Study of the influence of combined thermomechanical processing modes on the mechanical properties of economically alloyed steel 5KHV2S

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Abstract. *Despite the rapid development of metallurgical processes for the production of semi-finished products aimed at improving the modes of smelting, casting and crystallization, a significant improvement in the properties of any cast metal, ensuring its wide application in modern mechanical engineering, is achieved by combined thermomechanical processing of workpieces, combining hot metal forming and heat treatment. The technologies and equipment currently used in Kazakhstan by machine-building manufacturers have long been obsolete and ineffective. A common problem for everyone is the high energy intensity of production, its low productivity and the quality of forgings and blanks produced, which leaves much to be desired. Namely forgings and blanks are the starting materials for the manufacture of high-quality tools and technological equipment at mining and metallurgical engineering enterprises. Therefore, the purpose of this work is to develop rational modes of thermal and thermochemical processing of 5KHV2S steel, previously forged in a tool that implements alternating strain in metal, as well as to study the influence of combined thermomechanical processing modes on the mechanical properties of this steel. The studies carried out in this work on the hardness of 5KHV2S steel samples subjected to combined thermomechanical processing showed that the developed technologies contributed to an increase in both total and surface hardness compared with samples not subjected to pre-forging in a new forging tool that implements alternating strain in the metal.*

Keywords: *HEAT TREATMENT, THERMOCHEMICAL PROCESSING, ECONOMICALLY ALLOYED STEEL, HARDNESS.*

1. Introduction

Thermomechanical processing of alloy steels is a mandatory technological operation for processing various workpieces when forming a structure in metal products [1]. Grinding and texturing of solid solution grains in combination with directional shaping can significantly improve the mechanical and operational performance of various machine parts. As a rule, forging provides preparation of the microstructure for subsequent heat treatment of chromium and other steels containing carbide-forming elements. The intensity of the study of the structure during forging, as well as the processing of forgings and workpieces in the state of austenitic structure, provides an opportunity for the combined use of the actual hot pressure treatment in combination with heat treatment to obtain a metal structure with improved characteristics. Therefore, the development of new technologies for combined thermomechanical processing, including hot pressure treatment and subsequent heat treatment of workpieces made of economically alloyed steels for various purposes for mining and metallurgical engineering, is an urgent scientific and technical task.

As part of the implementation of the first stage of the grant theme AP09259236, a new technology for forging workpieces in a tool that implements alternating deformations in metal was developed and the influence of this technology on the evolution of microstructure and changes in the mechanical properties of steel grades 7HG2VM and 5KHV2S was investigated. In the course of experimental studies, the expediency of using the proposed forging technology and strikers for its implementation, instead of the currently used forging technology in flat strikers, has been proved, since the proposed forging technology with a similar forging as when forging in flat strikers, allows to obtain forgings and blanks of higher quality qualities with a uniformly distributed equiaxial fine-grained structure [2-3].

The purpose of this work is to develop rational modes of thermal and thermochemical processing of 5KHV2S steel, previously forged in a tool that implements alternating deformations in metal, as well as to study the influence of combined thermomechanical processing modes on the mechanical properties of this steel grade.

2. Materials and methods

To achieve this goal, the following modes of thermal and thermochemical treatment were proposed:

1) Heat treatment: quenching from a temperature of 880°C in oil, followed by tempering at a temperature of 200°C (mode 1) and 500 ° C (mode 2).

2) Thermochemical treatment:

2.1) cementation in a solid carburetor (920°C, 8 and 12 hours) + quenching from a temperature of 880°C in oil followed by tempering at a temperature of 200°C;

2.2) nitrocementation in a solid carburetor modified with carbamide (880°C, 6 and 8 hours) + quenching from a temperature of 880°C in oil, followed by tempering at a temperature of 200°C.

It should be noted that in order to conduct a comparative analysis, in parallel with the thermal and thermochemical processing of 5KHV2S steel, previously forged in a tool that implements alternating deformations in the metal, thermal and thermochemical processing of 5KHV2S steel, annealed at a temperature of 700°C with an exposure of 40 minutes, was carried out according to similar modes [3].

The designation and processing modes of the samples are given in Table 1.

Experimental studies were carried out at the laboratory base of Rudny Industrial Institute (Kazakhstan) and the Belarusian State Technological University (Belarus). Muffle furnaces SNOL 30/1300 LSF01 were used to heat the samples. The samples that were not subjected to hardening were heated in containers with cast iron shavings and a sealed gate between the lid and the body. The castle was covered with fine-grained quartz sand. During quenching, the container was removed from the furnace and immediately after opening, the samples on the suspension were removed from the chips and placed in quenching oil. During the hardening treatment carried out before quenching, two options were implemented. According to the first, carburization was carried out in containers with modified barium carbonate charcoal. After its completion, the containers were cooled together with the furnace, and then heated for quenching in a container with cast iron shavings. According to the second variant, high-temperature nitrocementation was carried out in a container with charcoal modified with urea. Since the saturation temperature coincided with the temperature of heating for quenching, it was carried out by directly removing the suspension with samples from the container with coal and immersion in quenching oil. In all cases, the polymer composition "THERMOVIT-M" was used as a quenching medium.

To determine the values of hardness indicators, as the main property characterizing the behavior of steels, a series of 5KHV2S steel samples subjected to thermal and thermochemical treatment in various modes was obtained.

***Table 1** – Modes of thermomechanical processing of steel 5KHV2S*

Sample designation	Initial state	Thermochemical treatment modes			Heat treatment modes	
		Type of treatment	Time, hour	T, ºC	T quenching, ºC	T tempering, ºC
1	forging	-	-	-	-	-
2	annealing	-	-	-	-	-
1q200	forging	-	-	-	880	200
1q500	forging	-	-	-		500
2q200	annealing	-	-	-		200
2q500	annealing	-	-	-		500
1c8200	forging	Cementation	8	920		200
1c12200	forging		12			
2c8200	annealing		8			
2c12200	annealing		12			
1nc6200	forging	Nitrocementation	6	880		
1nc8200	forging		8			
2nc6200	annealing		6			
2nc8200	annealing		8			

The determination of the values of hardness indicators was carried out on DuraJet-10 hardness tester (EMCO-TEST, Austria) by the Rockwell method according to the standard methodology and a Duramin microhardometer (Struers, Denmark) by the Vickers method with a load on the indenter of 10-2000 g, the exposure time is 10 s. Automatic loading of the indenter, exposure and unloading, automatic load testing exclude deviations during the measurement. The hardness testers used represent modern technologies and comply with current norms and standards.

3. Results

The results of the microhardness study are presented in Table 2.

***Table 2** – Microhardness of 5KHV2S steel samples after thermal and thermochemical treatment in various modes*

Sample number	Microhardness of the surface, MPa	Microhardness of the base, MPa
Initial state		
1	-	4250, 4180, 4320
2	-	3590, 3890, 3750
After heat treatment		
1q200	-	6490, 6550, 6630
1q500	-	5090, 5110, 5220
2q200	-	6120, 5850, 6050
2q500	-	4420, 4000, 4180
After cementation		
1c8200	7930, 7510, 7190	6870, 7020, 6810
1c12200	8040, 7730, 6970	6790, 6850, 6870
2c8200	7840, 6970, 6560	6260, 6380, 6420
2c12200	7720, 7230, 6890	6490, 6530, 6550
After nitrocementation		
1nc6200	8190, 7680, 7300	6520, 6330, 6370
1nc8200	8250, 7600, 7200	6630, 6560, 6580
2nc6200	7950, 7250, 6870	6220, 6170, 6330
2nc8200	8020, 7340, 6880	6410, 6480, 6440

Figures 1-2 show graphs of microhardness distribution over the cross section of the studied samples of 5KHV2S steel.

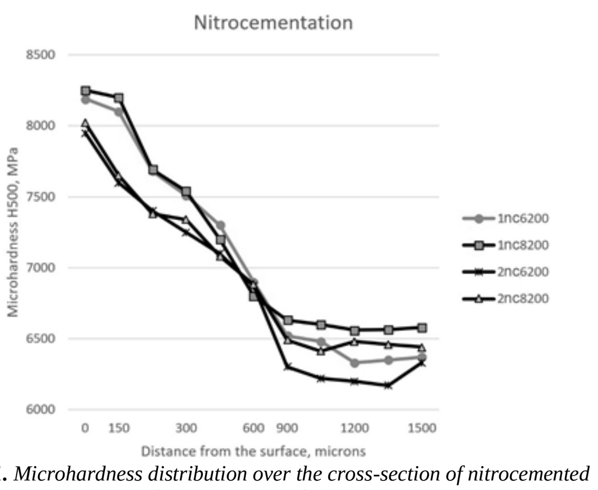

***Fig. 1.** Microhardness distribution over the cross-section of nitrocemented layers of steel 5KHV2S after heat treatment*

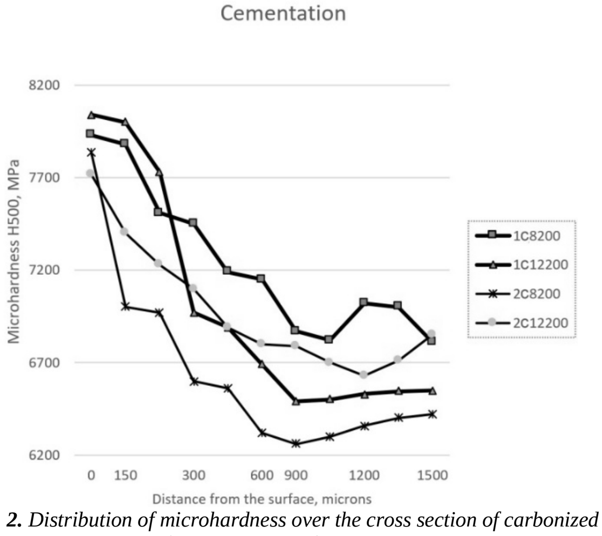

***Fig. 2.** Distribution of microhardness over the cross section of carbonized layers of steel 5KHV2S after heat treatment*

4. Discussion

The results of the studies shown in Table 2 indicate a higher hardness of 5KHV2S steel samples after forging in a tool that implements alternating deformations in the metal, compared with samples after annealing. Such a difference is observed both on the initial samples and on the samples subjected to hardening heat treatment. At the same time, the hardness of the samples after forging, quenched with subsequent tempering at a temperature of 200°C and 500°C was 6.5 GPa and 5.1 GPa, respectively, and for the samples after annealing, subjected to heat treatment under the same conditions – 6.0 GPa and 4.2 GPa. As can be seen from Table 2 and the microhardness distribution graphs (Figure 1-2), such a difference in the hardness of samples after forging and annealing is observed after thermochemical treatment.

Analysis of microhardness distribution graphs over the cross-section of 5KHV2S nitrocemented steel layers (Figure 1) showed that changing the duration of nitrocementation from 6 to 8 hours does not significantly change the hardness of the surface and core. On the surface, this indicator reaches 8.2 GPa, in the core it reaches 6.5 GPa. It should be noted that an increase in the duration of nitrocementation to 8 hours was reflected in an increase in the overall thickness of the layer.

A study of the microhardness distribution of cemented layers of steel 5KHV2S after the final maintenance (Figure 2) showed that the surface microhardness tends to decrease, the maximum value of which is registered at the level of 8.0 GPa. The decrease in this parameter is due to the high content of the carbide phase in the hardened layer, reaching 50%. In addition, there is a phase based on γ-Fe. This ratio leads to a violation of the integrity of the martensitic matrix of layers, reducing their ability to resist the introduction of the indenter. As in the case of nitrocementation, the thickness of the carbonized layers increases with an increase in the saturation duration from 8 to 12 hours. The hardness of the core reaches 6.8 GPa.

5. Conclusion

A comparative analysis of the conducted studies of the hardness indicators of 5KHV2S steel samples subjected to combined thermomechanical processing in various modes showed that the developed technologies contributed to an increase in both total and surface hardness compared to samples not subjected to pre-forging in a new forging tool that implements alternating deformations in the metal, which in turn should have a positive effect on their operational properties. Studies have established that after nitrocementation with final heat treatment, the hardness on the surface reaches 8.2 GPa, in the core reaches 6.5 GPa. Cementation with final heat treatment provides a hardness of 8.0 GPa on the surface, and reaches 6.8 GPa in the core.

6. References

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