

Method for calculating the minimum thickness of a layer of a heat-resistant coating for protecting the surface of the welded products from drops of molten metal when welding in CO₂

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Abstract. In the industry, welding in shielding gases occupies a leading position, both in Russia and abroad. The main disadvantage of welding in carbon dioxide is the increased spattering of the metal. Reduce the adhesion of molten metal to the product can be, covering the metal with a protective layer in the form of a solution of substances. The thickness of this layer will depend on the metal.

1. Introduction

The work calculates the minimum permissible thickness of the heat-resistant coating to prevent welding of molten metal droplets with the surface of the welded products outside the welding zone. The dependence of the thickness of the protective coating layer on the specific heat consumption (q_n) and its combustion (evaporation), size (r_k) and the initial metal temperature (T_0) drops, as well as on the time of its flight (t) before contact with the surface of the welded product and the details of the welding equipment.

2. Main part

In the welding industry, various heat-resistant coatings are widely used in welding in CO₂ to protect the surface of welded products and welding equipment from drops of molten metal [1-7]. The paper presents a methodology for calculating the minimum thickness of the protective coating layer of welded products and elements of welding equipment.

Solving the task, we take into account that:

1) at the moment of contact of the drop with the surface of the weld metal and the parts of the welding torch, the amount of heat

$$Q_k > Q_{\min}; \quad (1)$$

2) The droplet adheres to the surface of the weld metal after the existing coating burns (evaporates) from the contact surface;



3) in determining Q_k the heat losses of the droplet were taken into account for radiation, convection, and combustion (evaporation) of the coating

$$Q_k = Q_0 - Q_{rad} - Q_{kon} - Q_{sp}, \quad (2)$$

where Q_0 – the amount of heat of the drop metal at the initial instant of time (the moment of detachment from the electrode);

$Q_{rad, kon}$ – loss of heat drops at the time of its flight due to radiation and convection;

Q_{sp} – loss of heat drop on the combustion coating.

The amount of heat of the metal of the electrode drop at the initial instant is determined by the known formula

$$Q_0 = V_k \cdot \gamma_g \cdot T_0 \cdot C_k, \quad (3)$$

where V_k – volume of a drop;

$C_k \gamma_g$ – specific heat and density of liquid metal at temperature T_0 ;

T_0 – the temperature of the metal droplets at the time of its detachment from the electrode. The loss of heat during the flight of a drop due to radiation is determined by the equation

$$Q_{rad} = m_k \cdot C_k \cdot T_0 \cdot \left(1 - \frac{1}{\sqrt[3]{1 + \frac{3\varepsilon\sigma_0 F_k}{C_k \cdot m_k} T_0^3 t}} \right) \quad (4)$$

and due to convection - by the equation

$$Q_{kon} = at(T_0 - 290) \cdot F_k. \quad (5)$$

Then the total heat loss, taking into account radiation and convection, is

$$Q_{rad, kon} = C_k m_k \left[T_0 \left(1 - \frac{1}{\sqrt[3]{1 + \frac{3\varepsilon\sigma_0 F_k}{C_k m_k} T_0^3 t}} \right) + F_k \frac{at(T_0 - 290)}{C_k m_k} \right]. \quad (6)$$

Substituting $F_k = 4\pi \cdot r_k^2$ и $m_k = \frac{4\pi \cdot r_k^3}{3} \gamma_g$, we get

$$Q_{rad, kon} = C_k m_k \left[T_0 \left(1 - \frac{1}{\sqrt[3]{1 + \frac{9\varepsilon\sigma_0}{C_k \gamma_g r_k} T_0^3 t}} \right) + 3 \frac{at(T_0 - 290)}{C_k \gamma_g r_k} \right], \quad (7)$$

Where ε – black ratio;

σ_0 – coefficient of proportionality;

F_k – radiation surface of a drop;

m_k – mass of a metal drop;

t – flight time drops;

r_k – radius of a drop;

a – heat transfer coefficient;

γ_g – density of liquid metal;

$\gamma_g \cdot C_k$ – respectively, the density and heat capacity of the gas at 20° C;

V_r – gas flow rate.

Getting to the part, the drop gives some of its heat to the burning (evaporation) of the coating Q_{sp} .

This part of the heat can be determined from equation

$$Q_{sp} = q_p V_p, \quad (8)$$

where q_p – specific heat consumption per unit of combustion volume combustion;

V_p – volume of combustible coating.

The volume of the burnable coating depends on the thickness of its layer, the shape and size of the drop, for the determination of which special experiments were performed on surfacing on steel specimens of St3 rollers measuring 400x400x6 mm. Welding was carried out in carbon dioxide gas with a Sv-08Mn2Cr wire with a diameter of 1.6 mm. Welding modes: $I_{CB}=300...320A$; $U_{CB}=30...32 B$. After welding, the maximum width of the droplet drop zone was determined on the surface of the article and the size of the drops welded with the cleaned surface of the sample at a different distance from the weld. The size of the drops (r_k) was determined by their mass after removal from the surface of the sample. In the control experiments along the welded seam, an asbestos cloth was laid, from which droplets were then removed, weighed and their dimensions determined. It should be noted that the drops collected from the asbestos cloth had a shape close to the ball, and the drops collected from the surface of the metallic sample had significant deviations from this shape, approaching the shape of the hemisphere. That is why the radius of the droplet was determined by calculation and experiment, depending on its mass. Simultaneously, the temperature of the metal droplets was determined by the calculation method at the moment of contact with the surface of the sample, depending on their size and flight distance:

$$T_k = T_0 - \Delta T_k, \quad (9)$$

where T_k – the temperature of the drop metal at the moment of contact with the metal surface;

ΔT_k – drop in the temperature of the drop metal during its flight:

$$\Delta T_k = \frac{Q_{rad,kon}}{C_k \cdot m_k}. \quad (10)$$

Substituting the value $Q_{rad,kon}$ from equation (7), we obtain

$$\Delta T_k = T_k \left[1 - \frac{1}{\sqrt[3]{1 + \frac{9\varepsilon\sigma_0}{C_k \cdot \gamma_g \cdot r_k} T_k^3 t}} + 3 \frac{at(T_k - 290)}{C_k \cdot \gamma_g \cdot r_k} \right]. \quad (11)$$

Based on the results of the calculated data, a graphic dependence of the temperatures on the droplet size was constructed. From Fig. 1 that the temperature of a drop of molten metal depends on its size. It was shown that droplets with a radius of $0.1 \cdot 10^{-2} m$ have a temperature of 2600 ... 2790 K, and a radius of $0.2 \cdot 10^{-2} m$ - 2850 ... 2920 K.

Knowing the size and shape of the droplet, the speed of its flight and the maximum distance on which it still adheres to the metal surface, using equations (3) - (11), it is possible to determine the minimum

values of the heat quantity and the temperature of the droplet metal at the moment of their contact with the surface of the part, sufficient for a strong grip.

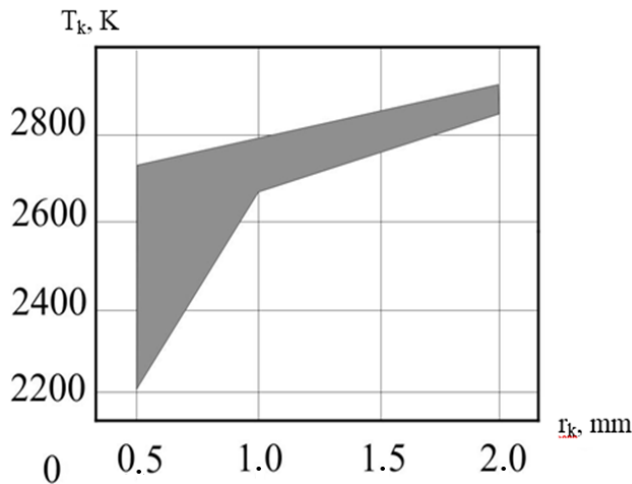


Figure 1. Dependence of the temperature of the metal droplets on their size at the moment of contact with the sample surface

Thus, according to experiments [1-4], droplets of a radius are welded to the surface of the part $r_k \geq 0,5$ mm at a distance of not more than 120 mm from the seam. The calculation shows that at the moment of contact with the surface the drop has about 7 J of heat, and the metal temperature reaches 2253 K.

Therefore, to prevent welding of the molten metal droplets to the surface of the part, it is necessary to apply a protective coating layer, upon combustion of which the droplet consumes all the excess heat and is cooled to a temperature less than 2253 K, i.e. its amount of heat will be:

$$Q_{\min} = 2253 \cdot C_k \cdot \gamma_{2253} \cdot V_k. \quad (12)$$

To calculate the thickness of such a coating (h_p), it is assumed that the volume of the coating that is burned by a drop equals the volume of the cylinder whose cross-sectional radius is equal to the radius of the drop, and the height to the thickness of the coating layer;

$$V_p = \pi \cdot r_p^2 \cdot h_p. \quad (13)$$

Then from (13), taking into account (2) - (7), (8), (10), (11) it is possible to obtain after corresponding transformations:

$$h_p \geq \frac{4r_k \cdot \gamma_g \cdot C_k}{3q_p} \left[T_0 - 2253 \frac{C_k \cdot \gamma_{2253}}{C_k \cdot \gamma_g} - \right. \\ \left. - T_0 \left(1 - \frac{1}{\sqrt[3]{1 + \frac{9\varepsilon\sigma_0}{C_k \cdot \gamma_g \cdot r_k} T_0^3 t}} \right) + 3 \frac{at(T_0 - 290)}{C_k \cdot \gamma_g \cdot r_k} \right] \quad (14)$$

3. Conclusion

Analysis of equation (14) shows that the thickness of the protective coating layer depends on the specific heat consumption (q_p) and its combustion (evaporation), size (r_k) and the initial metal temperature (T_0) drops, as well as on the time of its flight (t) before contact with the surface of the welded product and the details of the welding equipment. Consequently, the minimum required

thickness of the protective coating should be determined based on the maximum possible size of the molten metal droplets and the minimum distance of their flight. Then, knowing the specific heat consumption (q_p) on combustion of a unit of the volume of the coating, it is possible to determine by calculation the minimum necessary thickness for the purpose of preventing the welding of the largest drops with the surface of the products. The consumption of the metal necessary for the combustion (evaporation) of the coating depends on the physical-chemical properties of the coating.

An experimental test showed that the discrepancy between the calculated and experimental values (h_p) is from 1 to 14%. Consequently, the proposed equation allows us to calculate the optimal thickness of the coating layer by calculation, at which the droplets are not welded to the surface of the part.

4. References

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