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Application of Reinforcing Thermocycling Treatment for Materials of Stamps Hot Deformation

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Abstract. The paper is devoted to the search for technological methods of increasing the resistance of the stamp tool for hot deformation. New non-standard combinations of cyclization schemes and parameters of thermocycling processing within the regime were developed. This is allowed the creation of managed structural states in the metal due to the grinding of grain, the creation of high density of defects, and the acceleration of diffusion processes to effectively manage the structure, increase the mechanical, operational properties and prevent the destruction of the working surfaces of the tool. New modes of thermocycling treatment, which have a positive effect on the mechanical characteristics of HNM5 steel, have been developed and tested. The conducted heat treatment in experimental modes, consisting of thermocycling treatment as a preliminary, quenching and tempering as the final, allows obtaining a more homogeneous structure with the preservation of fine grain and a given hardness. The grain size of the steel HNM5 structure after the use of thermocycling treatment decreases from 5–6 to 7–8 points, and after the final heat treatment – to 9–10 points.

Keywords: stamp of hot deformation, thermocycling treatment, strength, relative narrowing, thermal resistance.

1 Introduction

Hot volume stamping is used to produce blanks for the responsible parts of cars, tractors, agricultural machines, airplanes, railway cars, machines, etc. [1]. It is quite common to use steel HNM5 for hot deformation stamps, which is now the widespread material in the production of hot stamping tools in batch production [2].

The problem of improving the quality, reliability, and durability of the tool for hot deformation of metal is relevant in connection with the improvement of the design of rolling mills and forging and pressing equipment, if necessary, to achieve greater compression forces and deformation rates. Therefore, the priority of materials science at the present stage is the development of new high-efficiency modes of strengthening, which allow increasing the level of physical, mechanical and operational properties of the tool.

Currently, thermocycling treatment (TCT) is the heat treatment under conditions of cyclic thermal influences that are intensively distributed [3]. However, it is used in production for a very limited list of products. The solution to this problem can be achieved by finding new non-standard combinations of cycling circuits and TCT parameters within the regime, which would allow the creation of managed structural states in the metal by grinding grain, creating a higher density of defects, accelerating diffusion processes and other physical effects.

2 Literature Review

The authors investigated the influence of the TCT process on the microstructure, mechanical and operational properties of stamp steels [4–9].

In [4], steels for stamps hot deformation – HNM5, H2NMF5, H3V3MFS5 were selected for the study. It was established that TCT with constant T_{max}, cooling between cycles in air up to 350 °C, cooling in oil from the last heating crushes the structure and makes it more homogeneous, which increases the mechanical properties of steel HNM5 after thermal cycling and tempering at a given hardness: KCU 1.4–1.6 times, durability characteristics by 5–8 %, ductility characteristics twice and more.

The authors of [5] describe an invention related to the field of metallurgy and can be used for heat treatment of steels in the manufacture of tools and machine parts in mechanical engineering: carbon tool steel is subjected to heat treatment, including repeated heating above Ac_1 at 40–80 °C at a speed of 4–8 °C/s, cooling in a cycle below

Ac_1 to 250–300 °C at a rate of 1–7 °C/s, tempering at 160–240 °C.

In [6], the authors tested TCT modes on stamps made of steel HNM5, the parameters of which were obtained experimentally and focused on obtaining an improved complex of mechanical properties (with high impact strength).

The application of the proposed method of thermocycling processing allows increasing the toughness of carbon tool steel by 4–6 times compared with traditional hardening while maintaining high hardness and strength [7].

3 Research Methodology

3.1 Objects of research

Chromium-nickel steel for stamps hot deformation HNM5 and its properties were selected as the object of study.

Steel HNM5 is tool-grade, high-quality, medium-alloy, semi-heat-resistant, high-viscosity and high-throughput. Its chemical composition and mechanical properties are shown in Tables 1, 2 (data according to GOST 5950-73).

Table1 – The chemical composition of steel HNM5, %

C	Mn	Si	Cr	Ni
0.5–0.6	0.5–0.8	0.1–0.4	0.5–0.8	1.4–1.8
Mo	W	P	S	Cu
0.15–0.30	–	0.03	0.03	0.3

Table2 – Mechanical properties of steel HNM5 after treatment

$\sigma_{0.2}$, MPa	σ_B, MPa	δ, %	ψ, %	*KCU*, kJ/m^2	Hardness	
					surface HRC	core HB
1270	1470	11	38	440	40–44	352–397

Steel has the following purpose: the production of hammer stamps, steam and pneumatic hammers with a mass of parts falling more than 3 tons, press stamp machine speed stamping during hot deformation of light-colored alloys, blocks of stamps for inserts of horizontal forging machines.

3.2 Methods of research

Metallographic methods and standard mechanical properties tests were used to study the mechanisms of hardening steel: impact and tensile tests.

It was used a pendulum coper MK-30A with a variable energy reserve in the range from 10 to 300 J and tensile machine P-20 for static testing of specimens of metals by static tensile loads in accordance with GOST 7855-68.

Koper pendulum MK-30A meets the requirements of GOST 10708-82 and is intended for testing of materials for shock bending in accordance with GOST 9454-78. Koper is intended for work in the premises of laboratory type. The tests were performed on specimens with sharp cuts of defined shape and size, in accordance with GOST 9454-78.

Hardness measurements were performed using Rockwell hardness tester.

Metallographic analysis of the structure of steel was carried out on a microscope MIM 7.

4 Results

The influence of technological methods on increasing the mechanical properties of steel HNM5 was investigated by the following methods:

1. Carrying out of heat treatment of steel HNM5 according to the standard (Figure 1) and experimental modes of thermocycling as preliminary heat treatment (Figure 2).

2. Determination of mechanical properties of the material for hot deformation stamps in the initial state and after the completed modes of heat treatment (Tables 3, 4).

3. Metallographic analysis of the structure of steel after previous and final modes of heat treatment (Figures 3–7).

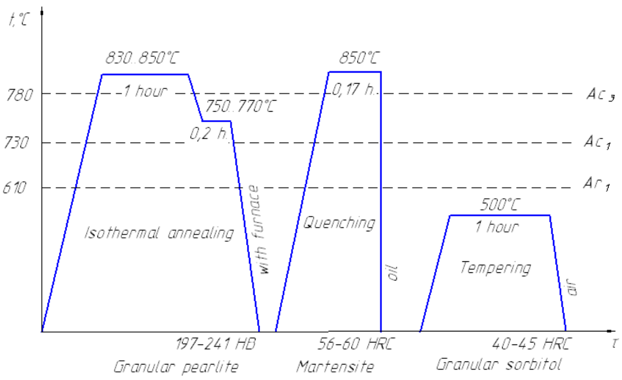


Figure 1 – Standard heat treatment of steel HNM5

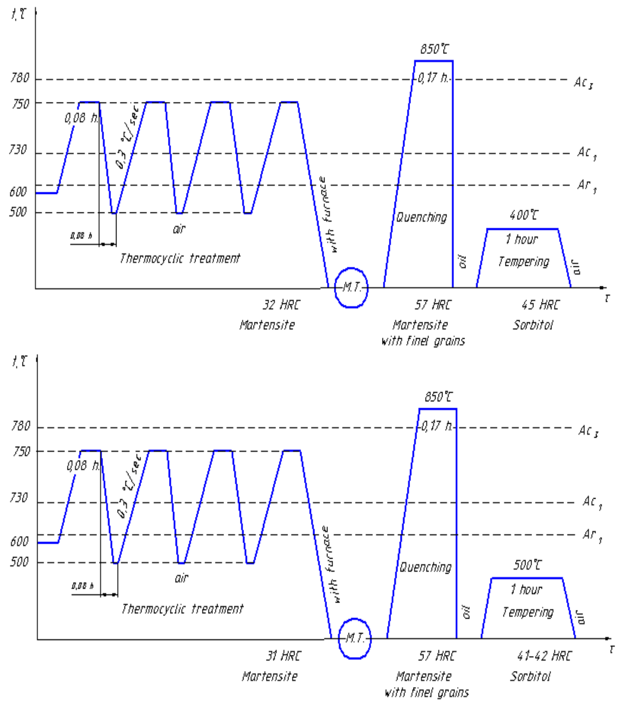
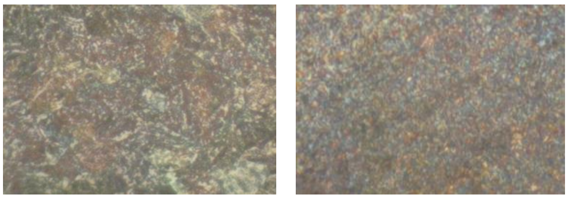


Figure 2 – Experimental modes of heat treatment



a b

Figure 3 – Microstructure of steel HNM5 after isothermal annealing (b) and thermocycling treatment (b), x480

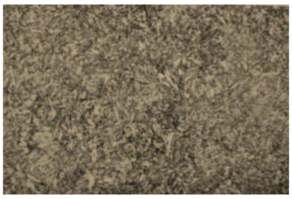
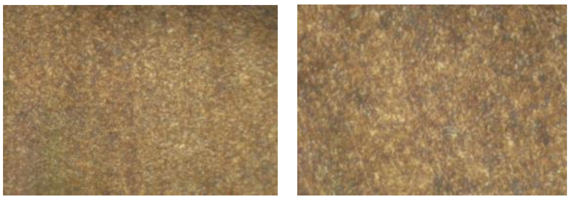
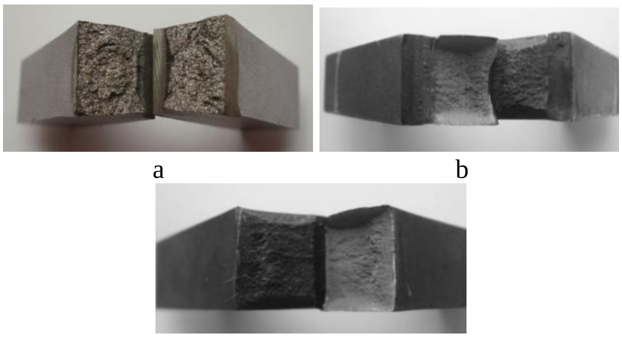


Figure 4 – Microstructure of steel HNM5 after standard heat treatment, x500



a b

Figure 5 – Microstructure of steel HNM5, x480: a – after thermocycling 750 °C + quenching 850 °C + tempering 400 °C; b – after thermocycling 750 °C + quenching 850 °C + + tempering 500 °C



a b c

Figure 6 – Macrostructure of samples of steel HNM5 after impact test: a – before thermal cycling; b – after thermal cycling 750 °C + quenching 850 °C + tempering 400 °C; c – after thermocycling 750 °C + quenching 850 °C + tempering 500 °C

a b c

Figure 7 – Macrostructure of samples of steel HNM5 after tensile test: a – before thermal cycling; b – after thermal cycling 750 °C + quenching 850 °C + tempering 400 °C; c – after thermal cycling 750 °C + quenching 850 °C + tempering 500 °C

Table 3 − Results of the impact test

Mode of heat treatment	The work, which was spent on the destruction of the sample $A_н$, N	Impact viscosity $a_н$, kN/m²
Without heat treatment	24.0	300
Isothermal annealing 850 °C, quenching 850 °C + + tempering 500 °C	35.2	450
Thermal cycling + + quenching 850 °C + + tempering 400 °C	166.0	2075
Thermal cycling + + quenching 850 °C + + tempering 500 °C	190.0	2375

Table 4 − Results of the tensile test

Mode of heat treatment	σ_B, MPa	δ, %	ψ, %
Isothermal annealing 850 °C, quenching 850 °C + + tempering 500 °C	1470	11.0	38.0
Without heat treatment	794	16.0	42.6
Thermal cycling + quenching 850 °C + tempering 400 °C	1654	6.7	42.9
Thermal cycling + quenching 850 °C + tempering 500 °C	1498	14.3	43.0

5 Discussion

Standard heat treatment of steel HNM5 includes isothermal annealing as pre-heat treatment, quenching, and tempering as final heat treatment (Figure 1).

The mode of pre-heat treatment is annealing temperature 830–850 °C; the exposure is about 1 hour; slow cooling to 750–770 °C, holding for 0.2 hours, cooling with the oven. The result is a structure of granular perlite with a hardness of 197–221 HB, grain perlite grain score is 5–6 points (Figure 3 a).

The structure of the steel after quenching is martensite. Steel HNM5 is characterized by low resistance to the growth of austenite grain because its carbide phase is mainly composed of soluble particles of the M_3C type. The hardness after quenching is 56–60 HRC.

The reduction of the hardness of steel HNM5 with an initial hardened structure can be achieved by tempering at a high temperature of 500 °C. After heat treatment, the steel has a structure of granular tempered sorbite with hardness 40–45 HRC (Figure 4).

After conducting a literary patent search and analyzing the literature data on the influence of thermocycling processing on the microstructure, mechanical and operational properties of tool steels, and stamped ones, two experimental modes of heat treatment were developed (Figure 2). Samples of steel HNM5 underwent thermal cycling according to the regime, which included four-cycle heating to a constant temperature of 750 °C and intermediate cooling in air to a temperature of 500 °C (above M_n). The hardness of the steel after TCT is 31 HRC, the grain score – 7–8 points, the structure after the experimental mode of thermocycling is shown in Figure 3 b.

After thermocycling, the specimens were machined. The final heat treatment was then carried out − quenching by standard heat treatment for steel HNM5 − heating to a temperature of 850 °C, the exposure for 0,1 hour and cooling in oil, and tempering − in one mode to a temperature of 400 °C, and in another − to 500 °C.

The hardness of steel HNM5 after quenching is 57 HRC, after tempering at 400 ° C − 45 HRC, after tempering at 500 °C – 41–42 HRC. The grain score of the structure after tempering at 400 °C is 9-10 points, at 500 °C – 8–9 points. Figure 5 shows the microstructures of steel HNM5 after two experimental heat treatment modes.

So, the conducted heat treatment in experimental modes, consisting of TCT as a preliminary, quenching and tempering as the final, allows obtaining a more homogeneous structure with the preservation of fine grain and a given hardness.

The impact tests showed (Table 3, Figure 6):

1. The use of TCT experimental mode, which included four cycles with heating to 750 °C, cooling between cycles in air, from the last cycle − with the oven, quenching with heating to 850 °C and tempering at 400 °C, allows increasing the value of KCU 4 times compared to typical heat treatment.

2. The use of TCT experimental mode, which included four cycles with heating to 750 °C, cooling between cycles in air, from the last cycle − with the oven, quenching with heating to 850 °C and tempering at 500 °C, allows increasing the value of KCU 5 times compared to typical heat treatment.

The tensile tests showed in Table 4 and Figure 7 are:

1. In the samples after heat treatment, which included TCT, quenching and tempering at 400 °C, the strength indices increased by 150 MPa with a simultaneous increase in the relative narrowing compared to typical heat treatment.

2. In the samples after heat treatment, which included TCT, quenching and tempering at 500 °C, the strength indices increased by 50 MPa with a simultaneous increase of 5 % relative elongation and relative narrowing compared to typical heat treatment.

6 Conclusions

The experimental modes of thermocycling that included 4 cycles of heating to 750 °C, cooling in the last cycle with the furnace, quenching of heating to 850 °C with cooling in oil and tempering to 400 ° and 500 °C, allow obtaining a more homogeneous structure with preservation of fine grains.

The grain size of steel structure after using thermocycling decreases from 5–6 to 8–7 points, after the final heat treatment the grain score was 9–10 points.

The tests of mechanical properties showed that for the obtained fine grain structures of steel HNM5 is tended a significant increase in ultimate strength (σ_B is about 100 MPa) while increasing the relative narrowing of about 1.5 times and KCU in 4–5 times after thermocycling, quenching and tempering, which significantly superior properties of steel after standard heat treatment.

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Застосування зміцнювального термоциклічного оброблення для матеріалів штампів гарячого деформування

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Анотація. Стаття присвячена пошуку технологічних методів підвищення стійкості штампового інструмента для гарячого деформування. У результаті дослідження були розроблені нові, нестандартні сполучення схем циклування і параметрів термоциклічного оброблення (ТЦО) у межах режиму. Це дозволило створити в металі керовані структурні стани за рахунок подрібнення зерна, створення підвищеної щільності дефектів і прискорення дифузійних процесів з метою ефективного управління структурою, підвищення механічних, експлуатаційних властивостей та запобігання руйнуванню робочих поверхонь інструмента. Розроблено і випробувано нові режими ТЦО, які позитивно впливають на механічні характеристики сталі 5ХНМ. Проведене термічне оброблення відповідно до експериментальних режимів, що складалось із попереднього термоциклічного оброблення з послідуючими гартуванням і відпуском, дозволяє отримати більш однорідну структуру металу із збереженням дрібного зерна і заданої твердості. Розмір зерна структури сталі 5ХНМ після використання термоциклічного оброблення зменшується з 5–6 до 7–8 балів, а після остаточного термічного оброблення – до 9–10 балів.

Ключові слова: штамп гарячого деформування, термоциклічне оброблення, міцність, відносне звуження, термостійкість.