Research of the Influence of the Rarefaction Degree on the Metal Protection Quality and Geometric Welding Parameters During Arc Welding in the Controlled Atmosphere

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Abstract. This article is devoted to the urgent issue of welding metals and alloys that are widely used in modern aerospace industry. The paper describes the effect of the degree of rarefaction of the controlled atmosphere on the quality of protection of the weld metal and the weld zone, as well as on the change in the geometric parameters of the weld during arc welding in a controlled atmosphere. The main advantages of arc welding in a controlled atmosphere of refractory, heat-resistant, heat-resistant, corrosion-resistant metals and their alloys are indicated. The welding modes used and the welds obtained with these modes are presented. The influence of the degree of rarefaction on the change in the quality of protection of the weld metal and the heat-affected zone is described. The degree of rarefaction of the controlled atmosphere ranged from 200 to 1000 mbar. Dependencies are obtained that describe the effect of the degree of rarefaction on the geometric parameters of welds.

1. Introduction

Today, in the aerospace industry, refractory, heat-resistant, heat-resistant, and corrosion-resistant metals and their alloys are increasingly used. Heating and melting of these materials in air is practically impossible, mainly due to their high chemical activity and propensity for gas saturation, due to their high affinity for atmospheric gases. The natural instability of most metals in their elemental form causes them to react with oxygen in the air when heated during welding. In addition to the reaction with the metal, the components of the air, oxygen and nitrogen can dissolve in the molten weld pool. Hydrogen gas, although not a normal component of air, can be present in the atmosphere around the arc, since high temperatures can destroy moisture, fat, and other hydrogen-containing materials. Various methods of protection are used to eliminate the harmful effects of the air atmosphere during heating and melting [1–9].

The most common welding method for these materials is arc welding in vacuum or inert gas. When welding these materials, the most affordable means of protection against the negative effects of the atmosphere on molten metal is the use of local methods of protection. For this, argon-arc burners, gas lenses and additional blowing of the root of the seam with inert gas are used. The main disadvantage of such methods of protection is poor protection of the metal of the heat-affected zone or even its absence, which does not favorably affect the mechanical properties of the welded joint as a whole [10–18].
A more advanced method of protection is welding using protective micromachs. When using this method, not only molten metal baths are protected, but also most of the metal of the heat-affected zone heated to high temperatures. The main advantage of such chambers is the creation of a protective atmosphere with a minimum content of oxygen and nitrogen, as a result of which providing more stable mechanical characteristics. In chambers with a controlled atmosphere, it is possible to weld with a consumable and non-consumable electrode, manually or automatically [19, 20].

2. Methods and materials
In this paper, we assess the effect of the degree of rarefaction of the controlled atmosphere on the quality of metal protection and the parameters of the weld during arc welding in a controlled atmosphere.

For the experiments, we used an experimental setup for the vacuum-arc layer-by-layer synthesis of metal products, developed on the basis of the electron-beam installation (EBI-M). The installation includes: a vacuum chamber with a volume of ~ 1 m³, equipped with a four coordinate CNC moving mechanism, a control panel for a vacuum system with vacuum gauges; plasma gas supply system; universal welding inverter with a water-cooled torch; liquid cooling unit.

A universal welding inverter FLAMA TIG 200E AC / DC PULSE was used as a power source. As a torch, a standard welding torch for welding with a non-consumable electrode was used. To cool the burner, the Miller Coolmate 3 liquid cooling unit was used.

The chamber was evacuated, followed by filling with premium grade argon (99.993%) until a residual pressure of 1000 mbar was reached in increments of 100 mbar. After that, welding passes were carried out (without the use of filler material) on 3 mm thick plates of steel 12Cr18Ni10Ti (analogs of AISI 304, AISI 316, AISI 321) in a protective atmosphere at various values of residual pressure. The chemical composition of steel 12Cr18Ni10Ti is presented in table 1. The parameters of the welding mode are presented in table 2.

| Table 1. Chemical composition of steel 12Cr18Ni10Ti. |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | C | Fe | Cr | Ni | Ti | Mn | Si | Cu | P | S |
| Content, % | ≤0.12 | 67 | 17-19 | 9-11 | 0.4-1 | ≤2 | ≤0.80 | ≤0.3 | ≤0.035 | ≤0.02 |

| Table 2. Welding modes. |
| --- | --- | --- | --- | --- |
| Arc current, A | 80 | Welding speed, mm/s | 7.5 | Arc gap, mm | 3 | Used electrode | WL-20 | Diameter of electrode, mm | 3.2 |

3. Results
The obtained welding results are presented in Figure 1. At a residual pressure of 100 mbar, it was not possible to initiate the welding process. Additionally, a study was conducted on a RHEN-602 hydrogen analyzer to determine the hydrogen content in welds. The measurement results are presented in Figure 1.

Next, macro sections were made from the welds obtained. The appearance of macro sections is shown in Figures 2–10.

On the obtained microsections, the main parameters of the welds were measured and the coefficients of their shape $\varphi_w$ were calculated. The main parameters were taken the width and depth of penetration of the weld. The shape factor $\varphi_w$ of the weld is the ratio of depth to penetration width. The obtained measurement and calculation results are presented in table 3.
**Figure 1.** Results of the effect of the degree of rarefaction on the quality of protection of the weld: 1 – chamber pressure 200 mbar, mass fraction of H\(_2\) 0.0004 %; 2 – chamber pressure 300 mbar, mass fraction of H\(_2\) 0.0004 %; 3 – chamber pressure 400 mbar, mass fraction of H\(_2\) 0.0003 %; 4 – chamber pressure 500 mbar, mass fraction of H\(_2\) 0.0002 %; 5 – chamber pressure 600 mbar, mass fraction of H\(_2\) 0.0003 %; 6 – chamber pressure 700 mbar, mass fraction of H\(_2\) 0.0002 %; 7 – chamber pressure 800 mbar, mass fraction of H\(_2\) 0.0002 %; 8 – chamber pressure 900 mbar, mass fraction of H\(_2\) 0.0001 %; 9 – chamber pressure 1000 mbar, mass fraction of H\(_2\) 0.0001 %.

**Figure 2.** Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 200 mbar.

**Figure 3.** Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 300 mbar.
Figure 4. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 400 mbar.

Figure 5. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 500 mbar.

Figure 6. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 600 mbar.

Figure 7. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 700 mbar.

Figure 8. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 800 mbar.

Figure 9. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 900 mbar.
Figure 10. Macro section of a weld obtained at a pressure in a chamber with a controlled atmosphere of 1000 mbar.

Table 3. Values of parameters and shape factors of welded passages.

| No. | Pressure, mbar | Width of penetration, mm | Depth of penetration, mm | The shape factor seam $\varphi_w$ |
|-----|----------------|--------------------------|--------------------------|----------------------------------|
| 1   | 200            | 2.61                     | 0.67                     | 0.257                            |
| 2   | 300            | 3.01                     | 1.00                     | 0.332                            |
| 3   | 400            | 3.08                     | 1.34                     | 0.435                            |
| 4   | 500            | 3.15                     | 1.37                     | 0.435                            |
| 5   | 600            | 3.01                     | 1.41                     | 0.468                            |
| 6   | 700            | 3.15                     | 1.41                     | 0.448                            |
| 7   | 800            | 3.15                     | 1.61                     | 0.511                            |
| 8   | 900            | 2.88                     | 1.64                     | 0.569                            |
| 9   | 1000           | 3.15                     | 1.94                     | 0.616                            |

Based on the obtained measurement and calculation results, graphs of the dependences of the width and depth of penetration, as well as the shape coefficient of the weld $\varphi_w$ on the pressure in the chamber, are plotted, the dependency graphs are shown in Figures 11, 12, 13.

Figure 11. Graph of penetration width versus chamber pressure.
Figure 12. Graph of penetration depth versus chamber pressure.

Figure 13. The dependence of the joint shape factor $\phi_w$ on the pressure in the chamber.

4. Discussion
From the obtained experimental results, it is seen that with an increase in the pressure of the protective gas in the chamber and its equalization with atmospheric, an improvement in the quality of metal protection is observed. At a pressure of 200 mbar, a large number of oxide films and deposits are observed in the area of the heat-affected zone on the surface of the welding arc.

After increasing the pressure to 400 mbar, the quality of protection improves, this can be judged by the reduction of soot in the heat-affected zone, it is practically absent. The surface of the seam is less contaminated, but also has a yellow tint, indicating poor metal protection.

At a pressure of 800 mbar, the degree of protection improves, oxide films are completely absent on the surface of the weld, but this protection is not enough for the metal of the heat-affected zone, a thin strip of soot along the weld indicates this.
After equalization of the chamber pressure with atmospheric (1000 mbar), the metal protection becomes satisfactory, however, a small deposit is present in the zone of metal heating to high temperatures. This is due to the fact that, in the presence of even a small admixture of atmospheric gas in argon, the degree of protection is significantly reduced. To improve protection, it is advisable to use additional purification of argon poured into the chamber.

As the pressure in the chamber increases, the penetrating ability of the arc increases by more than 1 mm. The penetration width also tends to increase as the pressure in the chamber approaches atmospheric pressure, this increase is not significant and is within 0.5 mm. Accordingly, the joint shape factor $\phi_n$ will increase, since it is directly related to the width and depth of penetration.

5. Conclusion
The influence of the degree of rarefaction of the controlled atmosphere on the quality of protection of the weld metal and the heat-affected zone is assessed. With increasing pressure of a controlled atmosphere, the quality of protection improves. When the residual pressure of the controlled atmosphere is close to atmospheric, the quality of protection of the weld metal and the heat-affected zone is satisfactory.

Dependencies are obtained that describe the effect of the degree of rarefaction on the parameters and shape factors of the welded passages. With increasing pressure increases the depth and width of penetration.

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