Investigation of the influence of electro-impulse current on manganiferous liquid-alloy

O. M. Zhbanova, L. N. Saithareyev, I. E. Skidin, N. N. Shapovalova, G. Gubin

State Higher Educational Institution
Kryvyi Rih National University
11,Vitalii Matusevych Street
City of Kryvyi Rih, 50027
Ukraine

Abstract. In the article it is shown 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 doped with manganese steel 35GL, 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 10-3s, a frequency of 5-33Hz, a force of 30-40A, a vacuum of 5-24, at a voltage in the power line of 180-240V 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 – with 21%, hardness (HB) - with 6%.

Keywords: electroprocessing, manganiferous steel, manganese carbides

1. Analysis of existing results.

The problem of improving the structure of cast products is the subject of many studies. To improve the quality and properties of casting becomes increasingly use electric current impact method 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.

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.

In the study it is showed the results of the first experiments on the impact of current on steel grade 40L. The modifying effect of constant voltage on alloyed and manganiferoussteel melts was studied by the authors of this study.

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

2. Justification of the parameters of steel modification with impulse current.

2.1. 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 80A, squelching from 1 to 24, and also the frequency from 5 to 33 Hz. To conduct research, 4 modifications were selected (Table 1)

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). 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.

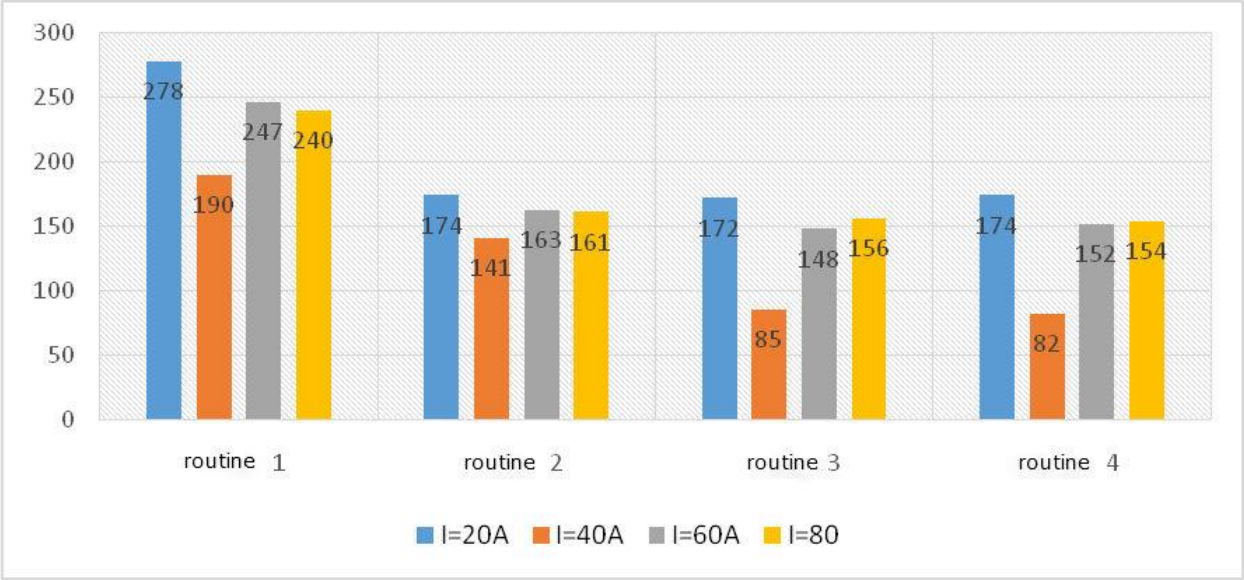
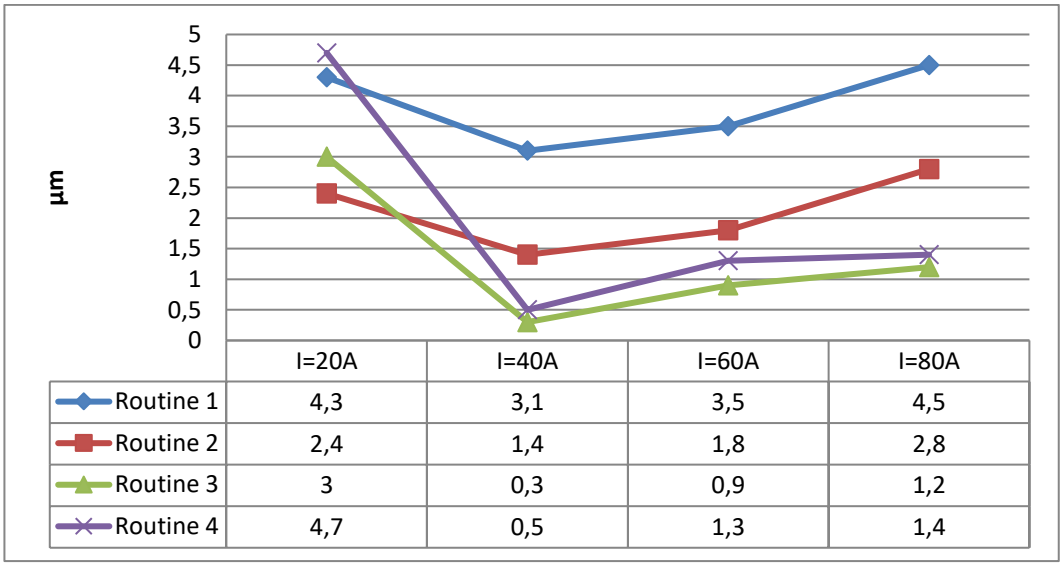


Fig. 1 – Influence on the size of the crystallite of the metal base of different routines of electro-impulse processing of manganiferous steel 35GL



	I=20A	I=40A	I=60A	I=80A
Routine 1	4,3	3,1	3,5	4,5
Routine 2	2,4	1,4	1,8	2,8
Routine 3	3	0,3	0,9	1,2
Routine 4	4,7	0,5	1,3	1,4

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

unmodified routine 1 routine 2 routine 3 routine 4

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

Modification routines 3 and 4 are the most appropriate since the smaller the austenitic crystallite the larger the total area between the crystallites and

consequently the less specific content of harmful impurities located on the boundaries of the crystallites.

With a current of 40A (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 30-40A, squareness 5-24, with voltage in the power line 180-240V (routine 3).

2.2. 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.

In most fields of view of a polished section modified by the selected sample routine disoriented inclusions of FeP, MnP, Fe3P, Mn3P up to 10 microns (Figure 4) are observed and their number is reduced by 2.5 times.

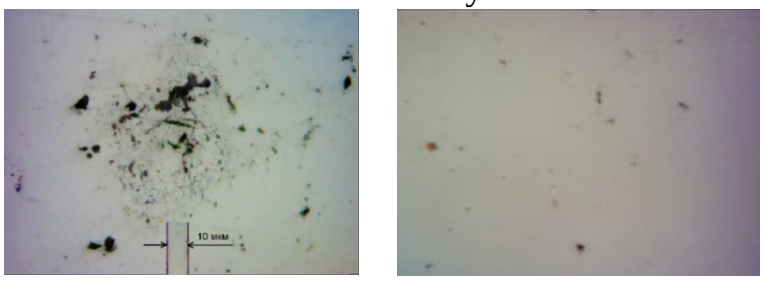


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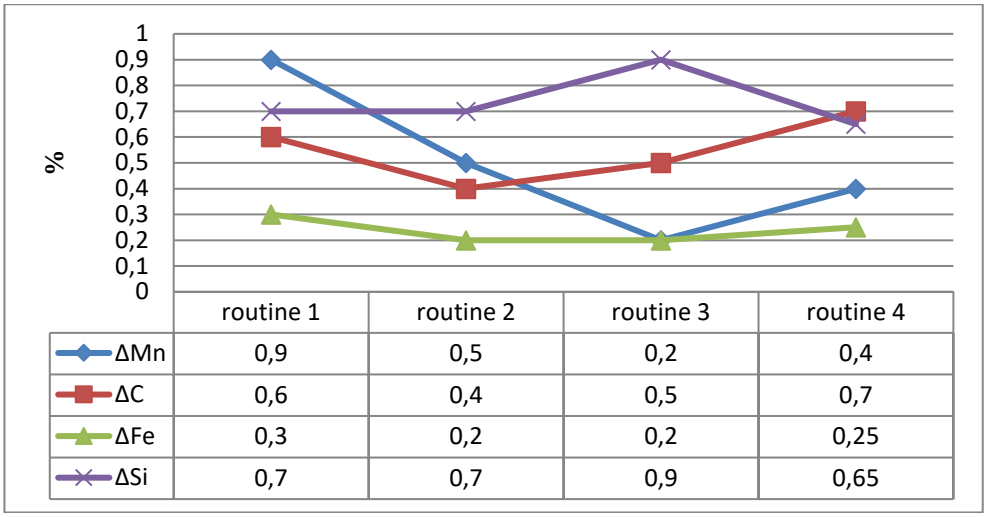
Fig. 4 - nonmetallic
a - an unmodified sample of steel 35GL, and b - a modified sample

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, data on the "migration" of the elements was found (Fig. 5). 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 40A

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 40A 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].

2.3. 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 is significantly (in 1,4-2,5 times) decreases (Fig. 6, Table 2).

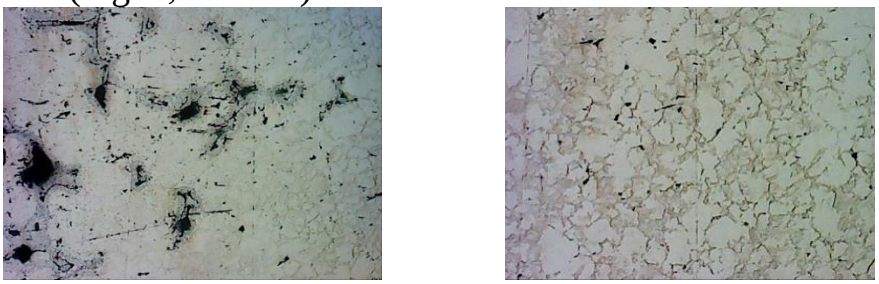


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Fig. 6 - Macrostructure of cast steel 35GL:
a - basic sample; b - a sample modified with current

Table2. - Changes in porosity in 35GL steel before and after modification with an electro-impulse current of variable polarity with a force of 40A

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.

3. Influence of electro-impulse modification on physical and mechanical properties of steel

The above 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.

CONCLUSIONS

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

- reduction of physical discontinuity: 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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