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STUDYING VIBRATION MODE IMPACT ON FORMING STEEL STRUCTURE IN PRIMARY CRYSTALLIZATION PROCESS

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There is considered the impact of the vibration mode on the steel 30CrMnSiNiMoA structure after the process of primary crystallization. It has been found that vibration has a positive effect on the process of grain refinement, reduction of the contamination index and the tendency to dendritic liquation. The optimum parameters of vibration have been established for obtaining fine grains and low index of contamination in steel.

One of the ways to improve the quality of ingots made of complex-alloyed steels is to control the structure at the stage of primary crystallization using various grain methods, contamination index, dendritic liquation.

Key words: steel, structure, vibration, frequency, average size

INTRODUCTION

Forming an ingot after primary crystallization have a great impact on the following operational properties of rolled steel, parts of mechanical engineering and metal structures when processing with such modes as vibration, ultrasound, etc. [1-5].

In works [4, 6] it has been shown that the impact of low-frequency vibration leads to the dendritic structure refinement, eliminating trans-crystallization and promotes the favorable forming of the secondary structure which finally increases operational properties of the product.

In this work there has been defined the task to study the mechanical impact by means of vibration on the process of primary crystallization of complex alloyed steel and forming its structure.

EXPERIMENTAL PART
Equipment and tools

As the object of studying there has been selected steel 30CrMnSiNiMoA, its chemical composition is shown in Table 1.

Steel 30CrMnSiNiMoA is heat-treatable alloyed steel and is used for manufacturing rolled products, essential parts in mechanical engineering that work in the conditions of complex loading, in the interval of the temperatures up to 200 0C. Melting steel 30CrMnSiNiMoA is usually produced in electric arc furnaces, their composition is regulated by GOST 21729-76. Though this steel is not highly-alloyed, in its composition there are various allotting elements, such as Cr, Mn, Mo, Si, Ni. All the listed elements have different melting temperatures and impact differently on the polymorphic transformation. The main disadvantages in forming the primary structure of this steel, as in other steels of this group, are porosity caused by a sufficiently wide liquidus-solidus interval, dendritic liquation and liquation in the phases of introducing. Besides, steel 30CrMnSiNiMoA is congenitally granular, i.e. its primary structure impacts the final structure formation after heat treatment.

A sample of rolled steel 30CrMnSiNiMoA has been melted in a modernized laboratory furnace UIP-25, then casted into a CMC crucible at the temperature of 1620 ^{0}C. The melt mass has been 0,2 kg. Then the crucible with the melt has been subjected to vibration with the frequency 80-120 Hz, the amplitude˝1,5-2,6 mm, the time of vibration varied from 3 to 7 minutes. At the end of the vibration action the temperature has not been measured, only the heat flux density has been monitored within the first 10 minutes of crystallization.

After the specified time, the vibration effect ceased, then the melt has been crystallized under natural conditions. At the end of the crystallization process and complete cooling, the structure and some properties of the resulting ingot have been studied.

To study the structure of the experimental ingot there have been prepared metallographic sections using the Struers sample preparation complex, etching has been carried out using the A3 electrolyte within 25 sec-

Table 1 **Chemical composition of steel 30CrMnSiNiMoA / wt. %**

C	S	P	Mn	Cr	Si	Ni	Mo	Fe
0,29	0,020	0,020	1,2	1,1	1,1	1,7	0,4	Rem.

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onds. Figure 1 shows some microstructures of steel samples subjected to the mechanical action As a reference there has been used a sample of 30CrMnSiNiMoA steel without mechanical impact. When studying the microstructure, the following parameters have been studied: the grain size, the average grain diameter, the number of grains in the 1 mm^2 area, and the steel contamination index.

Comparison of microstructures in Figure 1 shows changes in the nature of the structure: increasing the time and frequency of vibration leads to the formation of a more homogeneous structure, without distinct boundaries (Figure 1, d).

The metallographic analysis has been carried out using the Thixomet Pro program. The results of the analysis are presented in Tables 2, 3.

RESULTS AND DISCUSSION

As it can be seen from the data in Table 2, a significant change in the grain size occurs at frequency starting from 100 Hz, with the vibration frequency 110 Hz the average grain size decreases almost twice. The further increase of vibration frequency does not practically affect the grain size.

Figure 2 shows the vibration amplitude effect on the grain average size, while the vibration frequency and

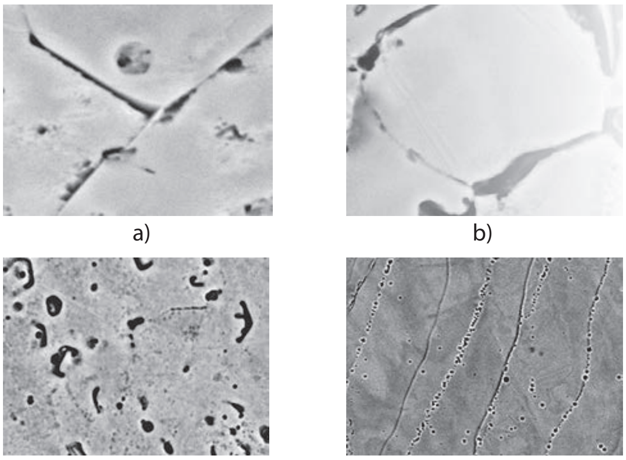


Figure 1 Vibration impact on the steel 30CrMnSiNiMgA microstructure; a – reference without impact; b – vibration frequency is 80 Hz, vibration time is 3 min.; c – vibration frequency is 100 Hz, vibration time is 7 min.; d – vibration frequency is 110 Hz, vibration time is 7 min. (×1 000)

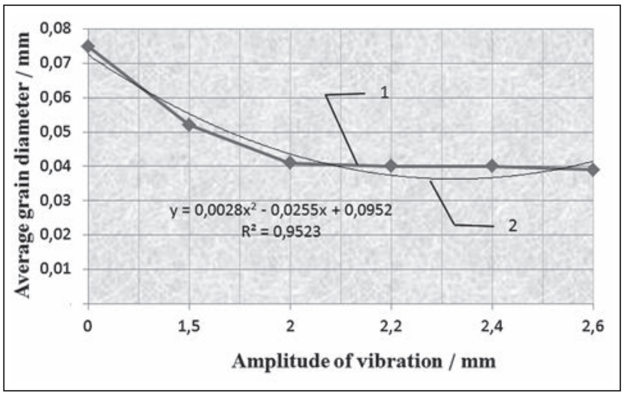


Figure 2 Vibration amplitude impact on the grain average size: line 1 – experimental; line 2 – calculated by the regression equation

time have not changed and amounted to: vibration frequency h = 110 Hz, vibration time t = 5 min.

Starting from the 2 mm amplitude, the grain size in the structure does not practically change, i.e. in the considered interval, the effect of the amplitude on the structure parameters is insignificant. It should be noted that the further increasing of the vibration amplitude has no practical sense because it leads to significant mechanical wear of the vibrating plate and additional costs of electricity.

In the last series of experiments there has been considered the impact of the vibration time on the grain average size. The results of the studies are shown in Table 3.

As it can be seen from the data in Table 3, increasing the vibration time has a favorable effect on grain refinement, but increasing the time more than 7 minutes does not lead to a significant improving of the parameters. The average diameter and grain grade after vibration within 6 and 7 minutes remains unchanged, the number of grains per 1 mm^2 area remains practically unchanged. Analyzing the data in Table 3 allows concluding that the further increasing of the vibration time is apparently inexpedient and should be limited to the vibration time of 5 - 6 minutes.

As it can be seen from the data in Tables 2 - 3 and Figures 2, 4, the vibration frequency and time have the greatest impact on the grain size, while the vibration amplitude impacts insignificantly in the studied range.

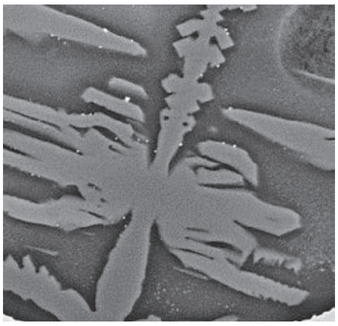
In this study chemical liquation has net been studied. However, the metallographic analysis of sections (001) has shown that the tendency to form a dendritic structure in samples subjected to vibration is less pronounced than in conventional crystallization (Figure 3). Reducing the tendency to dendritic formation most likely determines decreasing the grain average size in the

Table 2 **Vibration frequency impact on the structure parameters (vibration amplitude˝a = 2 mm, vibration time t = 5 min)**

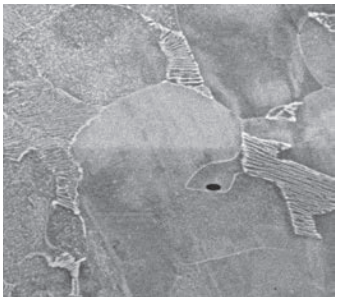
Mode number	Frequency / Hz	Grain average size / mm	Grains average number per 1 mm^{2}area	Grain grade	Average density of the heat flux / kW/m^2
0	0	0,075	168	4 - 5	37
1	80	0,069	211	4 - 5	49
2	90	0,064	428	5 - 6	53
3	100	0,052	483	5 - 6	62
4	110	0,041	669	6 - 7	64
5	120	0,039	675	6 - 7	67

Table 3 **Vibration time impact on the structure parameters (vibration frequency h = 110 Hz, vibration amplitude a = 2 mm)**

Mode number	Vibration time / min	Grain average diameter/ mm	Grain average number per 1 mm^2	Grain grade
0	0	0,075	168	4 - 5
11	3	0,060	249	4 - 5
12	4	0,047	456	5 - 6
13	5	0,041	669	6 - 7
14	6	0,037	723	6 - 7
15	7	0,037	729	6 - 7



a)



b)

Figure 3 Steel microstructure after crystallization: a – usual crystallization; b – crystallization under vibration impact, frequency is 110 Hz (×1 000)

structure. The absence or weakly manifested dendritic structure reduces anisotropy of properties and chemical liquation, as it is known that chemical liquation is particularly pronounced precisely between the axis of the dendrite and the inter-axial space.

In the ingot metallographic sections processed in modes 0, 4, 13 there has also been determined the contamination index. This has been determined by the formula:

$$I = \frac{b\sum a_i \cdot m_i}{l},$$

where b is the graticule division value at the given magnification in μm;

a_i is the average value of inclusions in the graticule division value;

m_i is the amount of inclusions of the given group;

l is the calculation length in μm.

The results of measurements are shown in Table 4.

The analysis of the data in Table 4 shows that in the range studied, vibration has a positive effect on the contamination index: in mode 4 the contamination index is reduced by 15 %, increasing the vibration time to 6 minutes reduces this index by almost 23 %.

Table 4 **Determining the contamination index**

Mode number	Mode characteristic	Contamination index
0	Without vibration impact	1,84
4	Vibration frequency h = 110 Hz, vibration amplitude a = 2 mm, vibration time t = 5 min	1,56
14	Vibration frequency h = 110 Hz, vibration amplitude a = 2 mm, vibration time t = 6 min	1,42

In the production site of KMZ n.a. Parkhomenko (Karaganda, Kazakhstan) there have been carried out trial tests of the vibration treatment impact on forming the structure of steel 30CrMnSiNiMgA in the process of primary crystallization. After casting an ingot weighing 0,8 tons has been subjected to vibration, after completing the process of crystallization and complete cooling, the samples have been cut in the center of the ingot at three points and metallographic sections have been made. Metallographic studies have shown the parameter values close to the data in Tables 3 and 4, which suggests that it is possible to improve the primary structure by the vibration impact.

CONCLUSIONS

The studies carried out have shown the possibility of improving the primary structure of steel 30CrMnSiNiMgA after smelting by vibration. The recommended vibration processing mode is as follows: the vibration frequency is 110 Hz, the vibration time is 6 minutes, the vibration amplitude is 2 mm (mode 14). The use of vibration treatment allows reducing the grain size in the steel structure, reducing the contamination index and reducing the tendency to dendritic liquation. Such positive changes in the steel structure allow suggesting the improvement of the operational properties of rolled and shaped products, as well as finished metal products made of this steel.

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Note: Responsible for the English language is Natalya Drak, Karaganda, Kazakhstan