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Advantages of Plasma Cutting in Superheated Water Vapor at Metallurgical Enterprises

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Abstract

Currently air plasma cutting is applied for cutting the tube ends at metallurgical enterprises. Plasma cutting process is accompanied by the release of metallic dust and harmful emissions (NO, NO2, CO, O3) in the environment. During cutting the cutting edges become saturated with nitrogen and oxygen and carburized. These phenomena promote increase of metal hardness of the cut surface and machining of pipe ends becomes complicated. To solve these problems, it is proposed to use superheated vapor as plasma-producing media. Comparative research of ecological data and metallographic study of metal surface of the cutting edge were conducted. According to the research data, concentration of dust and gases is by 50-60% less during cutting in water vapor as compared with the air plasma cutting; but when using protective water vapor curtain around the open portion of the arc this concentration is reduced to 70-75%. The depth of the heat-affected zone (HAZ) is reduced 3-3,5 times, and of the cast section 2,6-3 times. The microhardness of the metal surface in water vapor is reduced 1.7-2 times.

Keywords: Plasma cutting, superheated water vapor, ecology, water vapor curtain, cutting edge, heat-affected zone, cast section, microhardness

Introduction

Air plasma cutting is applied for cutting the tube ends after rolling at metallurgical enterprises. However, plasma cutting process is accompanied by the release of metallic dust and harmful emissions (NO, NO2, CO, O3) in the environment; on the other hand hardness of the cutting edge metal surface is increased and its machining is complicated. For solving ecological problems numerous practical solutions of the problem are developed using water (Kalizynski W., Klimpeb A.1983; Longer Bruno P. 1987; Dohn Kurt. 1987). Its use is very effective, but there are several drawbacks:

- When applying water curtain plasma cutting the ferrous metal the product is wetted around the open part of the arc; after a while it rusts and the cleaning requires extra costs;

- Quality of improving ecological parameters depends on the water flow rate; for example, the noise level decreases with the increase in flow rate, and it is economically unprofitable;

- Safety requirements become more stringent when using water.

To solve these problems, we suggest using superheated water vapor as plasma-producing media.

Working Methodology

Study of the environmental performance of plasma cutting was carried out in laboratory conditions where exhaust ventilation was not available. Concentrations of harmful dust and gas emission were determined by following methods:

1. The concentration of nitric oxide was determined by reaction with substituted ethylenediamine;

2. Dust concentration was determined gravimetrically

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using filters and the concentration of chromium oxide and manganese - by means of chemical analysis of samples taken in the filters.

3. The ozone concentration was determined by the method based on the reaction of ozone with divalent iron ions in the acidic medium;

4. The concentration of carbon monoxide was determined by the method based on the recovery of ammoniacal silver nitrate solutions by carbon monoxide followed by calorimetric analysis of colored solutions.

The microstructure of the cut surface was studied under an optical microscope at magnification from x50 to x400. Microhardness measurements were performed on a PMT-3.

Results

Superheated water vapor as a plasma-forming medium and protective curtain around the open part of the arc have been proposed and applied by us.

Wetting the product is excluded when using water vapor; water flow rate is decreased. Reduction of water use is obvious since at evaporation of 1 cm3 water 1700 cm3 of water vapor is formed. The benefits of energy and technological characteristics of water vapor plasma arc in comparison with the compressed air plasma arc are given in the works (Sabashvili, Tavkhelidze, Mchedlishvili, 2005; Sabashvili, Mamukashvili, Tskhvedadze, 1992; Sabashvili, 2002).

It is known that passing through a nozzle, supplied pressurized gas creates a certain thickness of gas layer around it spatially stabilizing, cooling and compressing the arc column. The gas layer provides thermal and electric insulation from the nozzle walls and shields the open portion of the arc column from the environment. In this case, it can be assumed that the arc burns in the chamber the walls of which are formed of water vapor. Gases formed during cutting are absorbed by water vapor. Effect of the process is enhanced when additional water vapor curtain is used around the plasma arc.

Comparative studies of ecological parameters of water vapor plasma cutting and compressed air plasma cutting were carried out. Interest was the quantitative estimation of fine dust and toxic gases, in particular carbon dioxide (CO), nitrogen oxide (NO2), ozone (O3), chromium oxide (Cr2O3) and manganese (Mn).

Degree of pollution of the work area with harmful substances depends on the mode of cutting, thickness of the cut sheet, operating conditions, equipment, etc.

The studies were conducted during plasma cutting 10 mm, 16 mm and 30 mm thick low-carbon steels. Air samples for analysis were taken at a distance of 0.5 m from the plasma torch.

The most reliable data, reflecting the degree of air pollution by gases and dust are obtained after a brief sampling, since in this case maximum concentrations are fixed with sufficient accuracy. In Table 1 are presented the research results obtained at following mode of cutting 16 mm thickness steel plate: arc current - 180A, arc voltage - 275 V, water vapor pressure - 4 atm., steam temperature - 2000C, cutting speed - 2.6 sm./sec.

As can be seen from the data shown in Table 1 concentration of dust and gases during cutting in water vapor is by 50-60% less as compared with the air plasma cutting. The concentration is less than 70-75% when using protective water vapor curtain around the open portion of the arc. by 15-20%. Compared with the permissible sanitary standards (Table 2), the obtained data are lower by 15-20%.

Table 1. Ecological parameters of plasma cutting process.

Cutting Method	Test	Concentration, mg/m^3					
	#	Dust	O_3	CO	No_2	Cr_2O_3	Mn
Air plasma cutting	1	61,2	0,28	36,0	5,4	2,4	0,42
	2	60,5	0,34	38,8	5,8	2,6	0,40
	3	61,7	0,30	42,8	5,6	2,2	0,44
	4	60,8	0,34	39,8	5,6	2,4	0,40
	5	61,2	0,32	38,8	5,8	2,6	0,42
Plasma cutting in water vapor	1	30,8	0,15	19,2	2,62	1,16	0,20
	2	28,6	0,18	19,6	2,68	1,40	0,20
	3	29,8	0,16	20,4	2,63	1,08	0,22
	4	29,6	0,16	18,8	2,76	1,14	0,18
	5	30,2	0,15	18,6	2,74	1,14	0,19
Plasma cutting in water vapor with protective water vapor curtain	1	16,2	0,082	9,76	1,46	0,62	0,12
	2	16,8	0,090	9,80	1,42	0,58	0,14
	3	16,2	0,086	9,80	1,42	0,60	0,16
	4	16,0	0,084	9,74	1,40	0,58	0,14
	5	16,2	0,084	9,74	1,44	0,58	0,12

Table 2. Maximum permissible concentrations (MPC) of harmful substances.

Substance	Dust	O_3	CO	No_2	Cr_2O_3	O_3
MPC,mg/m3	30,0	0,1	20,0	5,0	0,1	0,1

Based on the findings it can be concluded that the process of plasma arc cutting in water vapor is environmentally friendly and excludes the necessity of using the expensive exhaust facilities.

The important fact is that water vapor is the redox environment reducing the solubility of gases in the cut edge. Part of the oxidation (reduction) products formed in the cut cavity is removed as slag by the jet of water vapor, and part is condensed on the colder surfaces of the cut. $FeO-Fe_3O_4$ system provides good wetting of clean metal surface. Due to the small interfacial tension and high viscosity, iron oxides rapidly melt and are deposited on the surface shielding the edge surface, i.e. the flux is formed on the metal surface which can be easily separated after cooling metal. Flux plays an essential role in the formation of the molten metal. surface and insulates it from the contact with outside gases. On the other hand, hydrogen formed during dissociation of water vapor, combines with nitrogen and nitrogen adsorption on the cutting edges is reduced. Hydroxyl being highly stable compound is not soluble in metal and improves the cutting quality (cutting surface is characterized by metallic sheen). Hydrogen protects the cutting edges against oxygen saturation, preventing the oxidation of metal by binding oxygen, reducing metal from its oxides and hindering the formation of nitrides. From the foregoing it follows that by using water vapor cutting edge saturation with nitrogen and carburization are significantly reduced but chemical composition of cutting edge metal remains practically unchanged.

Comparative studies of 16 mm thick low carbon steel Cт3 samples were carried out. The samples were made by plasma cutting under identical conditions in water vapor and compressed air environment. The microstructures of metal into the depth from the cut surface are shown in Fig. 1 for air plasma cutting and Fig. 2 for water vapor plasma cutting.

When comparing the microstructures of the samples a weakly-etched zone in the form of a light strip can be noticed in case of air plasma cutting that corresponds to the cast section. In the case of water vapor, cutting similar zone is not noticed. Presumably, due to the partial or total nitrogen desorption of cast section, the phase composition of its structure is changed; therefore, the etchability of the structure varies. Consequently, the absence of a weakly-etched zone does not indicate absence of cast section revealing the structure of higher hardness. Directly behind the cast layer section metal structure con-sists of troostite and a small amount of ferrite. In the first case, the microstructure reveals dendrite-shaped martensite, which indicates carburization of the metal edge. In the second case, carburization occurs to a much lesser extent. With increasing distance from the edge the amount of ferrite is increased. The structure consists of Sorbite and sorbite-troostite with small plots of free ferrite. In this case micro-hardness is decreased. Then the structure corresponds to the initial state of the steel. Value of micro-hardness determines dimensions of cast section. Figure 3 represents a graph of micro-hardness distribution into the depths from the surface of cutting edge. The micro-hardness close to the cutting edge is 312 Kg/mm2-for air-plasma cutting and 184 Kg/mm2 for water vapor plasma cutting.

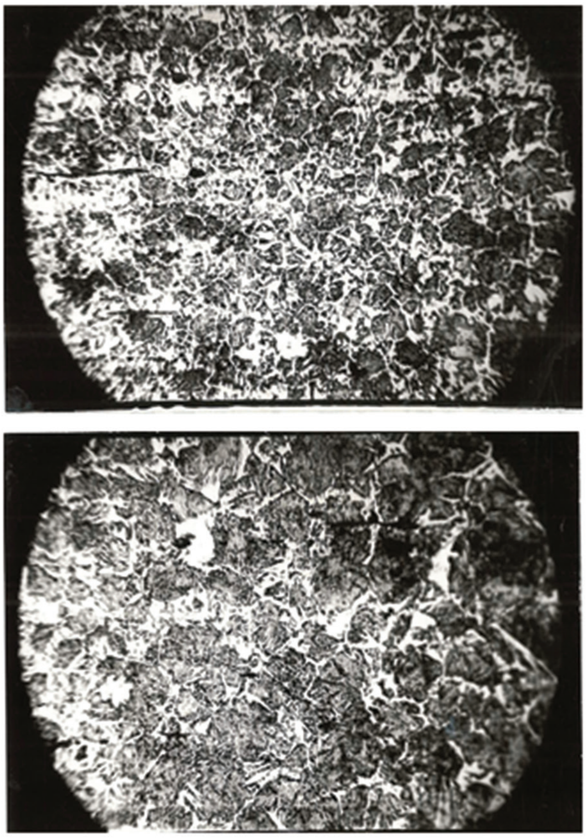

Figure 1. *The microstructure of metal into the depth from the cut surface when air-plasma cutting*

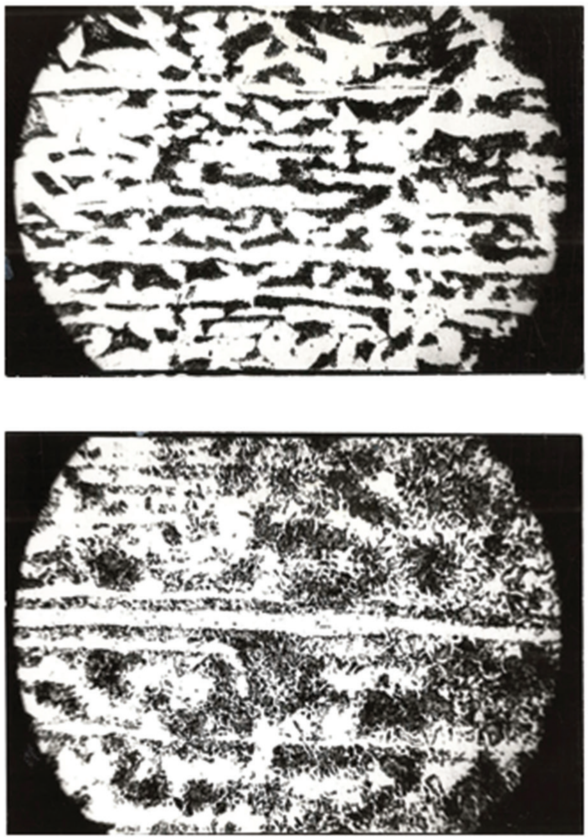

Figure 2. *The microstructure of metal into the depth from the cut surface when water vapor plasma cutting*

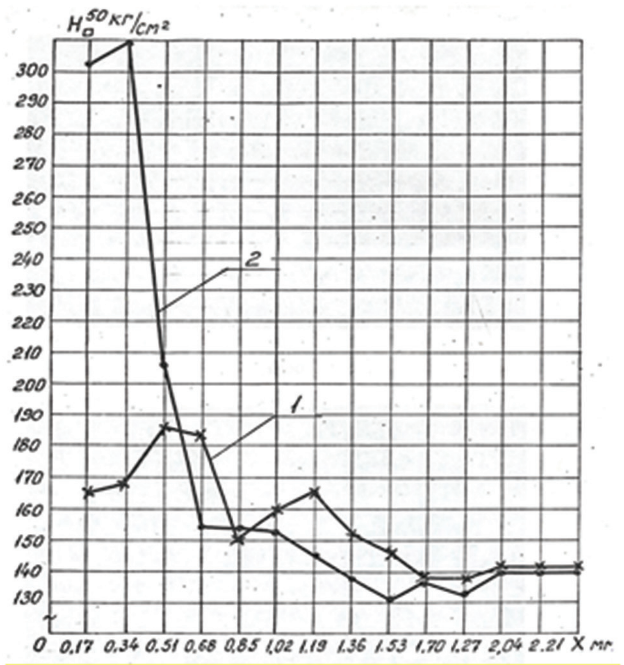

Figure 3. *Schedule of micro-hardness distribution in depth from the surface of the cutting edge: 1.Water vapor plasma cutting*
2. Air-plasma cutting

The micro-hardness of the metal in water vapor is reduced to a value of the base metal at a distance of 0.2 mm from the cut surface, and in case of compressed air – at 0.7 mm, corresponding to the depth of the HAZ. The length of the section with increased microhardness corresponds to the depth of the cast section. In case of water vapor plasma cutting maximum size of the section with increased hardness is up to 0.03 mm, and in the case of air plasma-cutting - 0.8 mm.

From the foregoing, it can be concluded that after water vapor plasma cutting of billets machining of cutting edges is not worsened.

Conclusion

The use of water vapor as plasma-forming medium improves the ecological parameters of plasma cutting process. In particular:

• The concentration of dust and gases is at 50-60% lower compared with the air plasma cutting. When using protective water vapor curtain round the open part of the arc, concentration is less than 70-75%;

• The depth of the heat-affected zone (HAZ) in water vapor is reduced 3-3,5 times, and of the cast section - 2,6-3 times;

• Micro-hardness of metal surface is reduced 1.7-2 times in water vapor;

• After water vapor plasma cutting of metal, machining of cutting edges becomes easy as the micro-hardness of the metal surface in water vapor is reduced to a value of the base metal.

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