IMPROVING THE QUALITY OF AIR-PLASMA CUTTING OF SHIP HULL STEEL BY WATER ADDITION INTO PLASMA

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ABSTRACT: The air-plasma cutting with water addition into plasma forming gas and water shower application allow this method to successfully compete with the plasma cutting under water. Water addition into plasma forming air provides the hydrogen formation, the plasma flow compression in the nozzle canal which increases energy characteristics of plasma. Due to water addition into plasma forming air the roughness, the non-perpendicularity, the nitrogen saturation of the edges and prevention of pores formation in the welded joints are reduced.

1. INTRODUCTION

About 80% of exploitable sheet metal is processed by different methods of thermal cutting in modern shipbuilding. Its labor intensiveness amount to about 20% of work volume of hull processing. The most important cutting technologies of ship hull steel are plasma cutting, laser cutting and gas-oxygen cutting. Independently of technique in operation the quality of cut surface is determined such indexes as cut surface deviation from perpendicularity, cut surface roughness, thermal influence zone.

The air-plasma cutting method is widespread in the former Soviet countries. The main defects of plasma cutting using air as plasma forming gas are high non-perpendicularity of cut edges, roughness and nitrogen saturation of edges. The last circumstance leads to pores formation at machine flux welding of the plates having thickness up to 10 mm deflection.

Therefore at some enterprises the air-plasma cutting is replaced by the oxygen plasma cutting under water. Our investigations have shown that the water addition to plasma forming air in certain proportions allows to eliminate all above-listed defects of the air plasma cutting. The ratio of air and water steam in plasma is determined by thermodynamic modeling of the plasma composition. The method of the air plasma cutting [1] with water addition into plasma doesn’t demand big capital outlays in contrast to the oxygen plasma cutting under water. The method of the air plasma cutting with water addition into plasma allows to easily update machines for the air plasma cutting and for metal-working shops at the enterprises.

Addition of water into plasma gives complementary squeeze of plasma arc and it also creates gas hydric mixtures. It increases the electric field intensity of arc and its power characteristics. Hydrogen generation reduces nitrogen solubility in steel in the cutting process and it prevents pores formation at the welding.

2. THE AIM OF THE WORK

The aim of work is the determination of ship hull details plasma cutting quality in the air plasma cutting, the oxygen plasma cutting under water and the air plasma cutting with water addition into plasma.

3. THE MAIN CONTENTS OF THE PAPER

In this paper, the quality of the air plasma cutting with water addition into plasma, the oxygen plasma cutting under water and the air-plasma cutting is compared to the three above indicated indexes. Profile drawing of a cut surface, its deflection from perpendicularity, structure, metal microhardness in the thermal influence zone and the nitrogen content in the under-surface layer of the edges are determined. Influence of the cutting conditions is investigated.

The authors have investigated the influence of the cutting conditions, polarity of the current and different plasma forming media on the cut edges gasing and their quality. Plasma cutting of the samples was carried out in the plasma forming media: air, oxygen, air+water, oxygen+water. In plasma cutting the cut edges are heated and cooled very quickly. The structure changes take place in the zone of thermal influence. Chemical composition of the metal on the cut surface and inside it differs from that of the main part of a metal sheet.

Metal structure change of the cut edges depends on their chemical composition and the thermal cycle character, which is similar to the thermal cycle in welding. Composition and properties change inside the edges and in the thermal influence zone can stimulate pores formation, cracks and other defects in welded joint and also reduce fatigue strength in the details under the dynamic loads in the free and non-processed edges after cutting.

3.1. Roughness and deviation from non-perpendicularity of the cut edges

Roughness of the cut edges according to GOST 14792-80 (State Standard) and EN ISO 9013 (2002) is an index, which determines quality class of the details cut. The character and depth of the furrows, which are created on the cut surface, determine the operational capability under cyclic loads for details having free edges.

The quality of the cut surface was evaluated according to the roughness indexes $R_s$ and $R_p$. Roughness indexes were determined with a profilograph-profilometer, model 252. The samples $30\times30\times10$ mm were taken. Ac-
According to GOST 14792-80 the length of 8 mm was taken as the basis. During research a sensor speed reached 300 mm/min, the ribbon speed was 60 mm/min and the vertical increase achieved 5×100.

A profile drawing and the macrostructure of surfaces after using different cutting methods for 09G2 steel are shown in Fig. 1.

The Profile drawings and the macrostructures show that the air plasma cutting with water addition provides less roughness of edges. During the air plasma cutting with water addition the smooth cut surface has been achieved, it has silvery color and its lugs and hollows have smooth junctions. \( R_z \) amounts to 10…20 and \( R_a \) amounts to 2.23 \( \mu \)k. These indexes correspond to the first class quality, GOST 14792. The air plasma cutting corresponds to the second class quality, \( R_z = 80 \) – 100 \( \mu \)k. The oxygen plasma cutting under water gives the second class quality.

The results of roughness investigation are confirmed by cut edges micro samples, which are shown in Fig. 2. (see further)

The investigations show that the water addition in the air plasma allows to reduce non-perpendicularity of the edges without reducing cutting efficiency, because the hydrogen is formed in plasma and water addition compresses and condenses plasma flow in the nozzle canal, and it provides higher energy characteristics of plasma. Cut width at the top edge is reduced 1.3…1.7 times as much. Welding arc voltage becomes 25…30 V higher. Plasma permeability increases, and it reduces non-perpendicularity of cut edges to 0.5 mm.

3.2. Nitrogen saturation of the cut edges

Plasma cutting is characterized by the formation of a thermal influence zone with fusion areas and structural changes. However, the significant thing is that nitrogen saturation of the cut edges in the depth up to 0.05 mm takes place during the air plasma cutting of a ship hull steels having thickness up to 10 mm. In plasma cutting nitrogen can penetrate into the metal from the plasma forming media or from the environment due to the air injection into plasma column. There are different opinions on the mechanism of nitrogen saturation. Nitrogen creates some nitrides with iron having different quantity of nitrogen, for example, FeN, \( Fe_2N \), \( Fe_4N \). Nitride \( FeN \) has maximum quantity of nitrogen 11.2% \( N_2 \); \( Fe_2N \) 6.0% \( N_2 \). Nitride \( Fe_2N \) can be obtained at the temperature of 450°C, and \( Fe_4N \) is formed when the temperature increases and it decomposes when the temperature exceeds 550°C. Nitrogen solubility in pure iron at 1600°C amounts to 0.044%. The nitrogen content in metal is described by Siverts’ equation at lesser partial pressures.

Maximum nitrogen solubility in α-iron amounts to 0.1%. However, under the air plasma cutting conditions the nitrogen content exceeds solubility limit approximately 10 times. It is determined by spectral-isotonic method using optical quantum generator that in air plasma cutting the nitrogen concentration in the under-surface layer can reach 8.7%, in the depth of 0.025 mm it can make 0.53%, in the depth of 0.050 mm it equal 0.095%. [2] Nitrogen concentration in the under-surface layer exceeds nitrogen concentration in the nitrides. However, no nitrogen formation in the air plasma cutting has been observed.

The researchers used a chemical method to determine the nitrogen concentration in the edges. For that the D32 steel sheets of 8 mm thick were cut using air plasma cutting and the air plasma cutting with water addition at the speed of 2.5 m/min with 10…12 mm distance of plasma nozzle from metal and 280 A current. During the air plasma cutting the welding arc voltage achieved 150 V, during the air plasma cutting with water addition it reached 175 V. During the air plasma cutting with water addition, water discharge in plasma made 0.25 l/min. The
consumption of plasma forming air in cutting operations achieved 80 l/min.

After cutting the plates out of the inside surface of the edges chips of 0.05 mm thick were taken for the chemical analysis. The work was carried out on WF3SA “Mikron” milling machine with the positioning accuracy of 0.005 mm. The analysis was carried out for the right and the left cut edges separately.

Nitrogen concentration in the air plasma cutting equaled 0.176…1.184/0.180% in the left edge and 0.167…0.172/0.170% in the right edge (midvalue is shown in the denominator). Nitrogen concentration in the air plasma cutting with water addition achieved 0.088…0.090/0.090% in the left edge and 0.062…0.068/0.065% in the right edge. Thus, water addition to plasma forming air reduces nitrogen content in the metal 2…3 times as much in the cut edge.

Nitrogen content in the left and right edges during both cutting operations was different. The lower amount of nitrogen in the right edges is explained by the fact that takes place the anode spot delay before the arc break at the right edge when the gas flow rotates clockwise. The left edges have smaller nitrogen saturation as the gas flow rotates anticlockwise.

The microstructure of the plate edges after using different cutting methods for D32 steel is shown in Fig. 2.

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Fig. 2. Microstructure of the plate edges after the air plasma cutting (a), the oxygen plasma cutting under water (b) and the air plasma cutting with water addition (c); x400
Fig. 3. Microstructure of metal in the thermal influence zone in the air plasma cutting (a), the oxygen plasma cutting under water (b) and the air plasma cutting with water addition (c); x400

Table 1. Influence of the plasma forming media and the cutting condition on the thermal influence zone

<table>
<thead>
<tr>
<th>A sample</th>
<th>Plasma forming media</th>
<th>Open-circuit voltage, V</th>
<th>Length of the nozzle canal, mm</th>
<th>Current intensity of cutting, A</th>
<th>Thickness of the white nitrided layer, mm</th>
<th>Width of the thermal influence zone, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air</td>
<td>400</td>
<td>3</td>
<td>330</td>
<td>Up to 1.12</td>
<td>0.50…0.70</td>
</tr>
<tr>
<td>2</td>
<td>Air+water</td>
<td></td>
<td>7 Compound</td>
<td>270</td>
<td>0.02…0.12</td>
<td>Equal 0.6</td>
</tr>
<tr>
<td>3</td>
<td>Oxygen+water</td>
<td></td>
<td>3</td>
<td>250</td>
<td>0.012</td>
<td>0.60</td>
</tr>
<tr>
<td>5</td>
<td>Oxygen+water</td>
<td></td>
<td>3</td>
<td></td>
<td>No</td>
<td>0.46</td>
</tr>
<tr>
<td>6</td>
<td>Oxygen</td>
<td>300</td>
<td>7 Compound</td>
<td>200</td>
<td>Start of cut 0.08</td>
<td>0.7</td>
</tr>
<tr>
<td>8</td>
<td>Oxygen+water</td>
<td></td>
<td>7 Compound</td>
<td></td>
<td>No</td>
<td>0.46</td>
</tr>
<tr>
<td>9</td>
<td>Air+water</td>
<td></td>
<td>3</td>
<td></td>
<td>No</td>
<td>Equal 0.6</td>
</tr>
<tr>
<td>10</td>
<td>Air</td>
<td>300</td>
<td>7 Compound</td>
<td></td>
<td>0.012</td>
<td>0.66</td>
</tr>
</tbody>
</table>

The maximum parameters of the microhardness are observed in air plasma cutting. The white solid layer of up to 0.03 mm deep is formed at the cut edges due to nitrogen saturation. The air-steam plasma and the oxygen-steam plasma don’t form the white layer. The nitrided layer at the start of oxygen plasma cutting is formed due to oxygen injection into the air.

The nitrided layer increases with the cutting current increasing. That explains the increasing of molten metal on the edges. The depth of the nitrided layer is reduced with the length of the nozzle canal increasing.

During the air-steam plasma and the oxygen-steam plasma formation the white layer on the cut edges has not been observed. Metal microhardness at the cut edge reaches 3450…3660 MPa while the microhardness of the main metal equals 1770…2120 MPa.

3.4. Pores formation in welding

The investigation of the pores formation has been carried out during the welding under the flux having the length of 1.0 m and the thickness of 8 mm, cut out from D32 steel sheets. The plates have been welded under the flux AIF-348A with wire Cu-08A having diameter 5.00 mm, at the length of 40 mm and the welding speed up to 28…30 m/h, with the arc voltage of 30…32 V and the current intensity being 600…660 A. When welding the back side of a seam the current intensity was increased up to 10…15%.

Pores formation can be seen with the help of roentgen graph and on the destruction surface. The fusion area \(F_F, \text{sm}^2\) and the pore area \(F_p, \text{sm}^2\) and also ratio \(F_F/F_p\) were defined on the destruction surface.

For plates cutting, the plasmatrone with vortex stabilization of plasma flow (clockwise) and film cathode with zirconium and hafnium cylindric insertions was used. The dependence of pores on water discharge of 1.5 \(l/d\) and air consumption was investigated.

The results are shown in Fig. 5.

Fig. 5 shows that during the right edges welding the resistance to the pores formation is higher than during the left edges welding. It confirms the above results showing lower nitrogen content in the right edges.
Fig. 4. Metal structure change in the cut edges during the air plasma cutting depending on the current intensity, the length of the nozzle canal (a) and the plasma forming medium (b): 1, 2, 3, 9, 10 – the air plasma cutting at the length of the nozzle canal 3 mm (1, 2, 9) and 7 mm (3, 10); plasma forming media: ● – air+water; x – oxygen+water; ▲ – oxygen

Fig. 5. Pores formation dependence on the water discharge (a) and plasma forming gas (b) during welding the right (1) and left (2) edges: – air+water; ●, ▲ – oxygen+water.
The air plasma cutting provides maximum resistance to pores formation with water addition $\left(4.6\ldots6.6\right)\cdot10^{-3} \, \text{l/s}$ the welding and the oxygen plasma cutting with the water discharge $\left(3.0\ldots3.6\right)\cdot10^{-3} \, \text{l/s}$. Increasing water discharge creates hydrogen pores with silvery surface, in contrast to pores with matted surface. The results achieved coincide well with the results of thermodynamic modeling of the plasma gas composition.

The research shows that the change of plasma forming gas consumption during the cutting influences the pores of welded joints. When welding the right edges, pores formation increases more than $1.8 \, \text{l/s}$ with the discharge of plasma forming media. In the oxygen plasma cutting it can be explained by the increase of air injection by the oxygen jet.

4. CONCLUSIONS

1. Adding water to plasma forming media is an effective method of the roughness reduction and non-perpendicularity of edges. That allows to eliminate mechanical operation of the free edges of details.

2. Adding of low water to air plasma reduces the nitrogen saturation of edges and prevents pore formation in welded joints.

3. Applying air plasma cutting with water addition has shown that it can successfully compete in the quality and economy with the oxygen plasma cutting under water.

REFERENCES
