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EFFECT OF REDUCING AGENT'S NATURE ON THE MICROSTRUCTURE AND CERTAIN PROPERTIES OF $30CrNi_2Mo$ HIGH-QUALITY STEEL

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Preliminary Note – Prethodno priopćenje

$30CrNi_2Mo$ high-quality steel is a heat-hardenable steel. This quenched-and-tempered steel has high strength properties, sufficiently good plasticity and hardness. It is used to manufacture component parts that work in a complex-loaded condition under the action of alternating loads. The classical way of heat treating for this steel is quenching with subsequent high tempering, as a result of which the structure of alloyed sorbitol type is formed. The experiment results allow us to state that killing with the new FS45A15 aluminum ferrosilicon reducing agent has a beneficial effect on the formation of a fine-grained structure.

Keywords: $30CrNi_2Mo$ high-quality steel, wearability, mechanical properties, microstructure

INTRODUCTION

$30CrNi_2Mo$ high-quality steel is a heat-hardenable steel. This quenched-and-tempered steel has high strength properties, sufficiently good plasticity and hardness. It is used to manufacture component parts that work in a complex-loaded condition under the action of alternating loads. The classical way of heat treating for this steel is quenching with subsequent high tempering, as a result of which the structure of alloyed sorbitol type is formed.

In some works [1-4], it is noted that it is possible to use heat-hardenable steel grades as wear-resistant materials, and their properties after some treatment are not inferior to the properties of widely used Hardox wear-resistant steel.

As noted in a number of works [3, 5] devoted to the study of Hardox steel properties, unique wear-resistant properties of Hardox steel are achieved due to the metallurgical quality of the steel and the formation of a special fine-grain structure.

At the present time, the analogues of Hardox steels are 18CrMnNiMoVB and $16CrMnNi_2VNbB$ grade steels, the supplier of which, in particular, is Severstal JSC. It should be noted that the chemical composition of these steels is significantly different from the composition of Hardox steels, in particular – carbon. This circumstance explains lower strength properties, hardness and wearability of the analogues compared to Hardox steel.

If there is made make a comparative analysis of the properties and chemical composition of the Hardox 500 and $30CrNi_2Mo$ high-quality steel (Table 1), it can be seen that they belong to the same structural class and have an approximately equal level of properties in terms of hardness and ultimate resistance.

Table 1 **Comparative analysis of properties and chemical composition of Hardox steel and $30CrNi_2Mo$ high-quality steel after heat treating / wt. %**

Specimen / Principle / %	$30CrNi_2Mo$ high-quality steel	Hardox 500 steel
C	0, 28	0,27
Si	0,22	0,7
Mn	0,5	1,6
Ni	1,55	0,6
S	0,025	0,025
P	0,025	0,025
Cr	0,8	1
Mo	0,2	0,6
B	-	0,004
$R_{0,2}$ / MPa	1 300	1 300
R_m / MPa	1 400	1 550

As it can be seen in Table 1, the heat-hardenable steels alloyed with chromium, manganese and nickel are closer in chemical composition. The use of heat-hardenable steels as wear-resistant materials has a clear scientific justification, if the latter is based on Charpy principle. According to this principle, the structure of wear-resistant materials should consist of isolated solid inclusions lying in a viscous, relatively soft matrix. In the structure of heat-hardenable steels the viscous matrix is an alloyed α-solution, and solid isolated inclusions are carbides and other interstitial alloys. Thus, in order to form a heat-hardenable steel structure with high wear-resistant properties according to Charpy principle, it is necessary to obtain a matrix α-solution

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with a good complex of plasticity and strength, and also round-shaped solid inclusions of small size with a homogeneous distribution character along the structure.

As it is known, one of the most important stages of melting, which largely determines the metallurgical quality of steel and forms the initial structure, is the process of killing. When melting steel, such classical reducing agents as ferrosilicon manganese and additional aluminum can be used. Aluminum plays a special role in the formation of a fine-grained structure, because it forms solventless inclusions of Al_2O_3, which in the subsequent crystallization play the role of crystallization centers and, thus, form fine-grained structure.

The purpose of this research was to study the effect of a new reducing agent on the structure and certain properties of 30CrNi2Mo high-quality steel in order to determine the possibility of its use as a wear-resistant material.

EXPERIMENTAL STUDIES
Equipment and tools

As an experimental reducing agent there has been used FS45A15 grade aluminum ferrosilicon, obtained by the technology developed by Abishev Chemical and Metallurgical Institute [6]. The composition of the experimental reducing agent is shown in Table 2.

It should be noted that in contrast to FSA grade aluminum ferrosilicon (GOST 1415-93), the experimental reducing agent has a high silicon content, which allows it to be used as a source of silicon upon alloying.

Table 2 **Chemical composition of aluminum ferrosilicon reducing agent / wt. %**

Grade	Si	Al	S	P	Mn
FSA45A15	40-45	12,5-17,5	0,1	0,02	0,31
FSA	10-20	20-25	no more than 0,01	no more than 0,05	-

As a comparative prototype (basic reference) we used $30CrNi_2Mo$ high-quality steel killed in a standard way. Experimental melting was carried out in UIP-25 Induction Furnace. Aluminum ferrosilicon was introduced into the furnace a few minutes before the end of melting operation. After complete cooling, specimens were cut from the mass of experimental melting for heat treating (heat treatment mode: thermohardening 860 °C, oil, tempering 400 °C air). After heat treating polished sections were made from prototypes for metallographic analysis. For metallographic analysis we used the Thixomet PRO software. We evaluated the grain score of the structure and the pollution index with nonmetallic inclusions. The pollution index was determined by the formula:

$$I = \frac{b\sum a_i \cdot m_i}{l} \qquad (1)$$

where

b – is a scale division of a graticule at a given magnification in μm;

a_i – is an average value of the inclusions in graticule divisions;

m_i – is the number of inclusions in this group;

l – is a counting length in μm.

Metallographic analysis was carried out in at least 10 vision areas. The average data of the studies are given in Table 3.

As it can be seen from the data in Table 2, the introduction of FS45A15 grade reducing agent results in a certain refinement of the grain (the average grain diameter is reduced by 27,5 %) and a decrease of the pollution index by 11 %. The distribution nature of nonmetallic inclusions between grain junction line and grain volume has not changed essentially: inclusions are distributed approximately in equal proportions between the volume and the grain junction line.

Table 3 **Results of metallographic analysis**

Specimen	Average grain score	Average grain diameter/ mm^2	Pollution index with nonmetallic inclusions, I_{com} $*10^{-3}$		
			grain junction line	grain volume	combined
Basic reference	7	0, 029	1,12/53,8	0,96/46,2	2,08/100
Prototype model	8	0,021	0,98/52,9	0,87/47,1	1,85/100

Figure 1 shows the microstructures of $30CrNi_2Mo$ high-quality steel killed with FSA45A15, basic reference and Hardox 500 steel in the as-delivered condition.

The figures shows, that the microstructures of Hardox 500 steel and $30CrNi_2Mo$ high-quality steel killed with FSA45A15 are characterized by a fairly homogeneous structure without strongly marked boundaries (Figure 1 (a, b)). The structure of steel basic reference is characterized by strongly marked boundaries (Figure 1 (c)). In

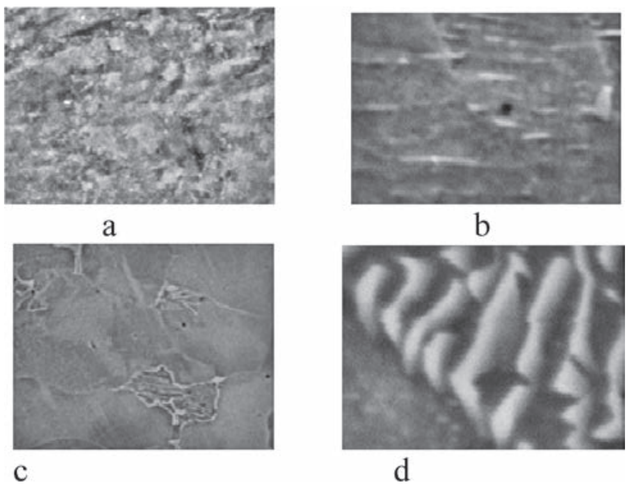

Figure 1 Microstructure of steels after melting and heat treating processes: a) Hardox 500 steel (X 500) in the as-delivered condition; b) $30CrNi_2Mo$ high-quality steel killed with FSA45A15 after heat treating (X 500); c) $30CrNi_2Mo$ high-quality steel – basic reference (X 500); d) $30CrNi_2Mo$ high-quality steel after heat treating (X 5 000).

both cases the structure is a sorbitol-like matrix with the interstitial alloy. At large magnifications, we can see the lamellar structure of the matrix (Figure 1(d)).

As it can be seen from the data in Table 3, the use of aluminum ferrosilicon as the reducing agent leads to the formation of a finer-grained structure and reduction of the pollution index with nonmetallic inclusions, i.e. increase the metallurgical quality of steel.

Based on the data, we can assume that changes in steel microstructure after using this new reducing agent will lead to some change in the mechanical properties.

To analyze this hypothesis, the prototype model was tested for hardness, ultimate resistance and wearability. All tests were carried out according to the corresponding GOST. Tests for hardness were carried out on the Wilson VH1150 Macro Vickers Hardness Tester, for strength – on the Instron Testing System up to 500 kN, the extent of wearability was evaluated by changing the weight on the advanced Roller Friction Test Machine SMC-2. A sample from $30CrNi_2Mo$ high-quality steel killed with FSA45A15 after heat treating was used as a roller, grey cast iron was used as a contact jaw. Test results are shown in Table 4.

Table 4 **Test results for mechanical properties**

Specimen	Hardness/ HB	Ultimate resistance/ MPa	Wearability/ x10^{-4}, g
Hardox 500 steel	425 - 475	1 250	26
Basic reference	340 - 360	1 200	39
Prototype model	350 - 370	1 400	31

As it can be see from the data in Table 4, $30CrNi_2Mo$ high-quality steel prototype model killed with aluminum ferrosilicon has a higher ultimate resistance and wearability, although its hardness has not changed much.

RESULTS AND DISCUSSION

The obtained results of tests for mechanical properties are not surprising, because when forming a finer-grained structure, the increase in strength is to be expected.

The absence of significant changes in hardness is explained by the fact that the phase composition of steel has not changed. Therefore, we should not expect any strong changes in such a structure-related factor as hardness.

The increase in wearability of the prototype model is easily explained from the perspective of Charpy principle.

On the presented microstructure (Figure 2) the change in the nature, size and shape of nonmetallic inclusions is clearly visible. Nonmetallic inclusions in specimens killed with aluminum ferrosilicon have a more rounded shape; they are smaller and fairly well-distributed in a vision area. The nature of nonmetallic inclusions has not been specifically investigated in this study. However, based on the chemical composition of steel and reducing agent, it is logical to assume that some of the inclusions are represented by aluminum

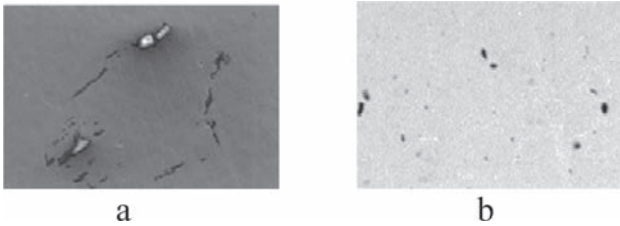

Figure 2 Nonmetallic inclusions in $30XH_2MA$ grade steel – (a) basic reference and (b) $30CrNi_2Mo$ steel killed with FS45A15, (X 500)

and molybdenum oxides as solventless ones. Some of the inclusions are interstitial alloys, having a carbide nature of $(Fe,Cr)_3C$, MoC type. All these interstitial alloys have a sufficiently high hardness, according to data [7] it is from 16 to 20 HV. Thus, the microstructure obtained is fully consistent with Charpy principle: a sufficiently strong and ductile matrix is an alloyed α-solution with nickel, giving an additional viscosity and lowering the transition temperature, and molybdenum, reducing the tendency of steel to be followed by temper brittleness. Solid and fairly small inclusions are well-distributed across the matrix.

CONCLUSION

The experiment results allow us to state that killing with the new FS45A15 aluminum ferrosilicon reducing agent has a beneficial effect on the formation of a fine-grained structure. After several processing methods $30CrNi_2Mo$ high-quality steel can be considered as an analogue of Hardox 500 steel as a wear-resistant material.

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Note: The responsible for England language is Margulan Sharip, Karaganda Kazakhstan