The influence of coatings heat resistance on the effectiveness of protecting a solid metal surface from drops of molten metal during MAG welding

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Abstract. A technique is proposed for determining the heat resistance of protective coatings. The use of this technique allowed determining the most effective coatings in terms of heat resistance, for example, PZ-1 and PZ-2, which can be recommended for widespread use in welding production.

1. Introduction
One of the requirements for protective coatings [1–9] is to ensure reliable protection of welded products from drops of molten metal during MAG welding. For this purpose, heat-resistant fillers are introduced into them.

However, the methods for determining the heat resistance of protective coatings are currently insufficiently studied. This paper presents the results of a study of the influence of both the components that make up the coatings and the protective coatings themselves on the temperature of a calorimetric system with a previously known effective heat capacity, based on experimental data, coating compositions are determined that most effectively protect the surface of the welded products from drops of molten metal during MAG welding.

It is based on the method for determining the heat of solid fuels combustion. Since the specific heat of coal combustion is a known value, coal was chosen as the main component, and the coating components and coatings themselves served as additives to coal.

2. The main part
The studies were carried out on a calorimeter B – 08 – MA, it is a device consisting of the calorimeter itself and the recorder. The principle of operation of the calorimeter is to measure the temperature change of the calorimetric system with a previously known effective heat capacity when burning a strictly defined amount of the test substance. For experiments, briquettes weighing 1.0 g were made using a press, a general view of which is shown in figure 1. A loaded bomb (figure 2) was installed in the calorimetric vessel shown in figure 3, the rest of its cavity was filled with distilled water. After the explosion (burning) of the test substance in an oxygen medium, temperature changes were recorded according to a metastatic thermometer using the optical system that equipped the device.
Figure 1. Briquetting press: 1 – base; 2 – matrix; 3 – needle; 4 – rack; 5 – handle; 6 – screw; 7 – a guide; 8 – pusher; 9 – a punch; 10 – a level with a groove; 11 – folding bar.

Figure 2. Calorimetric bomb: 1 – locknut; 2 – metal ring; 3 – flare nut; 4 – rubber gasket; 5 – cover; 6 – case.
The calorific value in the bomb of the tested analytical fuel sample (test substance) \(Q_b^a\) in J/kg is calculated by the formula:

\[
Q_b^a = \frac{c \cdot K \cdot [(n_2 + \Delta n_2) - (n_1 + \Delta n_1) + \Delta n] - \tau_1 q}{\tau},
\]

where:
- \(c\) – calorimetric system heat capacity, J/°C;
- \(K\) – thermometer scale division value, 0°C;
- \(n_1\) – thermometer reading corresponding to the initial temperature of the main period in the divisions of the thermometer scale;
- \(\Delta n_1\) – correction to thermometer readings per gauge (when reading thermometer \(n_1\)) in scale divisions;
- \(n_2\) – thermometer reading corresponding to the final temperature of the main period in the divisions of the thermometer scale;
- \(\Delta n_2\) – correction to thermometer readings per gauge (when reading thermometer \(n_2\)) in scale divisions;
- \(\Delta n\) – correction to thermometer readings, taking into account the heat exchange of the calorimeter with the environment in the divisions of the thermometer scale;
- \(\tau_1\) – mass of wire taken for igniter, kg;
- \(q\) – calorific value of the ignition wire burning, J/kg;
- \(\tau\) – weight of test fuel sample, kg.

The correction to the thermometer readings, taking into account the heat exchange of the calorimeter with the environment (\(\Delta \tau n\)), is calculated by the formula:
where \( v_1 \) – the average rate of change of the thermometer over a half-minute interval in the initial period in the divisions of the thermometer scale;
\( v_2 \) – the average rate of change of the thermometer over a half-minute interval in the final period in the divisions of the thermometer scale;
\( z_1 \) – the number of half-minute intervals of the main period with a rapid rise in temperature; \( z_1 \) always include the first period of the main period, regardless of the magnitude of the rise for this period;
\( z_2 \) – the number of half-minute intervals of the main period not included in the number \( z_1 \) (if the total number of half-minute intervals of the main period is \( z \), then \( z_2 = z - z_1 \)).

The number \( z_1 \) is determined depending on the value of the criterion \( a \), which is calculated by the formula
\[
a = \frac{n_2 - n_1}{n_2 - n_1}
\]
where \( n_2 \) – thermometer reading corresponding to the temperature after 2 minutes of the main period in the divisions of the thermometer scale;
\( n_1 \) – thermometer reading corresponding to the initial temperature of the main period in the divisions of the thermometer scale;
\( n_2 \) – thermometer reading corresponding to the final temperature of the main period in the divisions of the thermometer scale.

Then \( z_1 \) is defined according to table 1.

Table 1. The dependence of the number \( z_1 \) on the criterion \( a \).

| Criterion \( a \) | <0.50 | 0.50…0.64 | 0.64…0.73 | 0.73…0.8 | 0.82…0.91 | 0.91…0.95 | >0.95 |
|------------------|-------|-----------|-----------|-----------|-----------|-----------|-------|
| \( z_1 \)        | 9     | 8         | 7         | 6         | 5         | 4         | 3     |

We give an example of the calculation of combustion for a sample of pure coal: the readings of the metastatic thermometer are given in table 2. The correction to the thermometer reading, taking into account the heat exchange of the calorimeter with the environment (\( \Delta n \)), was calculated by the formula (2) with previously determined criterion \( a \):
\[
a = \frac{2.645 - 1.239}{2.720 - 1.239} = 0.95.
\]

Using table 1 we find \( z_1 = 4 \); \( z_2 = 10 - 4 = 6 \).

We calculate the average rate of change of the thermometer (\( v_1 \) and \( v_2 \)):
\[
\begin{align*}
v_1 &= \frac{1.220 - 1.239}{10} = -0.0019; \\
v_2 &= \frac{2.720 - 2.745}{10} = -0.0025; \\
\Delta n &= \frac{-0.0019 - 0.0025}{2} \cdot 4 + (-0.0025) \cdot 6 = -0.058.
\end{align*}
\]

Heat capacity \( c = 15000 \) J/°C; thermometer scale division \( K = 1.001 \) °C; correction to thermometer readings per gauge \( \Delta n_1 = 0 \) and \( \Delta n_2 = 0 \); mass of wire taken for igniter, \( \tau_1 = 0.0001 \cdot 10^{-3} \) kg; calorific value of the ignition wire burning \( q = 2.51 \cdot 10^6 \) J/kg, weight of test fuel sample \( \tau = 0.001 \) kg.
Next, by the formula (1) we calculate the calorific value:

\[
Q = \frac{15000 \cdot 1.001 (2.72 - 1.239 - 0.058) - 0.0005 \cdot 10^{-3} \cdot 2.51 \cdot 10^6}{0.001} = 21.879 \text{ MJ/kg.}
\]

**Table 2.** Thermometer reading.

| Half-minute reading numbers | Thermometer reading in scale divisions |
|-----------------------------|----------------------------------------|
| Period                      | Period                                 |
| Initial                     | Main                                   | Final      |
| Initial                     | Main                                   | Final      |
| 1                           | \( n_1,11 \) (igniter)                 | 1.221      | 2.430      | 2.720      |
| 2                           | 12                                     | 1.220      | 1.239      | 2.732      |
| 3                           | 13                                     | 1.223      | 2.542      | 2.732      |
| 4                           | 14                                     | 1.225      | 2.608      | 2.736      |
| 5                           | \( n_2,15 \)                           | 1.227      | 2.645      | 2.738      |
| 6                           | 16                                     | 1.229      | 2.678      | 2.740      |
| 7                           | 17                                     | 1.231      | 2.690      | 2.742      |
| 8                           | 18                                     | 1.233      | 2.700      | 2.743      |
| 9                           | 19                                     | 1.236      | 2.710      | 2.744      |
| 10                          | 20                                     | 1.237      | 2.716      | 2.745      |

The calculation data of the calorific value for pure coal and coal with the addition of protective coating components are given in table 3. Figure 4a shows histograms of the calorific value of pure coal and coal with the addition of protective coating components.

**Table 3.** Calculation of calorific value for pure coal and coal with the addition of coating components [1–4, 8, 9].

| No | Component                          | Calorific value, MJ/kg |
|----|------------------------------------|------------------------|
| 1  | Coal                               | 21.879                 |
| 2  | Coal + aluminum powder             | 21.693                 |
| 3  | Coal + kaolin                      | 25.184                 |
| 4  | Coal + liquid glass                | 18.462                 |
| 7  | Coal + silicone cream              | 20.397                 |
| 8  | Coal + dextrin                     | 28.925                 |
| 9  | Coal + mash liquid concentrate     | 24.954                 |
| 10 | Coal + anhydrous sodium carbonate | 19.375                 |
| 12 | Coal + silicon organic liquid      | 38.835                 |
| 13 | Coal + polyvinyl butyral           | 28.945                 |
| 14 | Coal + zircon                      | 26.679                 |
| 15 | Coal + chalk                       | 18.963                 |
An analysis of the results of the studies shows the effect of various components of the protective coatings on the specific heat of combustion of coal. Such components GKZH-94 (silicon organic liquid) as polyvinyl butyral, dextrin, zircon, KBZh (mash liquid concentrate), kaolin significantly increase it, whereas silicone cream, anhydrous sodium carbonate, chalk, liquid glass, on the contrary, reduce it. Such component as aluminum powder does not have a noticeable effect. Based on these results, it can be concluded that the heat-resistant coating should contain substances having a higher calorific value. Obviously, a large role will be played by the percentage of these substances in the coating, as well as the effect on them of other substances that make up the coating. For completeness of the analysis, the influence of the compositions of known protective coatings (table 4) on the specific heat of combustion of coal was studied.
Table 4. Common protective coating compositions.

| Coating | Composition |
|---------|-------------|
| MV      | Chalk – 35% (GOST 4415–75), water – 65% (GOST 2874–73) |
| KBZh    | Sulphite-alcohol stillage concentrate KBZh – 190 g and water 1000 g |
| PZ-1    | Sulphite-alcohol stillage concentrate KBZh – 75 g, soap – 35 g, anhydrous sodium carbonate – 25 g, water – 1000 g |
| PZ-2    | Sulphite-alcohol stillage concentrate KBZh – 85 g, soap – 35 g, kaolin – 40 g, anhydrous sodium carbonate – 37.5 g and water – 1000 g |
| AD      | Aluminum powder PAK-1 (GOST 5494–71) – 100 g, dextrin (GOST 6034–74) – 100 g and water – 1000 g |
| MZhS    | Chalk – 30%, liquid glass – 65% |
| AZhS    | Aluminum powder PAK-1 – 50 g, liquid glass – 1000 g |
| TsZhS   | Zirkon (TsMTU 4469–54) – 30%, liquid glass – 70% |
| TsPR    | Zirkon – 40%, polyvinyl butyral (GOST 9439–73) – 3%, solvent 646 (GOST 18188–72) – 57% |
| SK      | Silicone cream acc.to RTU 322–57 |

The experimental technique is similar to that described above. The calculation data of the calorific value for a sample of pure coal, as well as coal with the addition of protective coatings are given in table 5. Figure 4b presents histograms of the calorific value of pure coal and coal with the addition of protective coatings.

Table 5. Calculation of calorific value for pure coal and coal with the addition of coatings.

| No | Substance  | Calorific value, MJ/kg |
|----|------------|------------------------|
| 1  | Coal       | 21.879                 |
| 2  | Coal + AZhS| 22.199                 |
| 3  | Coal + AD  | 26.726                 |
| 4  | Coal + MZhS| 22.319                 |
| 5  | Coal + TsZhS| 22.516              |
| 6  | Coal + TsPR| 22.954                 |
| 7  | Coal + PZ-1| 23.100                 |
| 8  | Coal +PZ-2 | 24.358                 |
| 9  | Coal + SK  | 20.397                 |

As can be seen from the studies, the most heat-resistant coatings are type AD, PZ-1, PZ-2 and TsPR. The following substances give the greatest effectiveness to coatings: dextrin, zircon, kaolin, etc.

3. Conclusion

Using the technique for determining the heat resistance of protective coatings made it possible to determine the most effective coatings in terms of heat resistance: PZ-1 and PZ-2. The following substances give the greatest effectiveness to coatings: polyvinyl butyral, dextrin, zircon, etc.
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