CHANGES OF PHYSICAL-MECHANICAL CHARACTERISTICS AND STRUCTURE OF STEEL CUT BY PLASMA

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Abstract. The research is carried out in how to change the corrosion resistance on surfaces (created by plasma arc cutting) of low-alloy and non-alloy structural steel as well as non-alloy tool steel C80U. The effect of corrosion resistance on steel surfaces of alloyed components Cr, Mn, Si is examined. The processes in coating that develops on the steel surface after treatment by plasma arc cause the increase of corrosion resistance in all researched samples.

Key words: plasma, cutting, hardness, steel, corrosion, corrosion resistance.

Introduction

Operation with low-temperature arc plasma (1….5)10^4 K technology for cutting from steel flat blanks is connected with serious changes of material characteristics in the cutting area. The changes of material hardness, structure in thermal influence area as well possibilities to reduce hardness of blanks by heating technology for most common available structural steels are described in [1-4]. The urgent problem is to provide the corrosion resistance of steel blanks. One of the possibilities to increase the corrosion resistance is to treat them by plasma in environment of active gases. In high temperature of the cutting area the metal melts, and the components of it interact with active substances from environment and plasma gases. As a result of this interaction the protective deposit develops, it consists of different steel joints with carbonic, manganese, silicon, oxygen, hydrogen, sulphur, phosphorus. The color, chemical composition, microstructure, mechanical characteristics of protective deposit, as well as its corrosion resistance depend on various factors.

The chemical activity of the main element of steel – iron is so large, as on the surface even in the room temperature protective deposit develops just after any method of mechanical treatment, connected with disconnection of upper deposit. The corrosion resistance of the steel surface makes clear with developing of oxide [5]. The process of oxidation, in the result of which the oxide coat develops, consists of a number of simple processes. At first on the surface of coat gasiform oxygen molecules adsorb, then the molecules transform into atoms, which later ionize and join two electrons. The new developed ions of oxygen (anions) diffuse in the direction of the iron surface. Ionization of iron atoms follows as well as transition of iron cations and electrons from the phase of iron to oxide phase. The next phase is diffusion of iron cations and electrons from the coat in the direction of coat/gas. As a result of interaction between anions and cations the oxide of iron develops. FeO and Fe_2O_3 coats develop when ions move by vacancies – the node points of crystal lattice, which are not occupied by ions. The motion of electrons, accompanied by the motion of cations, move on defects of electrons – cations.

Oxide FeO behaves the same way as semiconductor with gap conductivity: in the process of coat growing cations diffuse by vacancies of crystal lattice and at the same moment electrons move to the oxide/gas zone also. Oxide Fe_2O_3 behaves as semiconductor with electron conductivity and the process of coat growing passes on the boundary surface iron /oxide. Anions diffuse by anions vacancies of crystal lattice in the direction to the iron surface.

The intensity of oxidation process or speed of oxide coat growing is dependent on the surrounding environment. In case if the oxidation process occurs in the environment with high moisture, the corrosion is described as a galvanic process [6]. The speed of oxide coat growing is described by expression $dh/dt = a.I$, that demonstrates if increasing of the coat thickness h in time t is proportional to formative current intensity of the galvanic element I. The speed of the interaction process between oxygen and iron describes the constant k.

$$k = [2EMo(t_+ + t_-)\, t_e] / r\rho F, \tag{1}$$

where E – the value of electro propulsion of galvanic element,
Mo – mass of oxide mole,

t_+, t_-, t_e – rates of current, which are supplied through coat by cations, anions and electrons;
ρ – density of coat;
F – Faraday number.

This expression is typical for ideal coats. In cases, when oxide coats have micro defects, chinks or other defects, the process of oxidation in order of chemical composition of steel, surrounded environment and temperature can be described by linear, parabolic as well as logarithmical coherence. It is possible to describe the process of oxidation by linear coherence only in cases if the coat does not the disturb process, then the speed of oxidation does not change in time. Oxide coat growing process is dependent on temperature. In low temperatures (< 400 ˚C) logarithmical coherence is observed, in temperatures over 400 ˚C – parabolic, but after heating over 4000 ˚C the development of coat from the liquid phase occurs together with the process of steel crystallization and cooling as well as this process is effected by the environment and plasma gases. The speed of oxidation process is alternating.

Materials and methods

To clarify, how the oxidation process has an effect on the characteristics of different marks of steel, including corrosion resistance, hot rolled low-alloy and non-alloy structural steels as well; samples of tool steel of 7 different marks have been observed. Some of the sample surfaces were cut by automatic equipment SATO ELEKTRONIC CNC-801 with low temperature plasma arc (plasma environment was structured by air), some were treated by metal cutting tools but some kept original material characteristics after manufacturing – hot rolling. All samples were held in room temperature and observed visually for 200 days. One party of samples was placed in a room with humidity 75±10 %, the other – in the same conditions of humidity but with elevated content of acid (pH 5±0.5 %). The chemical composition and width of examples are given in Table 1.

Table 1

The chemical composition and width of examples

Steel	Width of example	Chemical composition, %, max					
	mm	C	S	P	Mn	Si	Cr
S235J2	8	0.17-0.22	0.045	0.045	1.50	-	≤0.25
C20	10	0.17-0.24	0.040	0.035	0.352-0.65	0.17-0.37	≤0.25
C45	10	0.52	0.003	0.013	0.352	0.391	0.245
C80U	10	0.75-0.85	0.030	0.030	0.1-0.4	0.10-0.30	≤0.25
65Mn4	13	0.62-0.70	0.04	0.035	0.70-1.0	0.17-0.37	≤0.25
40Cr4	10	0.36-0.44	0.040	0.035	0.65	0.17-0.37	0.95
30CrMnSi 4-4-4	10	0.31	0.008	0.016	0.91	1.02	0.95

The chemical composition of alloy steel 30CrMnSi 4-4-4 is updated by spectral analysis using a stationary optic/emission spectrometer „Foundry Master" in ltd RIMANS. The chemical composition of steel C45 is estimated by a portative spectrometer ARS MET 8000 OES in ltd „Investīciju centrs". The macro and microstructure of steel blanks (with surfaces treated by different methods) are searched by a light microscope Neophot 30 – magnification X200.

Results and discussion

The results of the research are given in Table 2. The results demonstrate that before treatment the microstructure of structural steel consists of ferrite and perlite. In thermal influence area the microstructure changes substantially; ledeburite, beiniteand martensite appear in the composition – this, mostly, changes hardness.

Table 2

The color and microstructure of samples (in different planes) after exposing 200 days in the environment with humidity 75 ± 10 %

Material	Rolled surface	Milled surface	Cut by plasma surface	Color of rolled surface	Color of milled surface	Color of surface cut by plasma
S235J2	Ferrit+perlyt	Ferrit+perlyt	Perlit+beinit	Black	Light grey	Dark grey with corrosion spots
C20	Ferrit+perlit	Ferrit+perlit	Perlit+martensit	Black	Light grey	Dark grey with corrosion spots
C45	Perlit+ferrit	Perlit+ferrit	Perlit+martensit	Black	Grey with corrosion spots	Dark grey
C80U	Perlit	Perlit	Martensit	Black	Grey with corrosion spots	Grey
65Mn4	Perlit+ferrit	Perlit+ferrit	Ledeburit	Black	Corrosion deposit	Black
40Cr4	Perlit+ferrit	Perlit+ferrit	Perlit+martensit	Black	Grey	Dark grey
30CrMnSi 4-4-4	Ferrit+perlit	Ferrit+perlit	Ledeburit+beinit	Black	Grey	Black

The research of the microstructure demonstrates that after cutting by plasma arc on the surfaces - in the thermal influence area, the structure changes in the direction from the cutting place to the middle part of the sample, as well as different marks of steel have different microstructures. The presence of martensit structure in the cutting area is typical for all marks of steel; the differences are only in the amount of it: as the carbonic content is larger – martensit structure is present more. The presence of manganese stimulates the developing of ledeburite structure.In overheated iron area of samples the structure of ferrite /perlite develops with orientation to the structure of Vidmanstet.

The research of the microstructure demonstrates that after cutting by plasma arc the color of blanks in the thermal influence area is different. The tone changes from black for steels 65Mn4 and 30CrMnSi 4-4-4 to light grey for steels S235J2 and C20. A different tone of the cutting area is involving with the chemical composition of steel.

Researching in the corrosion resistance of protective deposit the reaction of the selected steels was observed visually in different conditions. It is cleared up, that for samples placed in room temperature and in the conditions of elevated air humidity the impact of corrosion is observed only on alloyed steels C45 and C80U on mechanically treated surfaces of alloyed steels C45 and C80U as well as on plasma cut surfaces of steels C20 and S235J2.

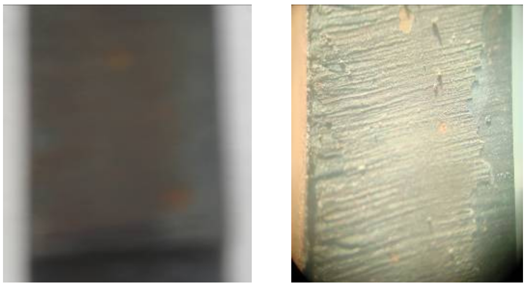

Fig. 1. **Plasma cut surfaces of steel 65Mn4 (left) and C80U**

For samples placed in a room with presence of hydrochloric acid steams (pH 5±0.5 %) the corrosion on mechanically treated surfaces is very marked. On rolled surfaces the point shape corrosion is observed.

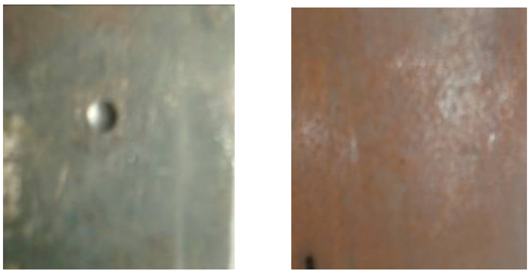

Fig. 2. **Rolled (left) and mechanically treated surfaces on samples of steel 65Mn4 after placing in a room with presence of elevated rate of hydrochloric acid steams**

The experiments to specify the changes of the oxide coat composition compared to chemical composition of the initial material by using the stationary optic/emission spectrometer „Foundry Master" as well as the portative spectrometer ARS MET 8000 OES did not produce the anticipated results.

The different reactions on different influence of gasiform environment are explained by thickness, chemical composition as well as microstructure of the oxide coat. Different surfaces of the researched samples had different conditions of oxidation.

On the mechanically treated surfaces the oxide coat develops in temperatures lower then 400 ˚C and it has poor thickness as well as the oxide coat develops with defects and this provides a possibility to diffuse the components of environmental gasses.

On the rolled blank surfaces the oxide coat develops in higher temperatures (~1000 ˚C), it is more thick and develops for a longer time. In the air with elevated rate of hydrochloric acid vapors corrosion pitting develops.

On the plasma arc cut surfaces the oxide coat develops in the interval of temperatures, when iron is heated over 4000 ˚C. Water vapours over 4500 ˚C divide in atomic hydrogen and oxygen. The gases from the surrounding air, water vapours and components of ionized gas easily push into liquid iron. During the cooling process a chemical reaction between atoms of different elements from liquid alloy takes place. Iron dissolves a portion of oxygen (not over 0.22 %). Iron oxide is excreted from liquid during the time of iron cooling, as well as the oxidation process of hydrogen, manganese and silicon takes place. Moreover, nitrogen from the surrounding air reaches with iron and nitrites Fe_2N, Fe_4N develops. Consequently, in the upper part the amount of oxygen noticeably increases, as well as the content of carbonic, manganese, silicon decreases. The content of carbon in the coating in relation to the content of it in the basic material increases in cases if the material before cutting was not heated as well as decreases, if the material before cutting was heated.

The processes in coating, which is made by plasma arc, trigger off such changes, if corrosion resistance increases in all samples that were researched. In order to save corrosion resistance of the parts, there is not a need to treat the cutting area by the cutting technology anymore. This surface has to be with a sufficiently small roughness rate, sufficient rate of accuracy and stability of the shape.

Conclusions

1. Corrosion resistance on surfaces of low-alloy and non-alloy structural steels as well as non-alloy tool steel C80U, which are created by plasma arc cutting, increases.
2. The chemical composition, microstructure as well as color on the surfaces, cut by plasma are dependent on gases, which form plasma; on carbonic content in non- alloy steels as well as the chemical composition of alloy steels. The presence of alloyed components Cr, Mn, Si increases the rate of corrosion resistance.
3. The structure of perlit with inclusions of martensit in the cutting area develops for steel marks C20 and C45. The structure of martensit in the cutting area develops for the steel mark C80U. The microstructure of steel 30CrMnSi4-4-4 consists of ledeburit and beinit. The structure of ledeburit

in the cutting area develops for the steel mark 60Mn4. In overheated area of the samples the structure of ferrite /perlite with orientation to the structure of Vidmanstet develops.

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