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VIBRATION IMPACT ON PROPERTIES AND PARAMETERS OF STEEL INGOT POROUS STRUCTURE

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The paper deals with the vibration effect on the porous structure of alloyed steel. It is shown that the use of vibration in this mode affects positively decreasing porosity and the nature of the pores in size distribution in the ingot. Mechanical properties of the ingot, such as tensile strength and toughness, after the vibration action are also improved.

Keywords: alloyed steel, ingot, vibration, porous structure, mechanical properties.

INTRODUCTION

The basic problem of obtaining a homogeneous dense structure in ingots of complex alloyed steel is the presence of a large interval between the liquidus and solidus associated with the presence of different alloying elements [1-4]. The presence of a wide interval between the solidus and liquidus leads to uneven crystallization, formation of a loose structure, formation of increased porosity and non-uniform grain. One of the promising trends of improving the quality of ingots made of complex alloyed steels is controlling the structure within the primary crystallization stage using various processing methods, such as vibration, ultrasound, etc. [5-8]. The use of these additional effects on the structure leads to formation of a homogenized structure with a fine grain, practically free of pores, not averse to liquation, which provides improving the operating properties.

In works [9, 10] there is shown a positive effect of vibration on changes in the microstructure of the ingot [9]: decreasing liquation, total porosity, improving mechanical properties.

The task of this workis studying the effect of vibration on the ingot porosity. The occurrence of porosity in the ingot is associated with the presence of gases dissolved in the melt, the presence of heat fluxes, certain chemical reactions in the process of casting and smelting steel. It should be emphasized that the ingot porosity is practically an unavoidable defect because it cannot be eliminated by heat treatment or any other thermal action. In the process of rolling or forging some reduction in porosity is possible, but in this case the percent of the porosity change cannot be predicted, therefore, in order to obtain high-quality rolled products or forging, it is necessary to have an initially dense ingot.

It is practically impossible to obtain an ingot with zero porosity. Sources in which it is indicated that the casting porosity is less than 0,5 %, do not, as a rule, indicate how exactly porosity has been determined, although this is the key moment. It should be emphasized that in this case the definition of porosity by picnometer methods or apparent density methods is incorrect. Very small sieve-like porosity of a closed type can be formed in the ingot body that is not detected by the indicated methods.

In this work for studying porosity there has been used the method of mercury porosimetry that allows registering pores with the radius up to 40 angstroms. For measurements there has been used the PASCAL system of the Therme Fisher Scientific Inc trademarkwith automatic pressure increasing by the stepped graphic method.

EXPERIMENTAL STUDIES

To study the effect of vibration on the ingot porosity there have been prepared various samples. Steel 30CrMnSiNiMoA has been used as the object of studies (Table 1).

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

C	S	P	Mn	Cr	Si	Ni	Mo	Fe
0,29	0,02	0,02	1,2	1,1	1,1	1,7	0,4	Res

Steel 30HGSNMA is an improved alloyed steel used for manufacturing critical parts such as axles, shafts, gears, flanges and other parts operating under conditions of complex loading in the temperature range up to 200 ^{0}C. Although this steel is not highly alloyed, it contains various alloying elements, such as Cr, Mn, Mo, Si,

Sv.S. Kvon, V.Yu. Kulikov, A.Z. Issagulov, M.K. Ibatov, A.M. Dostayeva (a.dostaeva@kstu.kz), Karaganda State Technical University, Karaganda, Kazakhstan

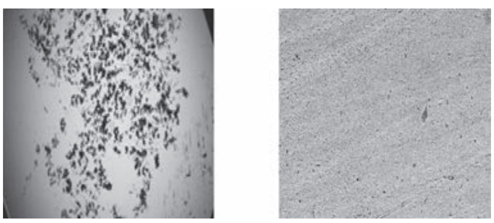
Ni. All these elements have different melting points and render different effects on the polymorphic transformation. Steel 30HGSNMAhas been melted in a modernized UIP-25 furnace then poured into a CMC crucible at the temperature 1 620 ^{0}C. The mass of the melt has been 0,2 kg. The crucible with the melt has been subjected to vibration in the frequency range 80…120 Hz, the amplitude 1,8…2,6 mm, the vibration time varied from 3 to 7 minutes. Table 2 shows the vibration modes used.

Table 2 **Sample number and vibration modes**

Sample number	Vibration frequency/ Hz	Vibration amplitude/mm	Vibration time/min
0	0	0	0
1	80	2	5
2	90	2	5
3	100	2	5
4	110	2	5
5	120	2	5
6	110	1,5	5
7	110	2,0	5
8	110	2,2	5
9	110	2,4	5
10	110	2,6	5
11	110	2	3
12	110	2	4
13	110	2	5
14	110	2	6
15	110	2	7

As the reference there has been used an ingot of steel that has not been subjected to vibration and crystallized under natural conditions. From the ingots obtained samples have been prepared for the further study, in particular metallographic analysis. To determine porosity, samples have been cut from the place of the largest pore accumulation (Figure 1). When selecting localization of sampling, a visual inspection of the section has been performed with magnification of 1 500. Samples No. 0 and No. 4 have been selected as the most vivid representatives of the vibration effect on the structure. The use of other vibration modes (No. 5, 9, 14, 16) forms approximately the same structure as shown in Figure 1b.

As it is seen in Figure 1, in the sample crystallized under natural conditions, the pores accumulate mainly in the center of the sample, they have rather large sizes.



a b

Figure 1 Presence of porosity in steel:
a – sample No. 0;
b – using mode No. 4 (X 1 500)

Such segregation of pores is associated with poor heat and mass transfer, the melt is a virtually continuous medium for the off-gases. In the sample of steel which process of crystallization has been accompanied by vibration, pores are also present, but the nature of their distribution is fundamentally different. The pores are arranged evenly over the section of the ingot and have a smaller size. This pattern of pore distribution is more favorable in terms of the ingot strength properties. The nature of pore size distribution is also important. From the point of view of strength, it is preferable to have small pores that are isometrically developed in all directions. For this purpose there have been taken porograms of the samples (Figure 2).

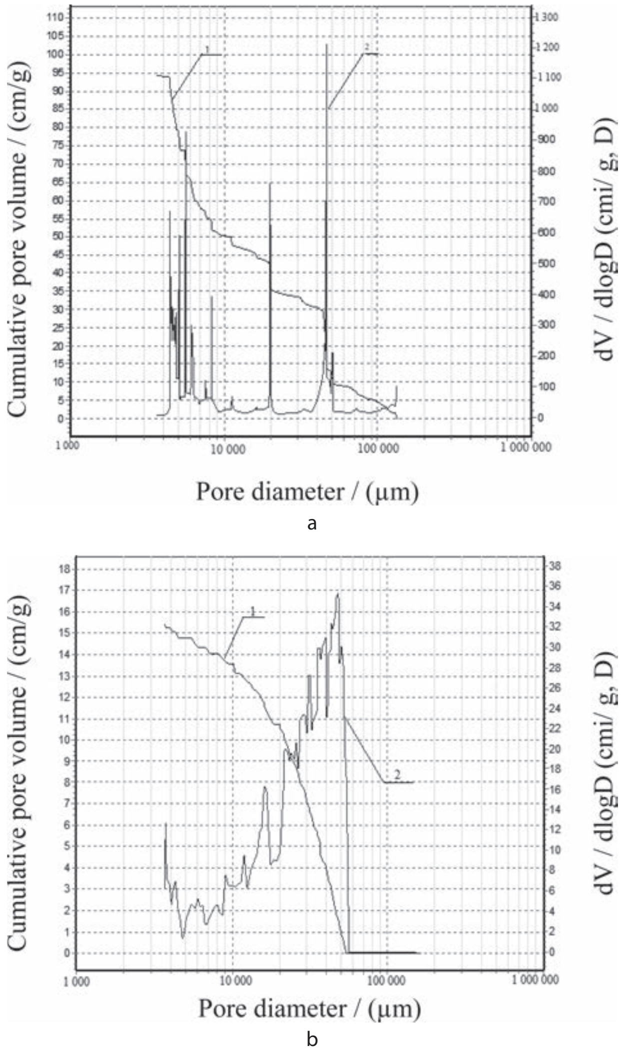


Figure 2 Porograms of steel samples:
a – without vibration;
b – using vibration (sample No. 4).

Comparing the porograms of the samples shows an unequal pattern of pore size distribution in the samples. In sample No. 0 with the total porosity 2.8 %, the majority of the pores (about 72 % of the total volume) are the pores with the radius 40 - 50 µm, i.e. rather large. In sample No. 4 the total porosity becomes smaller, about 1,1 %, but the main difference between the porous structure of this sample is changing the nature of the pore distribution. There are no large pores with the radius more than 60 micrometers, a larger fraction of the pores (about 60 % of the total volume) are the smaller pores with the radius 20 - 30 μm.

As it is shown in [1], in quality ingots it is important to obtain not only minimum possible porosity but also the specific nature of the pore distribution and the minimum possible average pore size. The analysis of the porograms shows that vibration has a positive effect not only on the total porosity but also on the nature of the pore size distribution. Reducing the total porosity and average size of the pore diameter should lead to improving mechanical properties of the ingot and to increasing its strength.

RESULTS AND DISCUSSION

To test this assumption the samples have been prepared from sample No. 0 and sample No. 4 to determine the ultimate tensile strength and toughness. Strength tests have been carried out on the INSTRON tensile machine, impact strength tests on the pendulum impact machine IO 5003-03-11. The results of the tests are shown in Figure 3.

As it can be seen in Figure 3, the effect of vibration under this mode leads to both increasing tensile strength and increasing toughness. Strength of alloyed steel is determined by several mechanisms [10]:

$$\delta_m = \delta_o + \Delta\delta_{mp} + \Delta\delta_n + \Delta\delta_\partial + \Delta\delta_{\partial.y} + \Delta\delta_з, \qquad (1)$$

where δ_o is the friction strain of the lattice $\alpha - Fe$;

$\Delta\delta_{mp}$ is hard solder hardening;

$\Delta\delta_n$ is hardening due to perlite formation;

$\Delta\delta_\partial$ is strain hardening (hardening due to increasing dislocation density);

$\Delta\delta_{\partial.y}$ is dispersion hardening;

$\Delta\delta_з$ is grain boundary hardening.

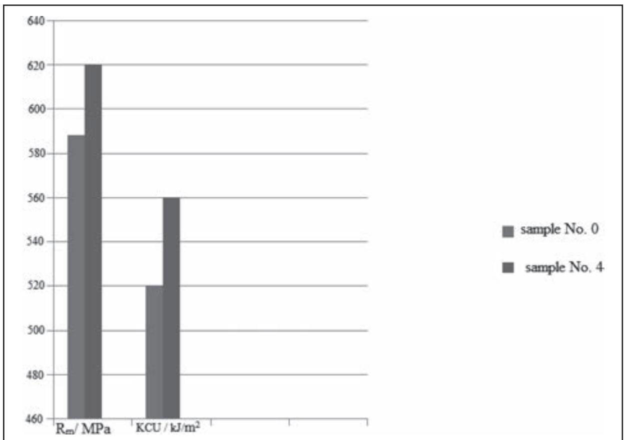


Figure 3 Changing mechanical properties under the vibration action

The presence of porosity, especially large, has a negative effect on the mechanism of strain hardening due to frictional strains of the lattice. The pores can be considered as a foreign phase in the matrix, which leads to the occurrence of additional stresses, respectively, the indicated terms in equation (1) acquire a negative value.

CONCLUSION

The results of the study show that vibration action at the 110 Hz frequency, the amplitude 2 mm and the action time 5 minutes makes it possible to reduce the ingot porosity, to reduce the average size of the pore diameter, to shift the pore distribution pattern towards smaller pores, and to exclude the presence of large pores with radii of more than 60 μm. The improvement in the porous structure of the ingot leads to increasing certain mechanical properties, in particular, tensile strength and toughness. The vibration impact on the crystallization process can be carried out directly in the ladle before pouring or subject to vibrational processing the mold with the melt in case of producing shaped ingots.

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Note: The responsible for England language is Natalya Drak, Karaganda Kazakhstan