ELECTROSLAG REMELTING AS A METHOD OF RECYCLING NON-COMPACT HIGH-SPEED STEEL TOOLS

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Abstract

The practice of using electroslag remelting for processing spent non-compact tools from high-speed grade steel is considered. The advantage of the remelting process according to the two-circuit scheme for that purpose is demonstrated. The electroslag remelting process according to that scheme with a T-type mold has been developed and investigated at experimental melts. Spent drills and cutters welded into solid electrodes were remelted with obtaining a high-quality ingot and preserving the chemical composition. The outer diameter of the electrodes was up to 200 mm with the forming part of the mold 180 mm. It was found that the use of a T-type current-supply mold allows remelting with reduced power on up to 25 % and obtaining a high-quality ingot without surface defects at the same time. The dependence of the remelting rate on the filling coefficient as well as the possibility of conducting remelting exclusively on the current-supply section of the mold without loss of productivity has been established.

Keywords: Electroslag remelting, double-circuit scheme, recycling, tool, high-speed steel, ingot, remelting productivity, ingot quality

1. INTRODUCTION

Electroslag remelting is one of the effective methods of recycling alloy steel grades [1-3]. During remelting there are minimal losses of alloying elements, metal is refined, and the conditions of metal solidification allow to obtain physically and chemically homogeneous ingot with a dense crystalline structure and high surface quality.

Electroslag remelting of high-speed steel grades has been long practiced and is successful [4]. However, remelting of spent tools according to the classical scheme is usually carried out only in cases where the parts are large enough to form a solid electrode and provide stable remelting conditions. Because the preparation of a consumable electrode with a constant geometry by connecting small parts requires significant effort, the recycling of such parts by the classical method of electroslag remelting in a direct scheme is appropriate only in the furnaces of electroslag chill casting.

As is known melting of the consumable electrode with a constant rate of decrease during the electroslag remelting process is essentially an unstable process [5-6]. The values of the characteristics of the electric current, magnetic field, and Lorentz forces can vary greatly during remelting. The distribution of electric current density in the slag bath is controlled by the shape of the electrode, the parameters of the liquid metal droplets, and the shape of the slag/metal interface. The maximum density of electric current is always reached at the tip of the electrode, or on the drops coming off it. Accordingly, the stability of the geometric parameters of a consumable electrode significantly affects the fluctuations of electrical parameters during remelting.

Since the individual parts of a non-compact tool are connected by welding, the resulting consumable electrode will be having a variable cross-sectional filling factor and electrical resistance. Electroslag remelting of such electrodes in a direct scheme to obtain a quality ingot is technologically difficult to perform due to the instability of the remelting process caused by these circumstances.

Remelting process according to the two-circuit scheme can be used to solve the problem of stability of the remelting process of the consumable electrode with variable geometric parameters. It is realized by the use of a mold of special design, which allows supplying additional electric power to the slag bath. Additional current supply to the slag bath from the conductive mold allows to significantly eliminate the effect of changes in the geometric parameters of an electrode over the course of the remelting process.

The concept of a current-carrying mold was developed at E.O. Paton Electric Welding Institute [9, 12]. The upper part of a current-carrying mold is equipped with a graphite ring, which forms a non-consumable electrode and allows to have an additional power supply to the melting space. Moreover, studies [7] have shown that a much higher value of electric current is achieved at this scheme of power supply to a slag bath than with a direct remelting scheme at the same total power supply.

ESR process on a two-circuit scheme - significantly expands its technological capabilities:

- maintain the temperature of the slag bath without a consumable electrode - which allows you to replace the consumable electrode without the risk of cooling the slag;
- additional heating of the peripheral zone of the ingot - which significantly improves the ingot surface and reduces or completely eliminates surface defects [10];
- changes the thermal pattern of the melting space - which significantly changes the profile of the liquid metal bath [11];
- changes the melting space hydrodynamics - creates the movement of slag in a circle, intensively mixing it.

At double-circuit (DC) ESR the mass of metal droplets that come off the end of the electrode increases by ~ 12 % at the same power. This is due to a significant change in the distribution of electromagnetic forces. The purity of the remelted ingot improves. The number and area of non-metallic inclusions in an ingot after DC ESR decreases, but their type does not change [8].

The task of this study was to investigate the efficiency of remelting of a prefabricated hollow electrode with variable parameters by ESR process according to the double-circuit scheme, as well as determine the relationship between remelting speed and filling factor and find out the possibility to do remelting only with the active current-carrying section of the mold without loss of productivity.

2. RESEARCH METHODOLOGY

The remelting of electrodes assembled from used small tools made of high-speed steel was carried out on an upgraded electroslag remelting furnace P951. The furnace is equipped with a current-carrying T-shaped mold with a diameter of the forming part of 180 mm, and a diameter of the current-carrying part of 225 mm (**Figure 1**).

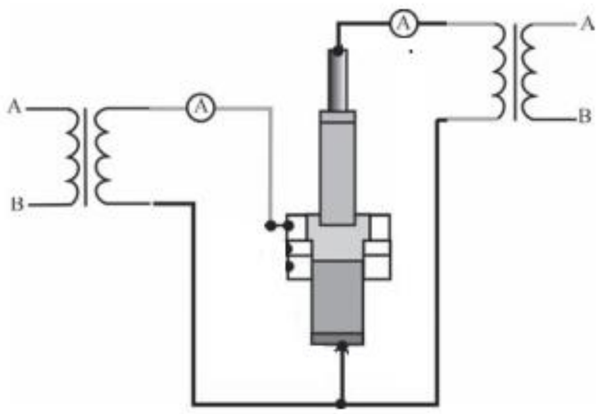


Figure 1 General scheme of electric power supply and connection of measuring devices of the furnace P951

Flux type ANF-29 was used for remelting during experiments (**Table 1**).

Table 1 The chemical composition of the flux ANF-29, wt.%

CaF_2	Al_2O_3	CaO	SiO_2	MgO	Flux melting point, ^{O}C
37-45	13-17	24-30	11-15	2-6	1,230-1,250

Consumable electrodes for remelting were prepared from the used small tools by welding individual parts into a single electrode (**Figure 2**). Tools with steel grade Р6М5 (Р6М5К5, Р6М5К5-МП, Р6М5Ф3-МП, 10Р6М5У-МП) were used.

Table 2 Chemical composition of steel Р6М5 according to for ГОСТ 19265-73

C	Mn	Si	Cr	W	V	Mo	Co	Ni	Cu	S	P
0.82…0.90	0.20…0.50	0.20…0.50	3.80…4.40	5.50…6.50	1.70…2.10	4.80…5.30	≤0.50	≤0.6	≤0.25	≤0.025	≤0.030

Figure 2 View of the prepared electrodes from the used small tool from steel P6M5

Since the experimental electrodes did not have a constant cross-section to conduct the remelting process the supply to the electrode of power in accordance with the classical scheme did not make sense. Therefore, during the remelting of the experimental electrodes, the process was mainly carried out due to the power of the current-carrying section of the mold. This allowed to melt the electrode stably and with constant productivity and eliminate the electrical instability. During the remelting, the electrical resistance of the experimental electrodes was measured.

Remelting was performed in two ways to compare the performance of the process and the quality of the ingot surface. In the first variant, the minimum electric power possible for the selected mold diameter was applied to the electrode to melt the metal. Accordingly, the estimated total power should be at least 200 kVA for a fill factor of 0.2-0.3, and the minimum value of power per electrode 50-60 kVA. The electrode/mold power distribution was 25/75 % for stable electrode melting with minimum performance. In the second variant, the melting power was supplied exclusively to the mold to test the possibility of conducting the remelting process solely due to the power of the current-carrying section of the mold.

3. RESULTS AND THEIR DISCUSSION

After consecutive remelting three experimental electrodes, with their replacement during remelting, an ingot with a diameter of 180 mm, a length of 1,225 mm, and a weight of 259 kg was obtained.

It was found that the resistance of the electrodes due to their different configuration was significantly different: for the electrode №1 = 38-40 Ohms; electrode №2 = 29 Ohms; electrode №3 = 33 Ohms.

Since melting was performed using a double-circuit scheme the potential difference between the electrodes and the current-carrying section of the mold was studied. The following was found:

- Electrode №1 - filling factor 0.25 diameter up to 200 mm, potential difference 3-4 V
- Electrode №2 - filling factor 0.37 diameter up to 180 mm, potential difference 10 V
- Electrode №3 - filling factor 0.37 diameter up to 170 mm, potential difference 9 V

Since the electrode №1 had the highest electrical resistance, which was 38 % higher than that of the electrode №2, and 21 % higher than that of the electrode №3 - this significantly affected the productivity of the process. Accordingly, the electrode №1 melted at a speed of 63 kg / h, the electrode №2 - 113 kg / h, and the electrode №3 - 110 kg / h at the same constant supply power. In addition, the low remelting productivity for the electrode №1 is also due to the small filling confidant, which was 0.25.

The test of the possibility of conducting remelting process exclusively with the help of the current-carrying section was carried out during the completion of remelting of the electrode №3. The power on the electrode was completely turned off and transferred to the current-carrying section. The power on the conductive section of the mold was 200kVA. Prior to switching off the power at the electrode, the power was distributed as 60/150 kVA. After turning off the power to the electrode, the melting rate of the electrode did not change, which indicates the possibility of melting in this mode (**Figure 3**).

Figure 3 General view of the remelting process of experimental electrodes made of used tool steel P6M5

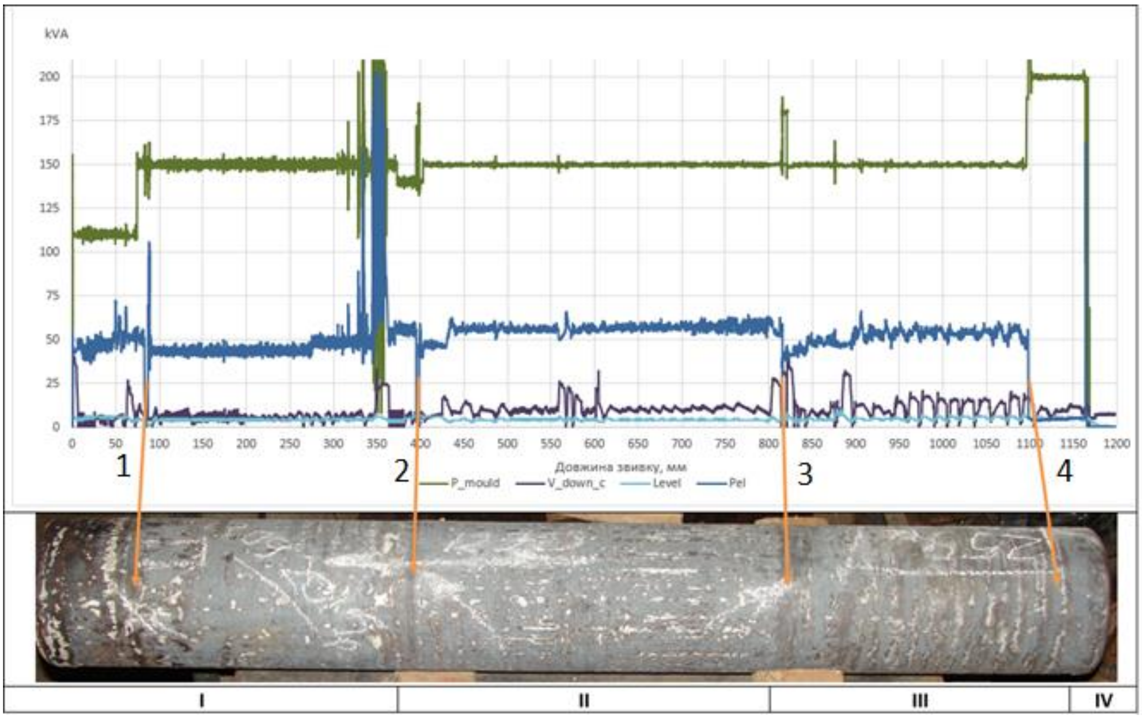
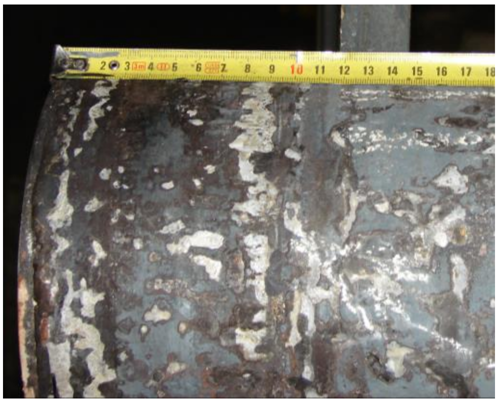
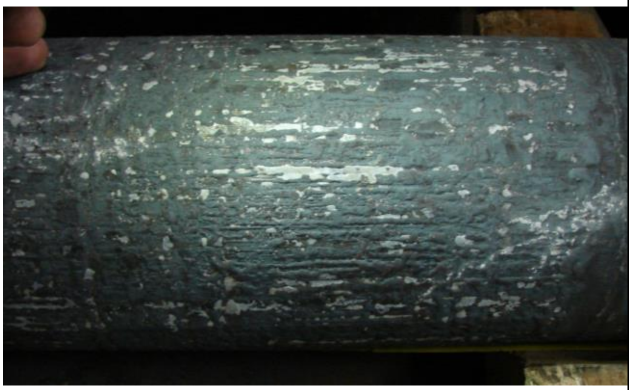
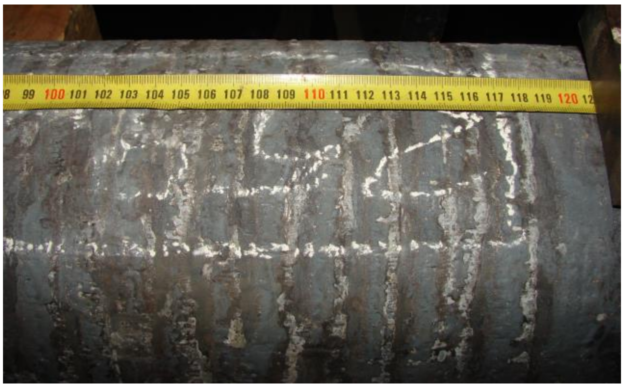


Figure 4 Time diagram of remelting productivity, power applied to the electrode and current-carrying section. Correspondence of an ingot surface to capacity

Separately consider the surface of the obtained ingot (**Table 3**). It should be noted that the surface of the ingot formed during the remelting of each individual electrode has some visual differences. The surface of the ingot can be quite clearly divided into four zones, which correspond to the individual stages of the experiment (**Figure 4**).

Table 3 Analysis of the surface of the obtained ingot

I - zone. The base of the ingot without corrugations and splashes, which in the direct connection scheme must be present at the bottom of the ingots. The absence of defects in the bottom significantly reduces the amount of trim and increases the yield. The dark color belt (arrow 1) in the first zone corresponds to the increase of power on the current-carrying section up to 150 kVA.	
II - zone. The transition after electrode changing (arrow 2) differs only in the color of the metal. There are no clamps and depressions in this area. But the whole area has minor defects on the surface, in the form of vertically directed bays up to 1.5 mm deep, in which the garnish remained. That defect is caused by unstable melting of the electrode due to its physical configuration	
III - zone. The surface is in slag belts and has a certain bumpy shape with a difference in height up to 1 mm. That defect is caused by the uneven movement of the carriage pulling the ingot and some unstable melting of the electrode due to its geometric configuration (see on the graph, V_down (Fig. 4).	
IV - zone. Remelting with 100% power on the current-carrying section of the mold. The surface of the ingot is perfect. No visible defects.	

Having analyzed in detail the surface of the experimental ingot, we can define it as a surface of good quality. The unevenness of the surface of the ingot for peeling reaches no more than 1.5-2 mm.

Samples for chemical analysis were taken from the lower and upper parts of the ingot. The results of the metal samples' chemical analysis show satisfactory chemical homogeneity of the obtained ingot.

In terms of its chemical composition, the obtained metal meets the standards for P6M5 steel (**Table 4**).

Table 4 Metal chemical composition after remelting

	Mn	Si	Cr	W	V	Mo	Co	Ni	Cu	S
Bottom of the ingot	0.39	0.4	4.22	6.28	1.98	5.12	0.3	0.37	0.2	0.02
Top of the ingot	0.37	0.42	4.13	6.14	1.91	5.04	0.26	0.33	0.19	0.018

CONCLUSION

1) Electroslag remelting according to the double-circuit scheme allows efficient recycling of spent oversized tools assembled into electrodes, preserving the metal chemical composition, and obtaining high-quality ingots. This approach significantly reduces the production chain of returning the metal to production and can be recommended for commercial use.

2) The configuration of the assembled from parts consumable electrode directly affects the stability of the process and the quality of the ingot when supplying even the minimum power to the electrode and practically does not affect the quality of the ingot if all power is directed to the current supply section of the mold.

3) Remelting of electrodes only due to the current-carrying section of the mold is possible without reducing the productivity of the process. At the same time defects on a surface of an ingot disappear.

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