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HEAT TREATMENT EFFECT ON THE PROPERTIES OF VIBRATION TREATED STEEL DURING CRYSTALIZATION

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Preliminary Note – Prethodno priopćenje

The effect of heat treatment on the structure and properties of 30HGSNMA steel that has been subjected to vibration treatment at the stage of primary crystallization is considered in the work. It is proposed to use normalization with accelerated cooling with a water-air mixture among possible treatment methods. The properties of steel after this heat treatment are investigated. It has been found that there is a significant increasing of hardness, tensile strength and impact strength, and the level of these properties is comparable with the level of properties after hardening and tempering. The introduction of one-stage heat treatment that consists in normalization with accelerated cooling, allows reducing the heat treatment cycle and increasing the equipment productivity.

Keywords: 30HGSNMA steel, heat treatment, vibration, structure, properties.

INTRODUCTION

30HGSNMA steel (Table 1) is widely used as high strength steel for manufacturing pipes; for manufacturing parts and products operating in complex stress conditions. For manufacturing the latter, the classic heat treatment is oil quenching at the temperature of 880 – 900 °C followed by tempering at the temperature of 540 – 600 °C with cooling in water or oil [1, 2].

Table 1 **Chemical composition / wt. %**

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

As a result of heat treatment, in this steel there is formed the structure consisting of martensite decomposition products: a sorbitol-like mixture, that is a doped α-solution and carbides mainly of the $(Fe,Cr,Mn)_3C$ type. The finely dispersed sorbitol-like mixture provides a good set of strength and viscosity properties that allow steel working after this heat treatment in complex stress conditions. Its tensile strength is ensured in the order of 600 MPa, impact hardness 0,5 MJ/m^2.

In previous studies [3-4] it was shown that an external action in the process of primary crystallization has a beneficial effect on the primary structure of steel. The external factors of the effect the studies used vibration and introduction of inoculants-frigitors. The favorable effect of these factors on the structure is explained by increasing the centers of primary crystallization, and by improving heat removal and diffusion in the liquid medium.

A favorable changing of the primary structure under the effect of external factors and the hereditary granularity inherent in one way or another in all alloy steels allow suggesting that after heat treatment, favorable changes in the structure will remain. This assumption is based on studying the structure of steels after heat treatment in the presence of a primary ordered structure [5,6]. The results of these studies allow considering various alternatives aimed at simplifying heat treatment of steel by the external action in the process of primary crystallization as the heat treatment of prototypes.

It is known that the simplest type of heat treatment is normalization of steel. Normalization allows obtaining a quasi-eutectoid ferrite-pearlite mixture that differs from the true eutectoid in higher dispersion, which leads to some increasing the mechanical properties of steel. However, normalization is not widespread as an alternative to the more expensive type of heat treatment, hardening and tempering, because the improvement of properties after normalization is much lower than after hardening and tempering. In this regard, normalization is used either for heat treatment of cheap carbon steels or as one of the stages of heat treatment of alloyed steels as a preliminary stage for homogenization of the structure.

It was shown in works [3-4] that after treating by vibration, the structure of steel becomes more homogeneous: the difference between the largest and smallest grains decreases, the degree of segregation both in terms of grain volume and in cross-section of the ingot

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as a whole decreases; in addition, the average grain size and pollution index are reduced.

In other words, the structure of steel under the effect of vibration in the crystallization process becomes more fine-grained and homogeneous. It can be assumed that the use of normalization as heat treatment of such a structure will have a higher effect on the final structure than in ordinary practice.

EXPERIMENTAL STUDIES
Equipment and tools

To verify this assumption, the following experimental studies were carried out.

Samples of 30HGSNM steel subjected to vibration during primary crystallization were used as the object of study. Steel was poured into shell molds mounted and fixed on a vibrating table. In the process of crystallization the mold with the melt were subjected to vibration at the following parameters: amplitude 2,5 mm, frequency 110 Hz, exposure time 5 minutes. At the end of the vibration, the filled forms were left on the vibrating table until completely cooled. Then the molds were broken, the castings were cleaned from the remnants of the mold and subjected to heat treatment under different conditions (Table 2).

Heat treatment was carried out in a Nabertherm LHT 02/17 furnace in the air atmosphere. At the end of heat treatment the samples were cut out from the experimental castings for further testing. Such properties as hardness, tensile strength, and toughness were investigated. An AXIO Imager A1 microscope was used for testing, a Wilson VH1150 Vickers hardness tester was used to determine hardness, an INSTRON testing machine was used to determine tensile strength, impact strength was determined using a MK-30A pendulum hammer. Table 2 shows the results of the tests.

Table 2 **The results of the tests carried put**

Sample etc.	Heat treatment mode	Hardness, / HV	Ultimate strength / MPa	Impact hardness / MJ/m^2
1	After casting, without heat treatment	227	324	0,26
2	Quenching 900°, oil, tempering 550°, oil	432	620	0,47
3	Normalization 9000, cooling in air	385	506	0,33
4	Normalization 900°, cooling in water-air mixture	424	602	0,43
5	Normalization 930°, cooling in air	389	517	0,35
6	Normalization 930°, cooling in water-air mixture	431	613	0,40

It is seen from the data in Table 2 that a one-stage heat treatment, consisting of normalization, significantly improves the properties of steel compared to the initial state. Hardness and strength of steel after normalization compared with the cast state increase by about 40 %, impact strength by 25 %. Such increasing the properties is quite natural, because during normalization two processes take place. On the one hand, the structure is homogenized, on the other hand recrystallization with formation of a quasi-eutectoid that is characterized by greater dispersion, which leads to increasing the level of properties.

It should be noted that the effect of the normalization temperature within the indicated limits does not practically affect changing the properties. Further expansion of the temperature range to select the normalization temperature does not make sense. Normalization temperature below 900 °C is not effective, because this temperature is actually the lowest temperature limit of the austenite zone for this steel grade. Raising the temperature above 930 °C also does not make sense, because it can lead to uncontrolled grain growth, which is characteristic of hereditarily granular steels and overheating.

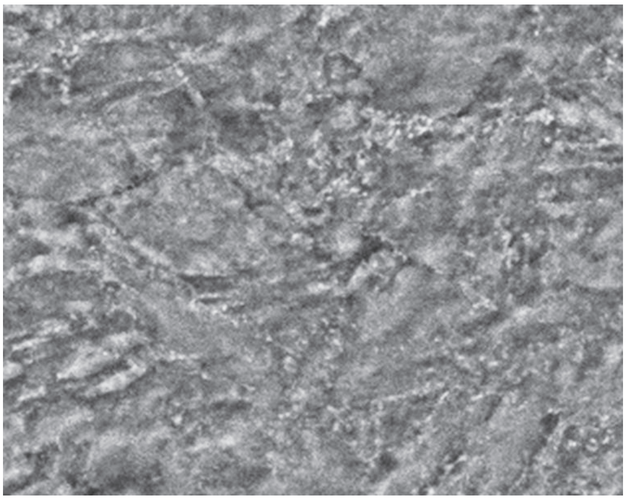
A much greater effect on changing the properties after heat treatment, as it is seen from the data in Table 2, is exerted by the cooling medium. Two options were used as the cooling medium: air or a water-air stream with the water temperature of 20 °C and the flow rate of 15 $cm^3/s \times m^2$.

The use of the water-air mixture leads to increasing the cooling rate, which provides other conditions for heat removal and recrystallization. It is known [1,7,8] that for carbon steels such a medium cannot provide a critical quenching rate and, consequently, a martensitic transformation. For alloy steels, due to the increased stability of austenite, a martensitic transformation at this cooling rate is possible in some cases, for example, by alloying with elements providing increased hardenability.

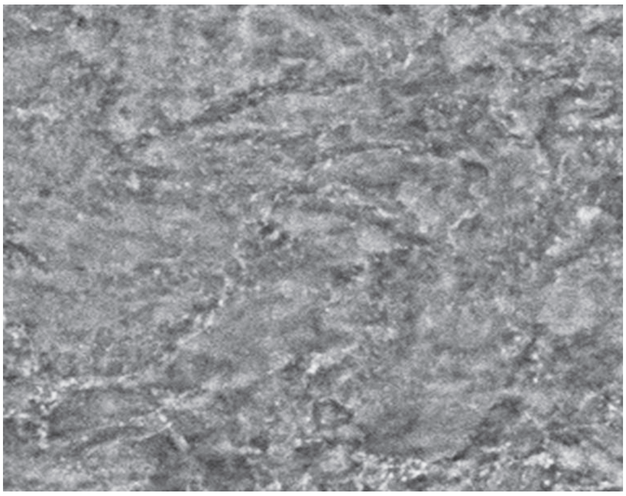
30HGSNM steel contains the chromium+nickel+molybdenum composition, i.e. the elements that provide sufficiently high hardenability of steel and, therefore, the possibility of a martensitic transformation at a lower cooling rate. On the other hand, when using one-step heat treatment, a partial occurrence of a martensitic transformation is undesirable, because in this case there is possible the formation of separate zones of residual austenite.

If we judge the changing hardness of the test samples after normalization, then we can assume that only recrystallization occurs with the formation of a finely dispersed quasi-eutectoid without phase recrystallization. For this purpose, the microstructure of the experimental samples was studied (Figure 1).

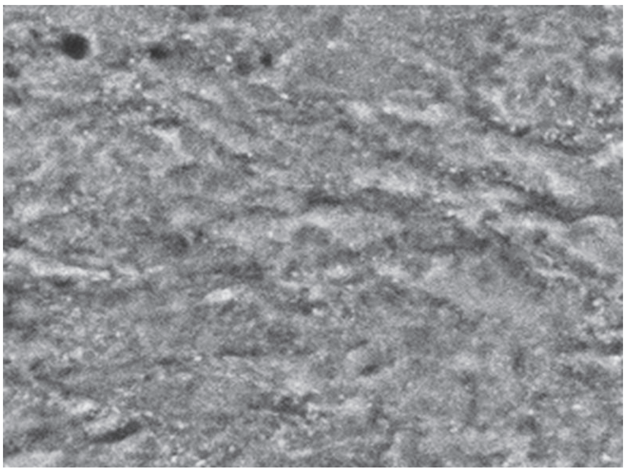
It is seen in Figure 1 that the structure of the samples after normalization is really characterized only by a sorbitol-like mixture, and after cooling with the water-air stream (Figure 1a), the mixture visually looks finer than after cooling in air (Figure 1b). In both cases, the resulting structure is comparable to the structure of the sample subjected to vibration.



a



b



c

Figure 1 30HGSNM steel microstructure after heat treatment:*a* – sample No. 5; *b* – sample No. 6; *c* – sample No. 2 (magnification × 400)

CONCLUSION

The studies carried out have shown that steel subjected to vibration in the process of primary crystallization, in order to improve mechanical properties, can only be normalized with a higher cooling rate than in calm air. In such steel that has a relatively ordered structure as a result of treating during primary crystallization, a finely dispersed sorbitol-like mixture is formed, comparable in properties and structure to tempering sorbitol formed after hardening and tempering.

The use of one-stage heat treatment (normalization with accelerated cooling) allows reducing the heat treatment cycle of steel and, thereby, increasing the productivity of thermal equipment.

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