U.P.B. Sci. Bull., Series D, Vol. 78, Iss. 1, 2016 ISSN 1454-2358

MICROSTRUCTURE CHANGES IN CUT FACE OBTAINED BY PLASMA AND LASER CUTTING OF SELECTED HIGH STRENGTH STEELS

Igor BARÉNYI[1]

The paper deals with armored martensitic ultra-high strength steels of Armox type and changes of their mechanical properties after the application of 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 the microstructure and consequently on basic material properties as are tensile strength and yield strength of studied steels.

Keywords: ultra-high strength, armored steel, plasma cutting, laser cutting, heat affected zone, martensitic structure

1. Introduction

The Armox steels are group of armored middle alloyed steels with martensitic structure, heat treated on very high strength and hardness as well as good toughness. These properties result from specific production process of the steel where most important steps are minimizing of H, N and O content by the vacuum furnace and very rapid cooling during quenching. If the final steel is exposed to the temperature above 200°C some phase transformations take place in the microstructure and the degradation of mechanical properties needed for the steel usage occurs. These conditions are typical for secondary processing of the steel as are cutting or welding.

There are published several studies about microstructure changes of carbon or low alloyed steels after plasma or laser cutting in scientific literature [1, 2]

Heat affected zone (HAZ) after the cutting by these processes could be classified to three different areas according that knowledge [3, 4, 5]:

1. *Surface area with full recrystallization* to the austenite and back to pearlite, bainite or martensite (temperature range from A3 to the solidus). The depth of this area is relatively low (about 50 μm) and depends on chemical composition of steel and parameters of used cutting process as are cutting speed or heat input. If martensitic transformation occurs in the area it may leads to internal stresses generation and consequently to the crack creation.

2. *Area with partial recrystallization* (temperature range from A1 to A3) where the heating up period is very short and therefore the austenitization is just

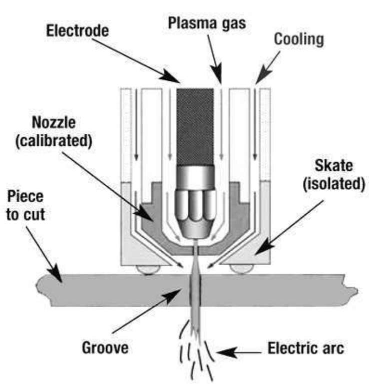
[1] Alexander Dubcek University of Trencin, Slovakia, email: igor.barenyi@gmail.com

partial. There is new phase created as a result of partial austenitization beside origin microstructure phases. The amount of new phase decreases in relation to distance from surface. In contrast to full recrystallization area in surface layer, the heating up temperature of this area is not so high and followed cooling is not so rapid. Therefore, the new created phases are more in steady state (bainitic or pearlitic type). The depth of this area is about 500 µm.

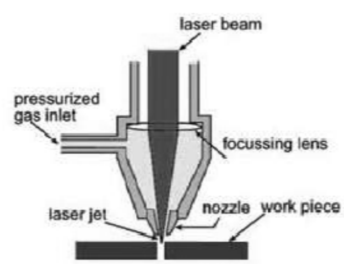
3. *Transition area between HAZ and core material* (heating up below A1) where any essential phase transformation is not present. Processes known from basics of tempering process take place in steels with martensitic structure. Morphology of martensite is changed from tetragonal to cubic tempered martensite, transformation of the residual austenite occurs and cementite and other carbides are created. This area could reach the depth of several millimeters from surface.

2.Principle and parameters of used cutting technologies

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 [6, 7].



a)



b)

Fig. 1 Principle of cutting technologies [6, 7]

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, 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 [7, 8].

Main parameters for laser and plasma cutting used for experimental sample preparation are shown in table 1 and table 2. The parameters are chosen in relation to material thickness (8 mm).

Table 1

Parameters of used laser cutting process

Thickness [mm]	Laser Output [W]	Frequency [Hz]	Cutting Speed [$m.min^{-1}$]
8	1900	10000	2,9

Table 2

Parameters of used plasma cutting process

Thickness [mm]	Voltage [V]	Current [A]	Cutting Speed [$m.min^{-1}$]	Plasma gas: O_2
8	130	50	0.55	Supplementary gas: O_2 / N_2

3. Materials and methods used for experiments

Three types of ARMOX steel are used for experiment – ARMOX 440, 500 and 600. Their basic characteristics and chemical composition are described in the table 3.

Steels are delivered in the metal plate shape with various thicknesses. The metal plates with thickness 8 mm of every used Armox steels were cut with using plasma, laser and water jet cutting technology in order to prepare the experimental samples. Standard metallographic preparation procedure was used to prepare the experimental samples for optical metallography. The procedure consists of grinding, polishing and etching in Nital (3% solution of HNO_3 in ethanol).

Cutting by water jet is not based on heat transfer, therefore the process 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 [9]

Steel										
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. Microstructure changes in HAZ after laser cutting

Visible HAZ were observed on laser cut faces by all examined steels with the depths in range 400÷600 μm (fig. 1). Most significant HAZ with higher depth were observed with Armox 600 steel. The zone has two characteristic areas which are the surface layer and boundary line between HAZ and basic material.

The surface layer consists of marked martensitic needles fading gradually to the structure of bainitic type (fig. 3). This structure is a result of very rapid cooling after heat up to the austenitization temperatures where the cooling speed decreases in relation to the distance from surface.

The boundary line between HAZ and basic material is the area of partial recrystallization (fig. 4). Islands of origin martensitic structure bordered by newly segregated ferrite and carbide phases were observed in that area. In some observed cases the microstructure of the island became bainitic.

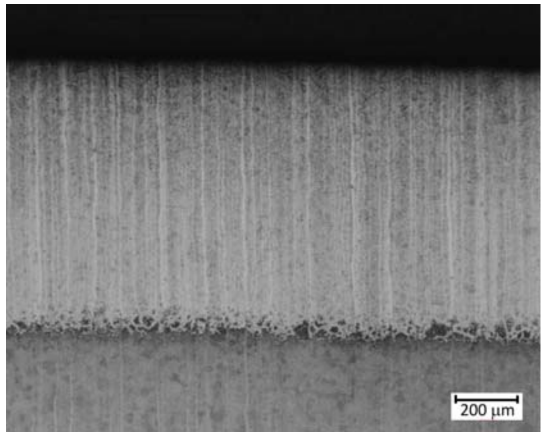


Fig. 2 HAZ after laser cutting – Armox 600, mg. 50x

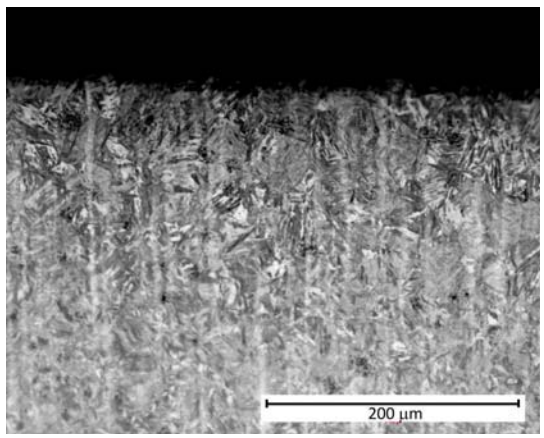


Fig. 3 Surface layer of HAZ after laser cutting – Armox 600, mg. 200x

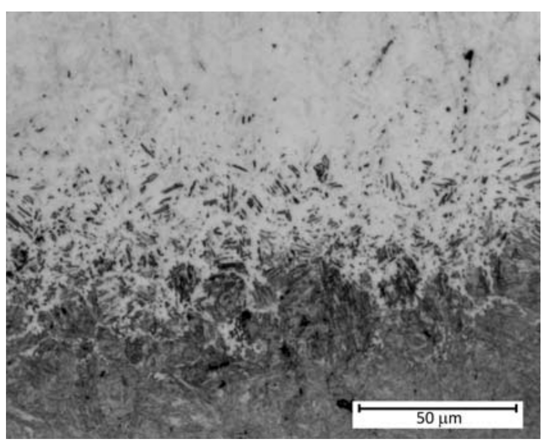


Fig. 4 Boundary line between HAZ and basic material after laser cutting – Armox 600, mg. 500x

5 Microstructure changes in HAZ after plasma cutting

Visible HAZ was also observed on plasma cut faces by all examined steels but with the bigger depths in range 800÷900 μm in comparison to laser cutting (fig. 5). Armox 600 is again presented as a case with biggest depth of HAZ. The zone has also two readable characteristic areas which are the surface layer and boundary line between HAZ and basic material.

Plasma cutting uses O_2 an N_2 as the cutting or supplementary gases by contrast to laser cutting. These gases have high affinity to carbon and react with present phases what leads to partial saturation of the cut surface. Therefore the observed HAZ are appeared as darker in comparison to laser cutting. On the surface of all HAZ by plasma cutting faces (fig. 6) were observed coherent non-constant oxide white layers unseen on samples cut by laser. Under the white layer were found martensitic needles which became finer with increasing of the distance from surface. The needles close to surface are bigger in comparison to the laser cutting face what is the consequence of higher temperature appeared during cutting.

Partial recrystallization area between HAZ and basic material is also characterized by island of origin martensitic structure bordered by newly segregated ferrite and carbide phase (fig. 7). This area is appeared as continuous wide dark ribbon at lower magnification what mean wider partial recrystallization are in comparison to laser cutting.

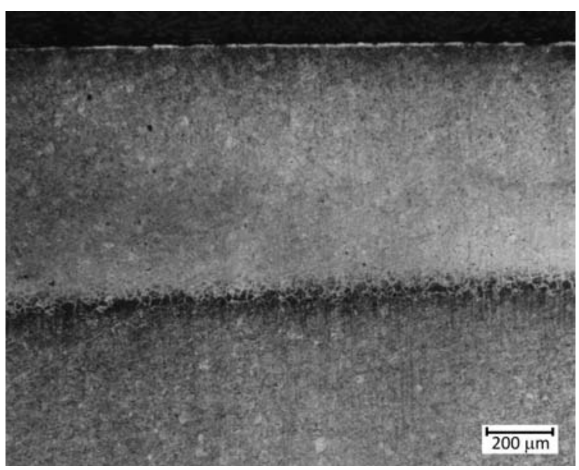


Fig. 5 HAZ after plasma cutting – Armox 600, mg. 50x

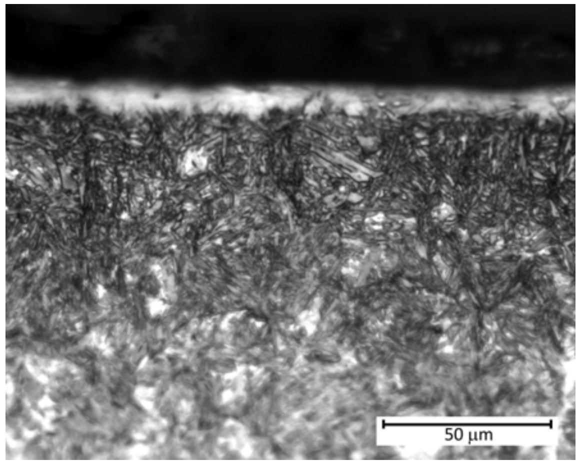


Fig. 6 Surface layer of HAZ after plasma cutting – Armox 600, mg. 500x

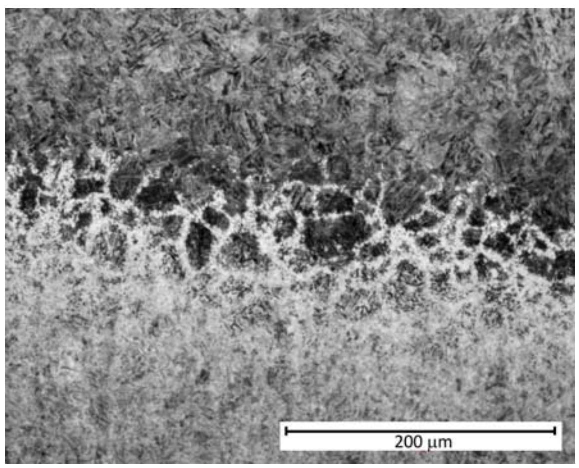


Fig. 7 Boundary line between HAZ and basic material after plasma cutting – Armox 600, mg. 200x

6 Conclusions

Conclusions found by microstructure observation of cut faces after laser and plasma cutting of Armox 440, 500 and 600 steels could be summarize to the following points:

- Surface layer consisted of martensitic needles are present at both cutting processes. Moreover, white coherent oxide layer is visible on plasma cutting faces.
- Partial saturation by gases (N2, O2) was observed at plasma cutting faces.

- Area with partial recrystallization is found in both laser and plasma cutting. The Area is wider at plasma cutting.
- Depth of visible HAZ by plasma cutting faces is significantly bigger in comparison to the laser cutting.
- In relation to selected material type, smallest depth of HAZ was found on Armox 440 but biggest depth was found on Armox 600.

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 cutting process where no treat of the heat affection is present. 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.

REFERENCES

[1] *J.D. Harris*: Plasma Arc Cutting of Bridge Steels - Report 384. Washington, D.C. USA: Transportation Research Board, National Academy Press, 1997.

[2] *A. Belhadj, P. Baudouin P., Y. Houbaert*: Simulation of the HAZ and magnetic properties of laser cut non-oriented electrical steels, Journal of Magnetism and Magnetic Materials, Volume 248, Issue 1, July 2002, Pages 34-44, ISSN 0304-8853, http://dx.doi.org/10.1016/S0304-8853(02)00064-1. (http://www.sciencedirect.com/science/article/pii/S0304885302000641)

[3] *O. Híreš, M. Hatala, S. Hloch*: Cutting of metal materials by circular saw, water jet and plasma beam (in Slovak). Ostrava, 2007, ISBN 978-80-8073-769-6.

[4] *M. Hatala*: The Principle of Plasma Cutting Technology and Six Fold plasma cutting. *, In: Fascicle Mechanics*, Tribology, Machine Manufacturing Technology, 2005, vol. XIX,. ISSN 1224-3264

[5] *O. Híreš, M. Hatala*: Cutting of material by laser beam (in Slovak). TnU AD v Trenčíne, 2009, ISBN 978-80-8075-365-8.

[6] Plasma cutting process. [2015-01-24]. http://www.farmweld.co.uk/plasma-cutting

[7] Avion Metals, Inc.: Values added services. [2010-04-10]. http://www.aviationmetals.net/valueadded.php

[8] C. Biris, C., Daec, M. Tera: *Considerations On The Choice Of The Cutting Method And Technique Employed For The Cutting Of Parts Made Of Titanium Alloys*. In: International scientific conference METAL 2008, Ostrava, 2008.

[9] SSAB, Inc.: ARMOX 440, 500, 600. Datasheets. [on line cited 2010-04-10]. Available from http://www.ssab.com/products-and-solutions/armox/