Investigation of the Influence of Electro-Impulse Current on Manganiferous Liquid-Alloy

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Abstract. The article shows that for improving the quality of castings, more and more often, technical solutions are used related to the influence of electric current on the melt during its crystallization. The positive results of such a modification are improved processes of heat and mass transfer and structuring. However, these results only concern the electrical treatment of non-ferrous metals and alloys, as well as some castings. The influence of the electric current limits on the degree of modification of manganese-containing steels during their crystallization in the foundry, as well as on the physical and mechanical properties of the casting requires careful research that would be close to real conditions. The authors compared the macro and microstructures of steel 35GL doped with manganese and modified during crystallization in the foundry form of the electro-impulse current with different current parameters: intensity, duration of impulses, frequency, squinting. It has been established that the modification of an alternating polarity with an electric pulse current of more than 10–3 s, a frequency of 5–33 Hz, a force of 30–40 A, a vacuum of 5–24, at a voltage in the power line of 180–240 V provides a reduction in structural inhomogeneity (the crystallite of the metal base and manganese carbides are reduced respectively from 280 to 82–85 microns and from 6.7 to 0.3–0.5 microns). These structural changes lead to a significant increase in the basic mechanical properties of cast structural steel 35GL: strength limits – 9%, impact strength – 21%, hardness (HB) – 6%.

Keywords: Electroprocessing · Alloy · Microstructure of steel

1 Introduction

The problem of improving the structure of cast products is the subject of many studies. To improve the quality and properties of casting the electric current impact method is increasingly used to melt during crystallization [1].

The research was mainly carried out on non-ferrous metals and alloys [2–4]. Electricity treatment of these melts contributes to reducing the probability of occurrence of macro and microflaw of the structure and causes directional crystallization in the inter-electron space.

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2 Literature Review

Positive results of the application of electroprocessing also exist in the manufacture of pig iron castings [5, 6]. Electricity treatment also has a positive effect on the processes of heat and mass transfer and structure formation.

The study shows the results of the first experiments on the impact of current on steel grade 40L [7]. The modifying effect of constant voltage on alloyed and manganiferoussteel melts was studied by the authors of this study [8].

The urgent task is conducting a complex of studies to analyze the effect of modifying the pulsed current of manganiferousmelts during their crystallization in the casting-form. According to preliminary data, repetitively-pulsed current modification of the melts has some advantages compared to treatment of direct and alternating current. The first one is lower energy consumption while simultaneously reducing the losses on metal heating.

The obtained theoretical and practical results of researches of different authors testify that under the influence of a constant electric current on the alloy an alloying elements move from a body of a casting to its surface. However, the only clear and universally accepted theory of current influence on the melt has not existed yet. Nowadays the question of the influence of current on the mechanisms of phase formation in rare-solid states with different types of conductivity of solid inclusions is not sufficiently unexplored. Particularly many contradictions are expressed regarding the mechanism of mass transfer of elements in the inner layers of the casting under the action of a constant and electrical impulse current.

3 Research Methodology

3.1 Analysis of Current Influence on Crystallite Size

The authors carried out a large volume of experimental studies on the influence of electro-impulse current in the process of crystallization of the casting during the study of steel grade 35GL.

The treatment of the melt with an electro-impulse current was carried out from the beginning of the casting of the metal in the form to the end of the encryption, with the parameters of the current strength varying from 20 to 80 A, squelching from 1 to 24, and also the frequency from 5 to 33 Hz. 4 modifications were selected (Table 1) to conduct research.

Table 1. Routines of electro-impulse current influence.

Current parameters	Routine 1	Routine 2	Routine 3	Routine 4
Current strength	20, 40, 60, 80			
Squelching	2	5	15	24
Frequency	5	10	33	33

All four routines of modification have an effect on the morphology of crystallite of the metal base (Fig. 1) and the crushing of manganese carbides (Fig. 2).

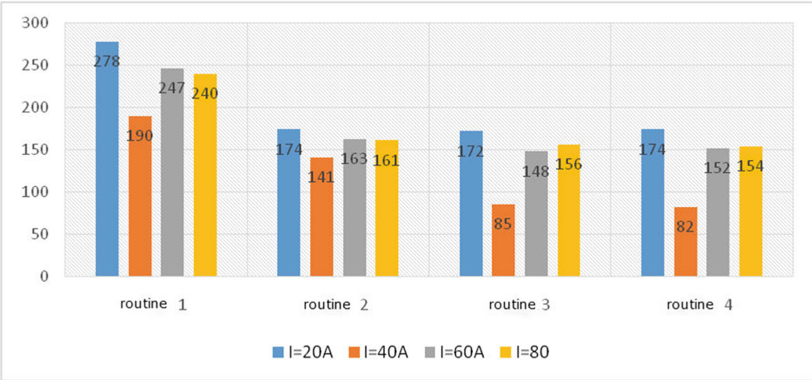


Fig. 1. Influence on the size of the crystallite of the metal base of different routines of electro-impulse processing of manganiferous steel 35GL. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically.

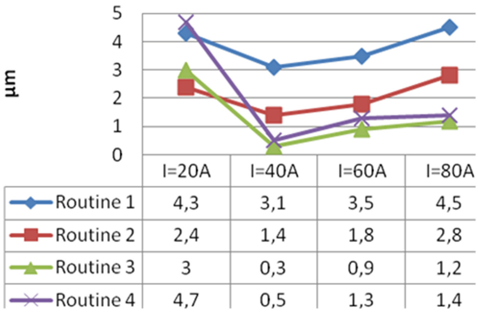


Fig. 2. The magnitude of manganese carbide crystallite, depending on the strength and routines of modification with the electro-impulse current of steel.

When modifying according to the routine 1, the crystallite of the metal base has the largest size, while in routine 2 the crystallite is significantly reduced and is 156 µm, manganese carbides are located along the boundaries of the crystallite of the metal base (Fig. 3). Treatment in routines 3 and 4 reduces the size of the crystallite from 278 µm to 82–85 µm, the distribution of manganese carbides becomes more even. They are mainly located not in the boundaries, but in the center of the crystallite of the metal base.

Fig. 3. Comparison of microstructures in different modes of electro-impulse processing.

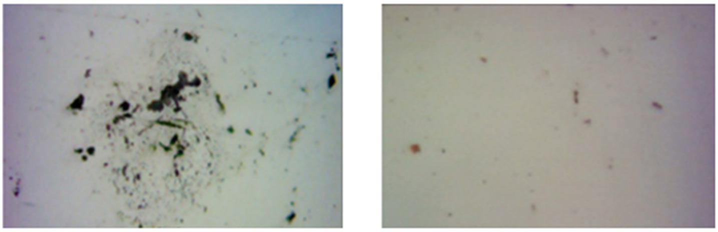


Fig. 4. Nonmetallic: a - an unmodified sample of steel 35GL, and b - a modified sample.

Modification routines 3 and 4 are the most appropriate since the smaller the austenitic crystallite is, the larger the total area is between the crystallites, and consequently the less specific content of harmful impurities is located on the boundaries of the crystallites.

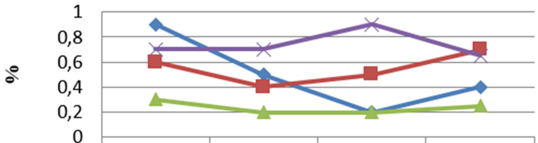
With a current of 40 A (routine 3) in 35GL steel samples the crystallite size of manganese carbides is the smallest: crystallites are 10 times smaller than unmodified specimens and 2 times smaller than when treated under routine 4. Thus, the smallest structure is obtained in samples at modulating the electro-impulse current of variable polarity with the following parameters: duration of impulses - more than 10–3 s, frequency – 5–33 Hz, strength – 30–40 A, squareness – 5–24, with voltage in the power line 180–240 V (routine 3).

3.2 Influence of Electro-Impulse Current on Chemical Discontinuity

On the unfertilized polished section of the unmodified sample accumulations of non-metallic inclusions (exogenous) are revealed.

Disoriented inclusions of FeP, MnP, Fe_3P, Mn_3P up to 10 microns (Fig. 4) are observed in most fields of view of a polished section modified by the selected sample routine and their number is reduced by 2.5 times.

Data on the “migration” of the elements was found (Fig. 5) on the basis of the generalization of the results of the chemical analysis of the contents of the elements near the anode and cathode of 35GL steel samples. As a result indicator, the relative change in Mn concentration between the anode and the cathode (electromigration) is used. The mechanism of ion division with mutual diffusion in the melts in the presence of electromigration was determined by a change in the set of interconnected parameters: atomic volume, partial diffusion coefficients and effective charges of the components of the melt.



	routine 1	routine 2	routine 3	routine 4
ΔMn	0,9	0,5	0,2	0,4
ΔC	0,6	0,4	0,5	0,7
ΔFe	0,3	0,2	0,2	0,25
ΔSi	0,7	0,7	0,9	0,65

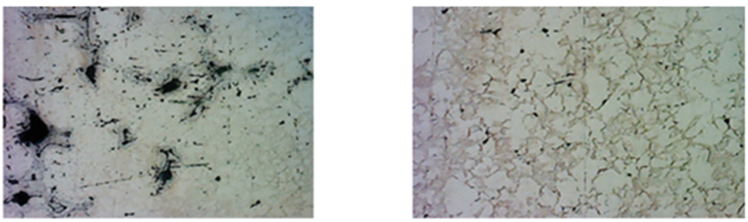
Fig. 5. Relative change in the concentration of the elements between the cathode and the anode in samples of steel 35GL when modified by an electro-impulse current of 40 A.

The electromigration of all chemical elements is rather low, the relative change in their concentration between the cathode and the anode at a current of 40 A does not exceed 0.9%, what is a positive result.

Consequently, the electro-impulse current of an alternating polarity provides a reduction of chemical discontinuity across the intersection of the casting, in contrast to the modification by a direct current [8].

3.3 Influence of Electro-Impulse Modification on Physical Discontinuity

As a result of the electrodes, the structure of the cast manganese-containing alloy has not only less, but physical discontinuity, compared with the basic (not modified current) chemical sample: the content of gases decreases significantly (in 1.4–2.5 times) (Fig. 6, Table 2).



a b

x 20

Fig. 6. Macrostructure of cast steel 35GL: a - basic sample; b - a sample modified with current.

Table 2. Changes in porosity in 35GL steel before and after modification with an electro-impulse current of variable polarity with a force of 40 A.

Characteristics of gas bubble	Unmodified samples	Modified samples
Volume ratio of gas bubble, %	6.5	2.7
Distance between gas bubble, μm	306	789
Number of gas bubble per cm^2, pcs	10–15	6–8
Diameter of gas bubble, μm	<0.6	<0.1
Crack length, μm	89–116	12–18

The electro-impulse current passing through liquid steel run away of formation of critical nucleus. This leads to active volumetric crystallization. The dendritical crystallization is discontinued much earlier than the unmodified casting. Metal in the volumetric crystallization zone has a finer structure and a higher density. In the modified casting the internal shrinkage is insignificant.

4 Results

The above mentioned structural changes, which are caused by the electro-impulse modification, provide an opportunity to increase the physical and mechanical properties of castings made of steel alloyed with manganese (Table 3).

Table 3. Physical and mechanical properties of quenched specimens.

Characteristics of the studied specimens	Limit of fluidity, MPa	Strength, MPa	Percentage extension, %	Contraction ratio, %	Impact hardness, kJ/m^2
Unmodified	230	503	11.00	19	243
Modified	302	540	12.05	21	296

Increase of enduring quality of steel occurs as a result of crushing crystallite of austenite and grain boundary strengthening. Electroprocessing reduces the proportion of manganese carbides in the structure, especially on the boundaries of the crystallite of the metal base. In the crystallite of austenite manganese carbides appear having high microhardness, preventing the formation of pinhole.

5 Conclusions

Reduction of physical discontinuity is contributed by electric discharge machining of a liquid-alloy steel 35GL with a current of variable polarity with an impulse time of more than 10–3 s, a frequency of 5–33 Hz, a strength of 30–40 A, a squareness of 5–24, at a voltage in the power line 180–240 V during crystallization in the casting-form:

- the content of gases and other nonmetallic inclusions is reduced, their distribution becomes more uniform, the crack length in castings is reduced by 7 times, the distance between gas bubble is reduced by 3.3 times, the number of gas bubble per cm^2 – by 1.8 times, and their diameter is 5 times;
- reduction of structural discontinuity: the size of the crystallite of the metal base decreases from 280 to 82–85 microns, and the size of manganese carbides, from 6.7 to 0.3–0.5 microns;
- significant increase in the basic mechanical properties of cast structural steel 35GL: the strength is increased by 9%, the impact hardness – by 21%, the hardness (HB) – by 6%.

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