Research of electric resistance surfacing (welding-on) of cylindrical steel and cast iron samples with low-carbon low-alloyed filler wire

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Abstract. In this paper, the possibility of applying the technology of electric resistance welding by wire (ERWW) of the various cylindrical parts surfaces, which make up a considerable amount of the total repaired products volume, is considered. The possibilities of using low-alloyed low carbon wires to recover steel and cast iron machine parts are also shown.

The restoration (repair) of worn parts of various machines and mechanisms is very often a technically sound and economically viable measure. Repair can significantly reduce the downtime of faulty equipment, as well as save significant material and labor resources in comparison with the manufacture of new products.

The ERWW method was developed in the 70s in the USSR, its founder is Klimenko Yu.V. [1]. Further technology developed [2, 3, 9], which offers the possibility of electrocontact powder coating, combined methods for producing pressure wire from the link. We only worked because of the detail. The essence of the ERWW method is to heat the filler material (wire) and the contact volume of the metal of the reconditioned part with electric current pulses and their joint plastic deformation, which ensures the formation of physical contact, activation of contact surfaces and volume interaction of the coating and the base material. As experience in the application of ERWW technology has shown, it is most effective in restoring and hardening external surfaces in cylindrical and conical parts of the “shaft” and “sleeve” type with uniform wear, which are stationary during operation or work on rolling or sliding friction. In the conical parts under consideration, the cone angle can be no more than 8°, since the welding technology of such parts does not differ from the ERWW of external cylindrical surfaces and does not require special equipment. The ERWW operation is performed on the specialized lathe-based installation (figure 1). There are two-way and one-way, according to the number of filler wires. The technological scheme of ERWW is presented in figure 2.

The method of electrical contact welding is most often used to restore steel parts (steel 20, 45, 40Cr, 50Mn, foreign analogues), and wires with a high carbon content, such as Np-65Mn (40Cr13, Np-30CrMnSiAl and their analogues) are used as welding wire. These wires make it possible to obtain coatings having a hardness of at least 50 HRC during the welding process. The use of these materials was determined by practice - such surface hardness was required for most products recovered by ERWW. However, there are many details that are made of steel 45 and its analogues, and the minimum required hardness of their outer surfaces is 270 - 310 HB. Also, cast iron parts (VCh60, analogs) [2]. The use of
ERWW for the restoration of such products was practically not considered in the literature, largely due to a significant decrease in the fatigue strength of products [3].

![Figure 1](image1.png)

**Figure 1.** The specialized lathe-based installation.

![Figure 2](image2.png)

**Figure 2.** One (a) and two-way (b) ERWW scheme, where: 1 - reconditioned part; 2 - the path of the passage of the welding current $I_w$; 3 - electrodes of beryllium bronze; 4 - filler wire; 5 - power supply (single-phase transformer with a capacity of 75 kVA) and electric power circuit of the specialized lathe-based installation [4]; 6 - water, cooling transformer, electrodes and component; P is the pressure force of the rollers. The welding pulse time $t_{pulse}$ is 0.1 - 0.14 s, the pause time between pulses is $t_{pause} = 2t_{pulse}$.

To obtain a surface hardness of 270 - 310 HB, it is advisable to use low-carbon wire as a filler. According to the results of preliminary studies, welding Sv-08Mn2Si (Table 1) or its foreign analogues was selected from several wires.

| Chemical element | Carbon C | Silicon Si | Manganese Mn | Chrome Cr | Nickel Ni | Sulfur S | Phosphorus P |
|------------------|----------|------------|--------------|-----------|-----------|----------|--------------|
| %                | 0.05 – 0.11 | 0.7 – 0.95 | 1.8 – 2.1 | <0.20 | <0.25 | <0.025 | <0.03 |

In order to consider the reconditioned surface to be of high quality, it is necessary to provide continuous (without breakthroughs), defect-free coatings (without cracks, pores and shells) having
sufficient adhesion between the product and the filler wire (between the coating layers), as well as the specified hardness of the welded metal.

For a well-studied Np-65Mn wire, it is recommended to perform an ERW with a shrinkage $\varepsilon$ of at least 65 - 68% (or a welding current of 6-8 kA), with a force of 1.5 kN, a pulse time of 0.1 ... 0.14 sec and time $2t_{\text{pulse}}$ pauses [5], and a compound that does not peel off during machining is already formed when the shrinkage is 40% [6]. Wire shrinkage is a compound welding mode parameter used to represent properties of coating via wire geometrical properties and could be evaluate from empirical formula

$$\varepsilon = \left(1 - \frac{h}{d_w}\right)$$

(h – welded metal height, mm, $d_w$ – wire diameter, mm). Based on this, since there are currently no recommendations on the possible ranges of the ERW modes of the Sv-08Mn2Si welding wire of different groups of parts, it was decided to consider them in the range of $40\% \leq \varepsilon \leq 90\%$.

During the ERW of Sv-0Mn2Si wire with a diameter of 2 mm of cylindrical samples of steel 45 with a diameter of 25 mm with a shrinkage of 40-45%, numerous cracks and delamination were found on macro sections (figure 3a), and when welding with a shrinkage of 90%, traces of a melted electrode bronze, which gave an occasion to reduce the shrinkage interval to $50\% \leq \varepsilon \leq 85\%$. The remaining parameters of the mode: the welding speed $n = \frac{85}{D_{\text{sample}}}$, the compression force of the electrodes $P = 1.5$ kN, the pulse time $t_{\text{pulse}} = 0.1$ s and pauses $t_{\text{pause}} = 0.2$ s.

No defects in the form of pores, shells, and cracks during the ERW of samples of steel 45 in the interval of wire shrinkage Sv-08Mn2Si $50\% \leq \varepsilon \leq 85\%$ were found on macrosections (figure 3, b - d). It was found that with increasing wire shrinkage $\varepsilon$ the interface between the welded metal and the base decreases. As shown in [6], a decrease in the interface between the metals to be joined should lead to an increase in the adhesion strength.

**Figure 3.** Macro sections of samples made of steel 45, welded with Sv-08Mn2Si wire with a diameter of 2 mm with different wire gauges, shrinkage $\varepsilon$ is equal 40% (a), 50% (b), 75% (c) and 85% (d).
To quantify the strength of the joints, tests were carried out on a tensile testing machine. We studied the adhesion strength \( \sigma_{adh} \) after ERW in one layer with a Sv-08Mn2Si welding wire with a diameter of 2 mm, depending on the change in wire shrinkage \( \varepsilon \). Wire shrinkage \( \varepsilon \) ranged from 50 to 85%. We also investigated the strength of metal bonding after arc surfacing in carbon dioxide with a Sv-08Mn2Si welding wire with a diameter of 1.2 mm and plasma spraying with PT-U5N powder (Figure 5). Experimental studies of adhesion strength were carried out on a sample of steel 45, the design of which is shown in figure 4. For comparison, figure 5 also shows the results of testing the adhesion strength \( \sigma_{adh} \) for samples after spraying with PT-U5N powder without subsequent melting and mechanized arc surfacing in carbon dioxide with a Sv-08Mn2Si welding wire with a diameter of 1.2 mm. It has been experimentally established that for Sv-08Mn2Si wire, when the shrinkage is varied from \( \varepsilon \) 50 to 85%, the adhesion strength \( \sigma_{adh} \) increases from 157 MPa to 424 MPa.

The adhesion strength \( \sigma_{adh} \) for plasma spraying with PT-U5N (Ni+5.2%Al) powder (without melting) and mechanized arc welding with Sv-08Mn2Si welding wire with a diameter of 1.2 mm are respectively 33 MPa and 450 MPa. According to the data of [7], an increase in the adhesion strength \( \sigma_{adh} \) by a factor of 5–10 is achieved when spraying with reflow compared to spraying without reflow. It is believed that such an increase in the adhesion strength \( \sigma_{adh} \) is quite sufficient for the reliable operation of most parts in operation. After an ERW using a Sv-08Mn2Si welding wire, the adhesion strength \( \sigma_{adh} \) is comparable to the adhesion strength \( \sigma_{adh} \) after spraying with reflow, which made it possible to assume that it is sufficient for welding with this material. An important technological property of the reconditioned parts is also the hardness of the outer surfaces of the parts, so it was important to study its changes when varying the welding mode (figure 6).

Figure 4. A collapsible sample for testing the adhesion strength: a) design for welding, b) design for testing; where 1 - half block; 2 - weld metal roller; 3 - pin; 4 - pinch plug; 5 and 7 - adapter to the tensile testing machine; 6 – plate
**Figure 5.** The dependence of the adhesion strength $\sigma_{adh}$ of the coating obtained by ERW of one welding wire Sv-08Mn2Si with a diameter of 2 mm with the base, from the shrinkage $\varepsilon$ after welding onto samples of steel 45.

**Figure 6.** The results of measuring the average hardness of the outer surface of a specimen made of steel 45 after an ERW of one roller using Sv-08Mn2Si welding wire from $\varepsilon$ shrinkage (for various ERW modes).
Figure 7. Comparison of the average hardness of coatings obtained after ERW by welding wire Sv-08Mn2Si with a diameter of 2 mm with different degrees of shrinkage ε and mechanized arc surfacing in carbon dioxide with a wire of the same grade with a diameter of 1.2 mm.

Unlike arc welding methods, the hardness of the coating deposited by ERW remains constant with increasing number of layers, as shown in figure 7. This is due to the lack of mixing of the main and filler material in ERW. Because of this, the hardness of the coating after ERW by the Sv-08Mn2Si welding wire of the outer surfaces of samples of steels 20 and 45 is almost the same, despite the difference in the amount of carbon in the main material by 2 times [8].

The microstructures after the ERW of samples of steel 45 with the Sv-08Mn2Si welding wire are respectively shown in figure 8, a - d. The joint zone between the steel 45 base metal and the Sv-08Mn2Si welded welding wire is characterized by a deformed ferrite-pearlite structure, which gives the welded metal high hardness. In the case of welding with a wire shrinkage of 50% (figure 10, a), the line of separation between the joined metals is clearly visible in the figure. When welding with shrinkage of 55 ... 80%, both sections of the dividing line and alloys with common grains are visible on microsections (figure 8, c and d). In figure 8, b, it is clearly seen that after an ERW by welding wire Sv-08Mn2Si with a shrinkage of 85% between the welded and base metals, the dividing line is completely absent, and common grains are observed in the joint zone, which once again confirms the relationship between the shrinkage and the adhesion strength of the coating to basis established in [5].
The restoration of cast iron parts is always a difficult task due to the properties of cast iron [6], first of all, the phenomena of chill hard spots appearance. With ERW, additional problems arise associated with the high thermal conductivity of cast iron - the base metal begins to melt earlier than the wire, when welding on the modes selected for steel parts. To obtain satisfactory coatings by different authors, different solutions were proposed: heating the filler material to a temperature of 700-800 °C or welding it through a sublayer [9]. These methods are effective, but much more time-consuming and resource-intensive than conventional electrical contact welding. The accumulated practical experience and preliminary experiments in the 40-85% ε modes showed that the coating applied to the cast iron base with Sv-08Mn2Si wire has sufficient strength characteristics, does not peel off during processing and does not cause cracks in the main layer in case of welding with 65-75% shrinkage. The sample and results of hardness test are shown in figure 9. Satisfactory coating strength allow continuing studying welding modes and technological properties of restored by ERW cast iron parts.

**Figure 8.** Micrographs (magnification ×240) of Steel 45 samples ER welded with Sv-08Mn2Si wire, shrinkage ε is equal 50% (a), 85% (b), 60% (c) and 75% (d)

**Figure 9.** Welded-on cast iron (VCh-60) sample (a) and results of hardness HB test (b)
Conclusions

1. The results of experiments on steel samples electric resistance welded-on by wire Sv-08Mn2Si are shown. It was concluded that it is possible to use low-alloyed low-carbon welding wire as a filler metal for ERW technology.

2. It was concluded that it is advisable to study the technological properties of such a coating and to refine the welding modes for use with cast iron parts.

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