Modification of structure and properties of metal of permanent joint formed in mode of pulsed change of energy parameters of mode

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Abstract. In Russia, as in other industrialized countries, is developing new welding technologies, which refers to the main methods of obtaining permanent connections in the manufacture of machine parts and structures. The possibilities of improving the quality of welded joints using the widespread in domestic and foreign production methods of DC arc welding are already largely exhausted. Ensuring the possibility of controlling the melting capacity of the arc, welding at increased gaps, in various spatial positions, reducing the spraying of the electrode metal, increasing the stability of the arc and its combustion, reducing labor and saving material resources. Thus, there is a situation when it is necessary to conduct additional research in order to optimize the existing technology. The objective of the work: to study the capabilities of modes of pulsed arc welding and surfacing on the structure and properties of permanent joints during manual arc welding and surfacing with coated electrodes.

1. Introduction

In Russia, as well as in other industrially developed countries, new welding technologies are being developed, which relates to the basic methods of obtaining permanent joints in manufacture of machine elements and constructions. Possibilities of improving the quality of welded joints using widespread methods of DC arc welding in domestic and foreign production are already significantly exhausted [1-3]. However, providing a possibility of controlling the arc melting capacity, increased gap welding in different spatial positions, a reduction of electrode metal spattering, an increase of stability of arc excitation and its burning, a decrease of labor costs and saving in material resources [4-5] and other effects become unavailable when solving complex production problems, based on application of traditional technologies in stationary modes. The mentioned circumstance limits the possibilities of traditionally applied welding methods and requires execution of additional research works to optimize the existing technology and to improve the efficiency of welding, fabricating and repair works [6].
2. Experimental procedure, applied materials and technologies
To conduct studies of influence of arc surfacing modes using direct current and during pulsed change of energy parameters of the mode, steel 09G2S, widely applied in the manufacture of various metal structures, was used.

To prepare the research samples, multi-pass welding of plates from steel 09G2S with a 6 mm thickness was carried out including the modes of formation of root and capping passes obtained using two methods: direct current and the mode of pulsed change of energy parameters of the mode. An experimental research complex consisting of inverter power source FEB-315 "MAGMA", having a mode of pulsed arc welding and surfacing, sensors that measure the main energy parameters of the mode, parameter recorder AWR-224 MD and a personal computer was applied.

For welding and surfacing, plates with dimensions of 100×50×6 mm were used. Seams were applied using LB-52U electrodes that are widely applied for performing welding, fabricating and repair works. Welding and surfacing were carried out in two passes: root and capping. Parameters of welding and surfacing modes using direct current (DCW) and in the mode of pulsed change of energy parameters (CMT) are given in tables 1 and 2.

The characteristic oscillograms of the main parameters of modes of current and arc voltage are given in figure 1. The parameters of the surfacing process were registered by means of device AWR-224 MD.

| Table 1. Parameters of direct current mode. |
|--------------------------------------------|
| Pass | $I$, A | $U$, B | $V_w$, m/h | Heat input level, kJ/m |
| Root | 90   | 25   | 4.9  | 1405 |
| Capping | 150  | 25   | 6.99 | 1642 |

where $V_w$, m/h – travel speed.

| Table 2. Parameters of pulsed arc mode. |
|----------------------------------------|
| Pass | $I_p$, A | $I_p$, A | $t_p$, s | $t_p$, s | $U$, B | $V_w$, m/h | Heat input level, kJ/m |
| Root | 90   | 40   | 0.3  | 0.3  | 20  | 4.29 | 1017 |
| Capping | 180  | 50   | 0.3  | 0.3  | 24  | 6   | 1606 |

where $I_p$ – pulse current; $I_p$ – pause current; $t_p$ – pulse time; $t_p$ – pause time; $V_w$ – travel speed

Figure 1. Oscillograms of current and voltage when surfacing with coated electrodes: a) direct current surfacing mode; b) surfacing mode with low-frequency modulation of current and arc voltage; $I_w$ - welding current; $U_w$ - welding voltage.
The change of the parameters of surfacing modes was carried out taking into account their relation to the alloying level of the built-up metal and chemical compositions of electrode and base metals.

The possibility of obtaining the required composition was determined by the initial concentration of elements and a degree of assimilation of these elements by the metal during formation of a droplet and a molten pool.

Analysis of the microstructure of a base metal, a metal of each layer of weld metal, and a heat-affected zone was carried out by means of metallographic microscopes “Neophot-32” and “Axio Observer D1m”.

The components of the structure were detected by etching of the metallographic sample obtained by grinding on sandpaper in decreasing order of granularity and polishing with diamond paste; the composition of the etchant is a 4% solution of nitric acid in ethyl alcohol.

Microsections for metallographic analysis were made according to a cross-section, which is perpendicular to the permanent joint. To obtain the compared images, studies of the microstructure were carried out in the central part of root and capping passes of the seam, in the transition zone of the capping pass to the base metal: in the areas of overheating and normalization.

Measurements of microhardness \( H_{50} \) of the weld metal, the metal of the heat-affected zone, and the base metal were carried out on a PMT-3 microhardness tester with a load of the indentor equal to 0.5 N (50 g).

3. Results of experimental studies and their discussion
The microstructure of the base metal represents perlite and ferrite with a grain size of \( \approx 4.7 \, \mu m \) (figure 2)

![Figure 2. A microstructure of the base metal, x500.](image)

There is rolled banding of perlite. The volume fraction of perlite is \( \approx 20\% \). The average microhardness is 1450 MPa. The structure of the metal of the capping pass is a ferritic-pearlite mixture of various configurations (figures 3-4). The microstructure of the heat-affected zone consists of several sections: a superheated area with a widmanstatten structure (figures 3b and 4b) and a normalization area with a characteristic fine-grained ferrite-pearlite structure are clearly visible (figures 3c and 4c).

Since the welding was carried out in two passes with application of various heat input modes, the metal structure of each layer was studied both separately, after surfacing single rolls on the surface of the steel plate, and after their layer-by-layer formation of the permanent joint zone.

Each layer was performed applying two welding methods: using DC and a pulsed mode. Analysis of the structure of built-up layers shows that the weld metal surfaced using direct current is represented by a ferrite zone extended from the fusion zone to the coating surface (figure 3a).

The structure of the weld metal, surfaced using the pulsed mode, is more homogeneous (figure 4b-d).
Figure 3. A microstructure of the coating metal formed using direct current: a) capping pass, ×200; b) superheated area, ×200; c) normalization area, ×200; d) root pass, ×200.

Analyzing the nature of microhardness change over the cross section of welded samples, it is possible to state that samples welded using direct current and the pulsed mode have a superheated area and a normalization area (table 3).

Table 3. Microhardness of formed metal.

| Welding manner   | Microhardness, MPa |
|------------------|--------------------|
|                  | capping pass      | superheated area  | normalization area | root pass |
| Direct current   | 1665               | 2180              | 2020              | 1860      |
| Pulsed mode      | 1770               | 2140              | 2100              | 2015      |

At that, the highest values of microhardness occur nearby the superheated area.

In the weld metal formed using the pulsed mode, the microhardness is on average by 10% higher than that obtained using direct current.

The worked-out modes were applied when restoring geometrical dimensions of worn out articles of mining equipment by surfacing accompanied by subsequent hardening of the surface layer of the restored articles with surfacing materials having enhanced physical and mechanical properties (figure 5).

The results of the carried out tests as well as subsequent operation of the restored articles at enterprises of Yakutia have shown their high efficiency and provision of a significant economic effect from the results of introduction of promising materials and technologies of repair, recovery and strengthening treatments of high-loaded articles operating in conditions of low climatic temperatures of the North.
Figure 4. A microstructure of the coating metal formed using the pulsed mode: a) capping pass, ×200; b) superheated area, ×200; c) normalization area, ×200; d) root pass, ×200.

Figure 5. Crowns of teeth restored by coating (on the left) and hardened by coating using pulsed mode of surfacing.

4. Conclusion
The structure of the weld metal formed using the mode of pulsed change of the energy parameters of the mode is more homogeneous as compared to the metal surfaced using direct current.

The metal of the root pass of the seam obtained using pulsed arc welding has a higher microhardness by ~10% owing to smaller dimensions of its structural components.

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