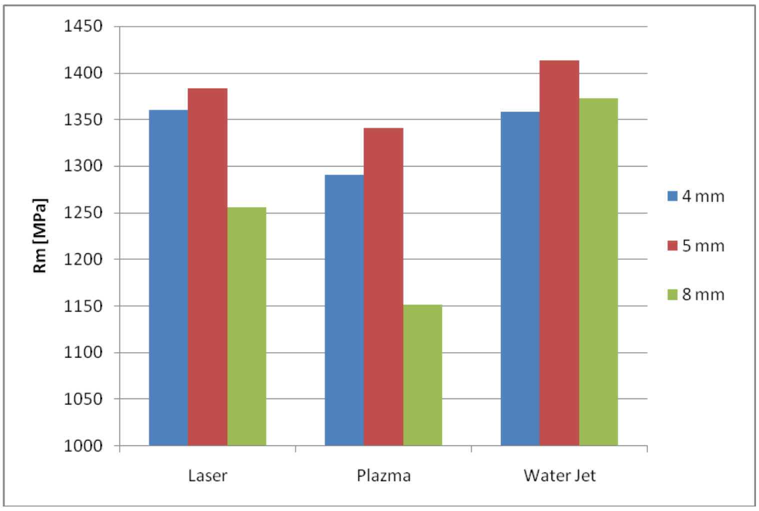


Figure 2 ARMOX 440 – results of tensile strenght R_m

The graphs indicated the decrease of tensile strength 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% where the reason of maximal decrease is in cutting parameter change due to almost two times bigger thickness than previous (4 a 5 mm) samples.

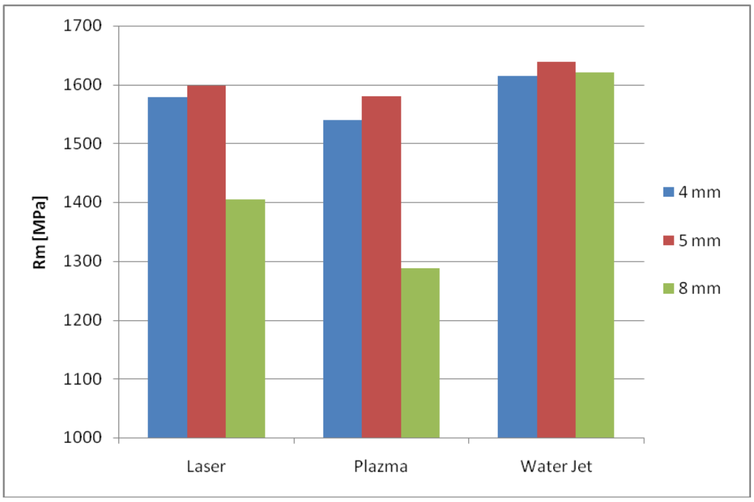


Figure 3 ARMOX 500 – results of tensile strenght R_m

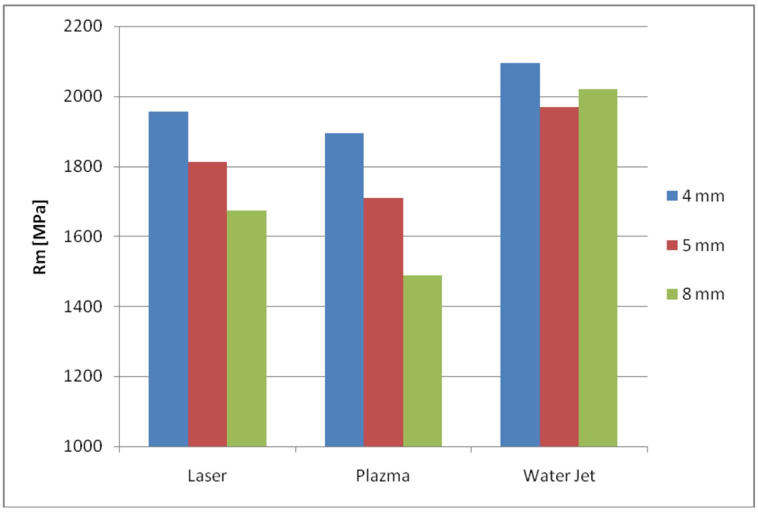


Figure 4 ARMOX 600 – results of tensile strenght R_m

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 from 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 made of Armox steels as are civil and army car protection, building protection or mobile army containers construction.

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