

The mechanism of heat distribution in welded joints made with the use of protective coatings

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Abstract. In the industry, welding in carbon dioxide takes a leading place, both in Russia and abroad. The main disadvantage of welding in CO₂ is the increased spattering of the metal. Reduce the spraying can be done by coating the metal by protective layer in the form of a solution of substances.

Introduction

Welding in CO₂ found its application in many areas of industry. This method has many advantages, but also there are drawbacks. One of the drawbacks that should be paid attention to is the increased spattering of metal, as well as the spraying of the surface of the welded products, welding equipment parts and assembly and welding devices. Because of this shortage, a greater consumption of the vibrating tool takes place, energy and an increase in surface cleaning operations from splashes of molten metal become more labor-intensive. The deterioration of the protection of the welding zone, leading to the formation of pores in the weld metal, as well as the additional heating of the parts of the welding torch, which leads to premature failure of the equipment, is due to the splashing of the gas supply nozzle of the burner. It was revealed that the incidence of vibration by workers working on cleaning surfaces from splashes of molten metal begins to develop after 7 ... 8 years of operation.

Various foreign and Russian scientists are engaged in identifying methods of struggle and the nature of the spray. To minimize spattering, it is necessary to find the optimal welding regimes in CO₂, providing control over the transfer of electrode metal; to develop welding materials that stabilize arc combustion and affect the transfer of electrode metal [1].

The consequences of spraying has another big problem – it is spraying. To reduce the spraying, a protective coating (PC) can be applied. PC is a protective layer in the form of a solution, which is applied to the surface of the metal to be welded; it dries before welding and anti-adherence spatter to the base metal. To reduce the spatter of welding equipment, PC is applied to the nozzle of the burner or the design of the apparatus is changed.

PC has a number of requirements; the main is the heat resistance of the coating components. Its sufficiency depends on the nature of the interaction of splashes of molten metal with the surface of the



welded article. The theory of the interaction of splashes with the surface develops and is constantly supplemented with new information allowing to increase the protective properties of coatings [1].

2 The main part

By applying a protective coating to the surface of the product, a surface-coating system is conditionally formed; the coefficients of thermal conductivity λ and thickness δ are different.

For example, let us take a semi-infinite body with a protective coating of a certain thickness δ_{zp} applied to it. The contact point (temperature) will be denoted by T . The temperature of the outer layer T_{zp} is known. Thermal contact between surfaces is ideal [2].

We select in the semi-infinite body (Figure 1) an element equal to the thickness of the plate with the initial temperature of the layer T .

The temperature of the outer layer is found from the theory of thermal conductivity. The density of the heat flux in the stationary regime is constant and in all layers has the same values. We write:

$$q = \frac{\lambda_{zp}}{\delta_{zp}} (T - T_{zp}) \quad (1)$$

The temperature head in the layer through the coating is determined from equation (1):

$$T - T_{zp} = q \frac{\delta_{zp}}{\lambda_{zp}} \quad (2)$$

from here we find the temperature T_{zp} :

$$T_{zp} = T - q \frac{\delta_{zp}}{\lambda_{zp}} \quad (3)$$

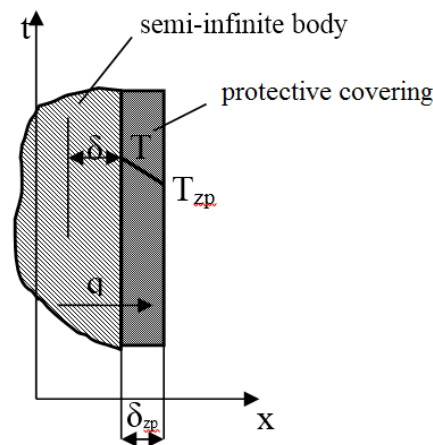


Figure 1. Scheme of temperature distribution using a protective coating.

Thus, the temperature of the outer layer depends on the values of the thermal resistances and the thickness of the protective coating.

Protective coatings have different coefficients of thermal conductivity. Consequently, the heat flux passing through the coating can have different values. The lower the heat flux density, the greater the thermal conductivity of the protective coating. It also affects the distribution of residual stresses. Due to the presence of coating layers, after welding, there is no rapid removal of heat from the plate, which promotes stress relaxation (local tempering).

Another factor that affects the distribution of residual stresses is temperature. About the time of welding, the source of heat is in constant movement. Temperatures of body points increase, reaching a maximum value, and subsequently decrease. At points more distant, the rise and fall of temperature is slower. Due to uneven heating of the metal and its expansion, welding stresses arise. The cooling temperature depends on many factors: the remoteness of the point in question from the seam, the parameters of the welding regime and the thermophysical properties of the material.

The coatings used to protect the welded articles from droplets (splashes) of molten metal when welding in CO₂ are complex. Thermophysical properties are different. Protective coatings are solutions and melts of high molecular weight polymers, colloidal suspensions, concentrated suspensions of various hard or ductile materials, etc. Since the protective coating affects differently the cooling rate, it will also affect the distribution of residual stresses.

The first time derivative of the temperature is the instantaneous cooling rate ω :

$$\omega = \frac{dT}{dt} \quad (4)$$

Determination of the cooling rate for butt-welding of the plates by equation (5):

$$\omega = -2\pi\lambda c\gamma \frac{(T - T_n)^3}{[q / (V\delta)]^2} \quad (5)$$

where λ – coefficient of thermal conductivity; c – specific heat; γ – density; T_n – heating temperature; T – the temperature to which the metal is heated; q/V – effective linear energy; δ – plate thickness. Welding was done without heating

We will replace $T - T_n = T - T_{zp}$ – the temperature flux through the coating, we put this value in equation (5) and after the transformations we obtain:

$$\omega = -2\pi\lambda c\gamma \frac{(T - T_{zp})^3}{[q / (V\delta)]^2} \quad (6)$$

Cooling rate through coating:

$$\omega_{zp} = -2\pi\lambda_{zp} c_{zp} \gamma_{zp} \frac{(T - T_{zp})^3}{[q / (v\delta_{zp})]^2} \quad (7)$$

In equation (7) we substitute the welding energy formula $q = \eta UI$. Calculations showed that the cooling rate through the protective coating layer decreased by 30-40% in comparison with uncoated samples. From equation (7), the dependence of the cooling rate on the welding energy and thermal properties of the coating is seen.

The theoretical data presented in Fig. 2 were obtained by substituting the values of the thermophysical characteristics of the protective coatings in equations (3) and (7).

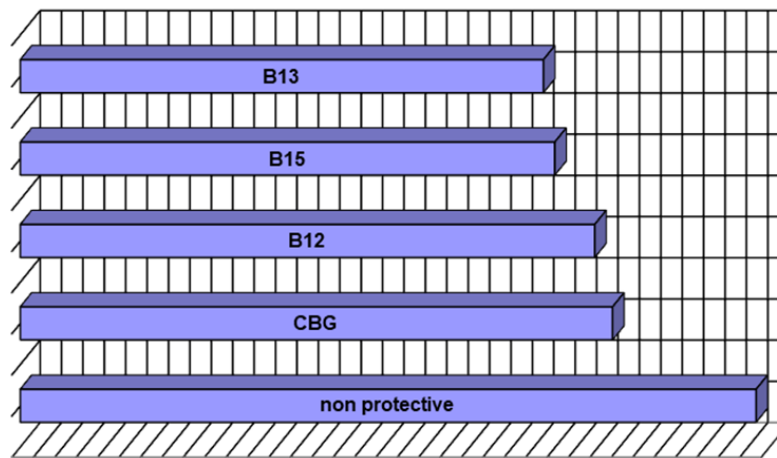


Figure 2. Calculated values of the plate-cooling rate for welding with a protective coating and without it.

With the help of equation (8), we can determine the length of stay of the weld metal above a given temperature:

$$t = \frac{1}{4\pi a(T - T_{zp})^2} \left(\frac{q}{v_c \delta_{zp} c_{zp} \gamma_{zp}} \right)^2 \quad (8)$$

The residence time of the weld metal above a predetermined temperature depends on the thermophysical properties of the protective coatings and on their thickness.

The substances have a coefficient of thermal conductivity λ is different and depends on density, pressure, structure, humidity and temperature [3-7]. First of all, it is important to know the dependence of the thermal conductivity coefficient on temperature, since the temperature at different points differs in the distribution of heat. For most materials, the dependence of thermal conductivity on temperature has a linear character:

$$\lambda = \lambda_0(1 + bt) \quad (9)$$

where λ_0 – coefficient of thermal conductivity at temperature t_0 ; b – a constant determined experimentally.

In Table 1, the results of studies for determining the thermophysical properties of protective coatings are presented.

Table 1. Thermophysical properties of protective coatings.

Nº	Protective	$\gamma, 10^{-3} \text{ kg}/10^{-6} \text{ m}^3$	$c\gamma, \frac{\text{J}}{10^{-3} \text{ m}^3 \text{ } ^\circ\text{C}}$	$\lambda, \frac{\text{W}}{10^{-3} \text{ m}^3 \text{ } ^\circ\text{C}}$	$a \cdot 10^{-6}, 10^{-3} \text{ m}^2/\text{s}$
1	MB	2.016	2065.6	0.002604	1.26
2	CBG	1.256	595.4	0.006757	11.35
3	B12	1.521	928.1	0.0074975	8.08
4	B13	1.878	2254.5	0.0085868	3.81
5	ALD	2.758	390.7	0.004307	11.02
6	MGS	1.256	292.1	0.0059701	20.43

7	AGS	2.616	437.4	0.0024218	5.53
8	CPR	1.989	1101.1	0.0064275	5.83

Based on the above data, it is possible to make an assumption about the distribution of residual stresses when welding along the protective coating layer and without it. The rate of plate cooling depends on the composition of the protective coating. The greater the thermal properties and the thickness of the coating, the lower the cooling rate and the residual stresses. However, it is possible, if it was evenly applied.

Equation (10) describes the distribution of temperatures when welding plates without a protective butt-end covering, considering heat transfer:

$$\Delta T = \frac{q / \delta}{4\pi c \gamma a t} e^{-r^2 / 4at} \beta(t) \quad (10)$$

where $\beta(t)$ – heat transfer function, $\beta(t) = e^{-bt}$; $b = \frac{2\alpha_T}{c\gamma\delta}$.

When welding plates with a protective coating, equation (10) will look like this:

$$\Delta T = \frac{q / \delta}{4\pi c \gamma a t} e^{-\left(\frac{r^2}{4at} + \frac{2\alpha_T t}{c_{zp} \gamma_{zp} \delta_{zp}}\right)} \quad (11)$$

By the equations (10) and (11), the temperature fields in the plates with protective coating and without it were built after welding in the period of temperature equalization (Fig. 3).

The graphs show that in the plates with different protective coatings at the same time a diverse temperature distribution.

According to theoretical data, an experiment was conducted. Samples for welding were made of steel sheet St 3 5 mm thick. Figure 4 shows the installation diagram. On the surface of each plate was applied a rectangular grid, the dimensions of the cells 10 × 10mm. In a certain sequence, chromel-alumel thermocouples were located at the grid nodes.

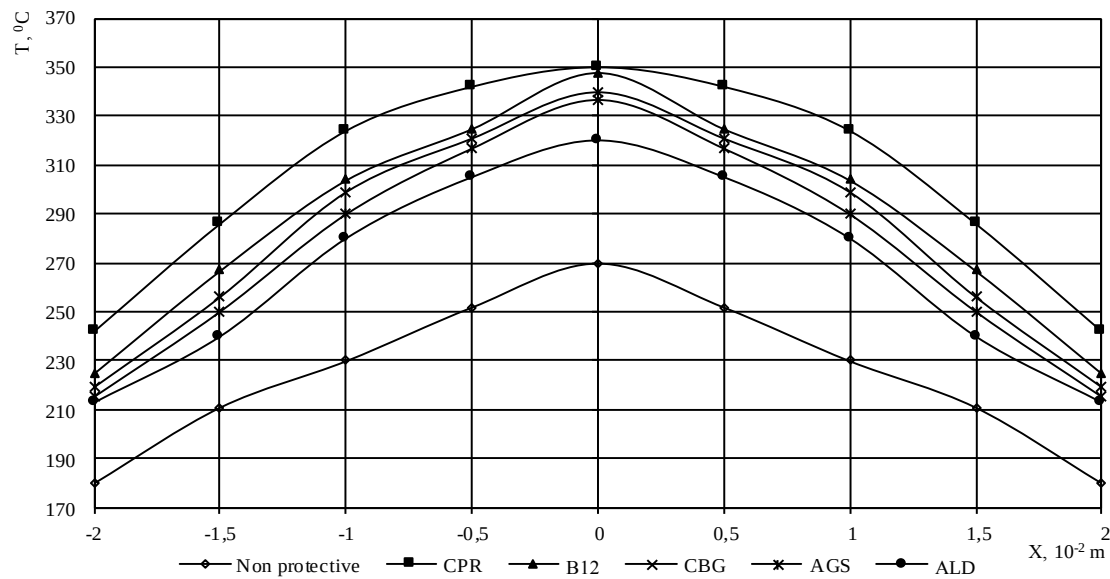


Figure 3. Distribution of temperature increments in sections parallel to the X axis in plates with different protective coatings and without it.

Welding was carried out in carbon dioxide, wire Sv-08Mn2Cr with a diameter of 1.6 mm in one pass (welding current 300 A, arc voltage 28 V).

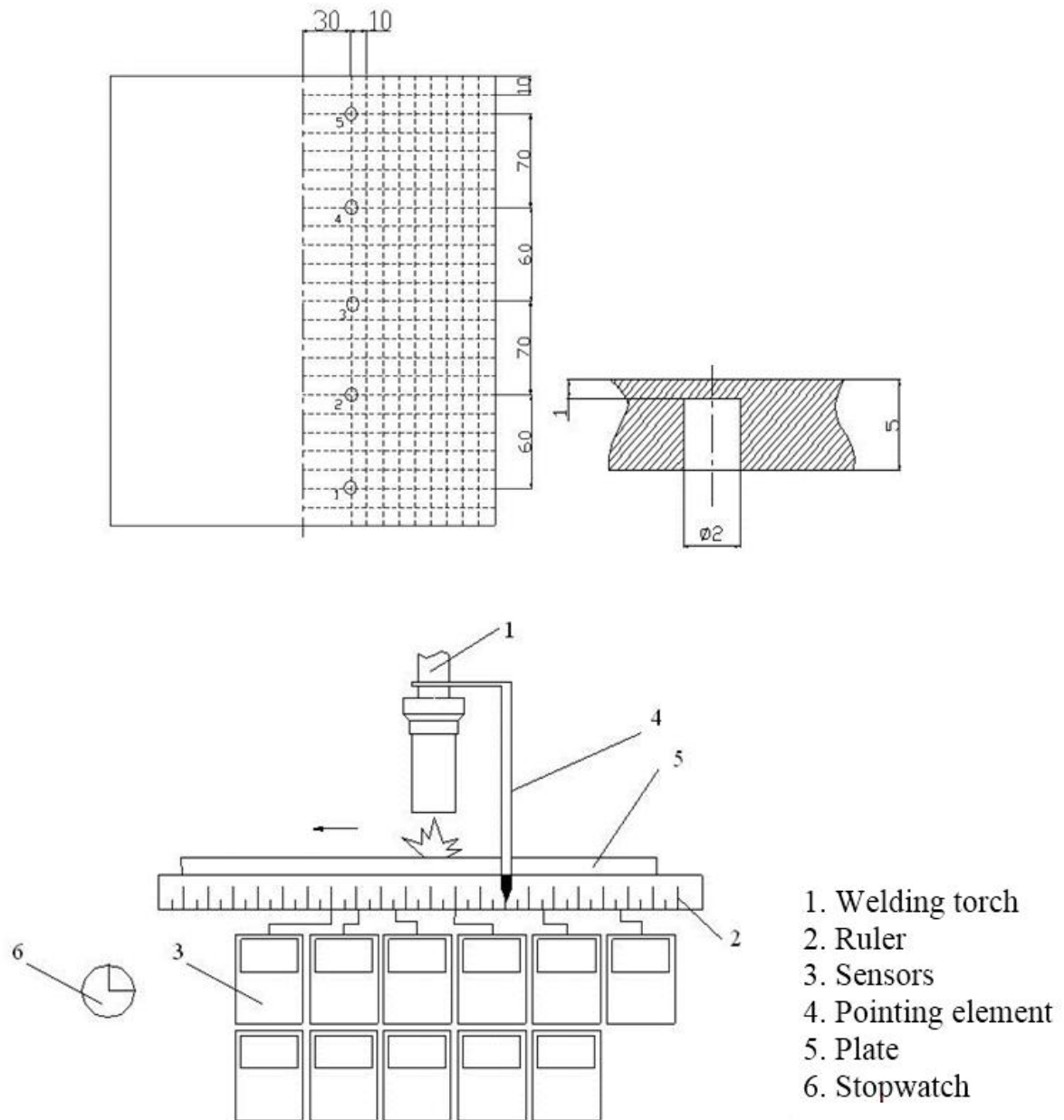


Figure 4. The scheme of the experimental setup.

According to the previously reported data, experimental dependences of the product temperature on the welding time with and without protective coatings for welding in carbon dioxide were constructed.

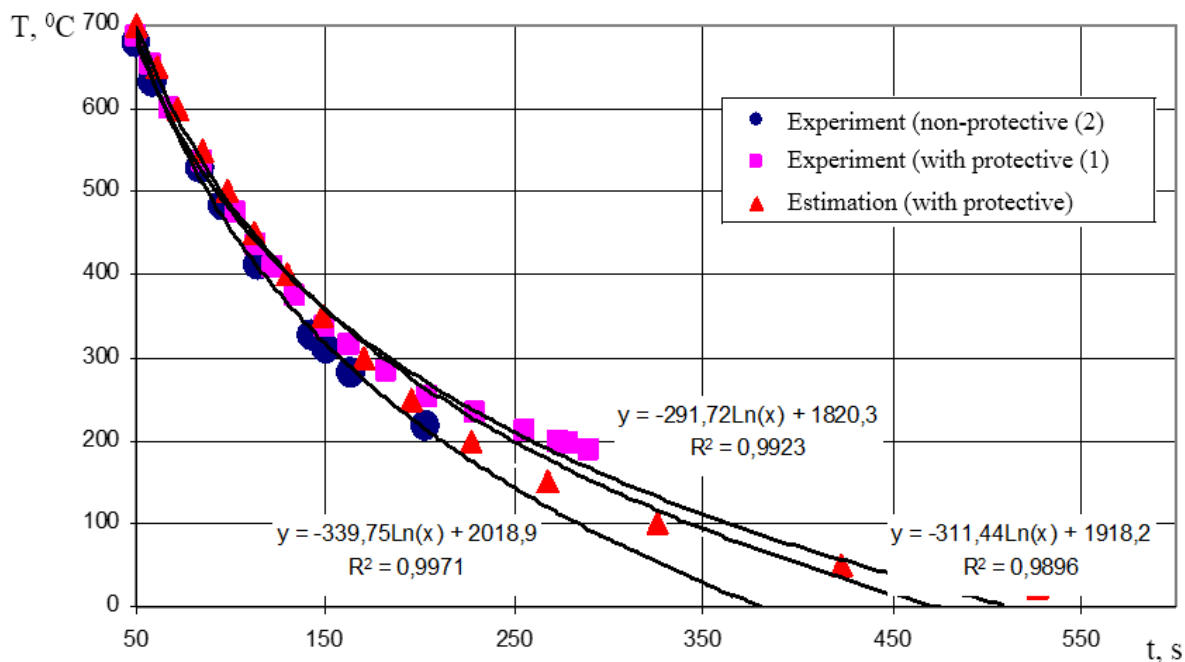


Figure 5. Experimental dependence of the product temperature on the welding time with and without protective coatings for welding in CO₂.

Analyzing the graph (Figure 5), we observe a decrease in the cooling rate of the welded article during welding with the use of protective coatings. There is a decrease in the cooling rate because the protective coating prevents the free flow of heat from the plate. The larger the volume heat capacity, the slower the plate cools down.

Conclusion

A protective coating is the main method of controlling the spraying of the metal surface during welding.

All coatings have different coefficients of thermal conductivity. Passing through the coating heat flow, also has different values. The lower the heat flux density, the greater the thermal conductivity of the protective coating. This affects the distribution of residual stresses.

Analyzing the plotted temperature fields in plates with a protective coating and without it after welding in the period of temperature equalization, it is evident that at the same time in the plates with different protective coatings the temperature distribution is diverse. Protective coating prevents free flow of heat from the plate.

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