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Influence of the Initial Structural State of Instrumental Steels for Cold Deformation on the Features of Their Thermal Processing

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ABSTRACT: High durability of stamps is the main condition for the operation of stamping shops. For the manufacture of stamping tools use a very wide range of steels and hard alloys. The more stringent the working conditions of the dies in terms of stresses arising during stamping, temperature, the more alloy steel is used for the manufacture of dies.
The problem of improving the quality of tool materials, the reliability and durability of stamping tools in recent years has to be addressed in the context of material saving and resource saving. Particularly relevant is the problem of saving severely deficient alloyed tool steels.
Therefore, an important and urgent task is the development of highly effective technologies for the thermal hardening of die tools for cold stamping made of carbon and low alloy steels. At the same time, a technology of thermal hardening is proposed, which increases the resistance of the dies by several times, which in some cases eliminates the use of high alloy tool steels.
The development of highly effective technologies for the thermal hardening of high-carbon tool steels is possible under the conditions of the maximum realization of the potential capabilities of steels by conducting preparatory thermal operations under more favorable conditions. This can be achieved by defining the mechanism of structure formation, both during preliminary and final heat treatment.

KEY WORDS: Eutectoid, hypereutectoid, forging, stamping, annealing, perlite, austenite, cementite, martensite, hardening.

I.INTRODUCTION

The final structural state and, accordingly, the required complex of final properties is determined by the features of the initial structural state, schemes and modes of heat treatment. Most structural steels for cold deformation are structurally related to eutectoid and hypereutectoid steels. In equilibrium, these steels have the structure of plate perlite and excess carbides. It is well known that such a structure does not provide high technical and economic indicators and high quality in subsequent mechanical and thermal operations, and especially in operating conditions.
In accordance with the above, in the practice of heat treatment of tool steels for cold deformation, the following sequence of operations has developed:
1) If the previous operation of hot plastic deformation (forging, stamping) was not performed according to the optimal regime, i.e. with the formation of large grains, the release of carbides along the grain boundaries, a preliminary normalization is carried out. After normalization, the grain is crushed, excess carbides in the form of a continuous grid around the grain do not have time to stand out.
2) Spheroidizing annealing (annealing on granular perlite). This type of annealing has two main goals:
- reducing the characteristics of strength and hardness of steel to increase its manufacturability at the stage of cold forming (for example, for forming a tool by cold extrusion) or to improve machinability by cutting;
- preparation of a structure that guarantees obtaining after the final heat treatment the necessary state of strength and viscosity characteristics (due to the creation of fine austenite grains). There are many ways to anneal on granular perlite: low- and high-temperature (with heating slightly below or above the critical Ac_1 point), long-term heating above Ac1 points, followed by slow cooling, pendulum or cyclic (multiple heating - cooling at 30-50 ° C around A1 with a limited exposure at these temperatures), a shortened two-stage (realized by slightly increasing the annealing temperature in the

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first stage to dissolve large carbides, then cooling to 600-680°C, which forms a significant the number of new crystallization centers, and subsequent heating to 770°C to dissolve the finely divided carbide fraction). All known schemes of spheroidizing annealing are almost equivalent in the formed structural phase state [1].

II. SIGNIFICANCE OF THE SYSTEM

The structure of tool steels after typical annealing is granular perlite. The dispersion of globular cementite inclusions, as a rule, is heterogeneous. The initial state of the annealed structure quite noticeably affects the process of austenization during heating under quenching and, therefore, the formation of the final quenched structure [1,2]. The dispersion of carbides, as well as their shape (granular, lamellar), have a decisive influence on the size of the austenite grain upon heating under quenching. The nucleation of the austenitic phase begins near carbides [3]. Accordingly, the rate of nucleation of austenite increases with decreasing size of carbide particles. Globular carbides dissolve more slowly than plate carbides, because have a smaller surface. Therefore, globular carbides themselves are effective barriers to the growth of austenitic grains upon heating. With an increase in the degree of dispersion (i.e., a decrease in particle size), the dissolution rate of carbides increases and the growth rate of austenitic grains increases. However, even finely divided point granular perlite is characterized by greater carbide stability than lamellar perlite.

The uneven distribution of carbides (in the form of strings enriched-depleted in carbides) causes a different grain size between individual bands. In bands with accumulations of insoluble carbides, the growth of austenitic grains is blocked; in strips depleted in carbides, a large grain is formed. The initial structure affects not only the grain size, but also the composition of the solid solution during austenization. The structure with small-plate carbides is capable of rapidly passing into the austenitic state. Globular structures dissolve in austenite when heated more slowly, with a gradual saturation of the solid solution. In these cases, the maximum saturation is achieved at the higher level and the faster, the more dispersed the carbides of the initial structure [3, 4].

Thus, upon annealing to granular perlite, the structure of steels changes in a direction favorable for subsequent austenization. However, annealing on granular perlite is not always the optimal preparatory operation from the point of view of simultaneous production of fine austenitic grain, maximum solid solution saturation, uniform structure over the entire metal volume, and the highest dislocation density during the final heat treatment.

The final heat treatment of carbon and low alloy tool steels includes quenching with continuous or step cooling followed by low tempering HRC 58÷62.

After hardening, the structure usually consists of martensite, excess carbides and residual austenite. The dispersion of martensitic plates is determined by the value of the actual austenite grain, which depends on the initial structural state. The resulting martensite plates are naturally oriented relative to the old phase — austenite.

When heated under quenching with limited exposure, fine-plate perlite transforms into fine-grained austenite, which, after quenching, forms fine-plate (fine-needle) martensite. However, a slight increase in the exposure in the austenitic region beyond the optimum can cause an intensive growth of austenite grains (due to the high dissolution rate of carbides) and, accordingly, enlargement of martensite plates.

With the initial structure of granular perlite, the martensitic structure is heterogeneous in composition, which is associated with the places of accumulation of carbides.

With the initial structure of point perlite, the dissolution of the carbide phase and saturation of the solid solution during heating proceeds intensively and throughout the volume simultaneously. At the same time, small globular carbides are reduced, which serve as barriers for migration of austenite grain boundaries. Thus, after quenching of steel with the initial finely dispersed globular structure, a uniform highly saturated, very finely needle martensite is formed.

Therefore, depending on the initial structural state, when heated, it is possible to obtain austenite of different saturation with carbon and alloying elements, and after quenching, a different amount of residual austenite.

Significant industrial experience shows that the best set of properties in the tool is created with an austenitic grain value of 9-11. In carbon and low alloy steels, the carbon concentration in martensite is 0.7–0.9% and 0.55–0.65% by weight, respectively [5].

III. LITERATURE SURVEY

As can be seen from the above, spheroidal annealing of carbon and low alloy tool steels is a preparatory (preliminary) thermal operation that provides the necessary level of physicomechanical properties of the cold deformation tool after the final heat treatment. However, preparatory thermal operation is not limited to spheroidizing annealing. Optimization of preparatory operations can take full advantage of the potential opportunities of steel in terms of a significant increase in the service life of cold forming dies.

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Changes that occur in the structure of the metal as a result of pretreatment can often be stable and persist even after prolonged exposure during subsequent heating. Three main directions of using pre-treatment are considered: 1) for the preparation of the microstructure of the main matrix; 2) for the preparation of a substructure using the inheritance of its elements; 3) for the preparation of a substructure with an effect on the second phase, mainly on sparingly soluble particles that do not undergo significant changes upon repeated lower heating [6].

In recent years, thermocyclic processing (TC) has become quite widespread, in which the idea of changing the structural phase state of the preparatory thermal cycles in the direction that ensures the formation of a favorable structural phase state with an increased level of final properties is used at the final thermal cycle of heat treatment. This is due to the fact that thermal cycles sharply accelerate diffusion (thermal diffusion).

According to some authors, the phase diffusion transformation is preceded by extreme excitation of particles in the initial phase, which sharply accelerates diffusion and promotes the appearance of superplasticity. The technology of thermocyclic processing (TC) consists in repeated impacts (3-7 times) on metal products by accelerated temperature changes during heating and cooling in order to quickly and "force" the formation of the necessary structure and obtain the necessary mechanical properties [3].

1. Pendulum shopping center. Used for grinding grain grades of ferrite-pearlite class. This is furnace heating 30–50°C higher than Ac_1, followed by cooling in air to a temperature 30–50°C lower than Ar_1.

2. The medium temperature TC. Used to obtain the sorbitol structure of structural carbon steels. They make rapid heating to temperatures Ac_1+30÷50°C with cooling in air to a temperature of 30-50°C below Ar_1 and then in water or oil.

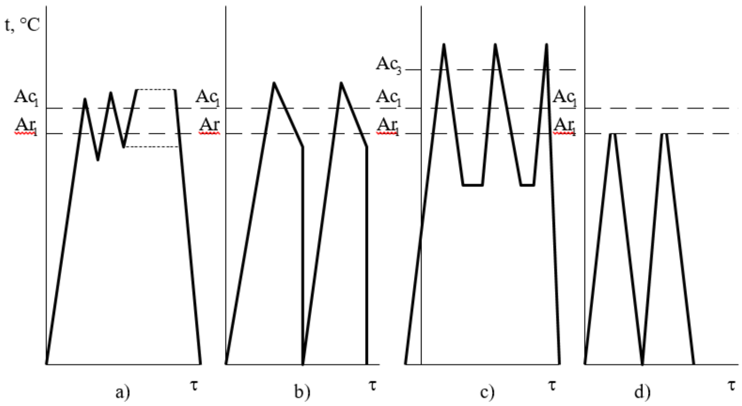

Fig. 1.The classification scheme of the main methods of metal TC:
a) - pendulum; b) - medium temperature; c) - high temperature; d) - low temperature.

3. High temperature heating and cooling equipment. This is most often cyclic electro-thermal treatment (CETT), which consists in electric heating at a speed of about 50° to a temperature of full austenization, cooling at a speed of 30-50° to a temperature of 420-450°C, corresponding to the fastest isothermal decomposition austenite and soaking at this temperature. In the last cycle, quenching from the austenitic state is carried out. High temperature heating TC is designed to obtain maximum strength with satisfactory ductility.

4. Low-temperature heating and cooling equipment. It provides for rapid heating (at a speed of 30-40° to a temperature 30–50°C below Ac_1, followed by locking in water or oil. Internal stresses are relaxed, and solid solutions decay intensively.

IV. METHODOLOGY

The medium temperature TC with heating in the intercritical temperature range with subsequent cooling in air below the critical point Ar_1 and further cooling in water or oil always grinds the grain, sharply increases the impact strength while maintaining strength [5].

Of particular interest is the use of low-temperature heating, when cyclic heat transfers in the temperature region below the phase transformation cause structural changes in steel, which can be inherited during the final heat treatment. This applies to cold-formed die steels, which, after preliminary quenching from commonly accepted heating temperatures, are subjected to pulsed nonequilibrium tempering at a temperature of 50-300°C above the temperature of the beginning of the third tempering stage.

It is assumed that, in comparison with ordinary tempering at the same temperature, a more dispersed structure is formed, i.e. an "Extremely unstable structural state" is achieved. Repeated quenching with a similar cyclic tempering in die

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steels eliminates structural-phase streakiness in the metal structure [5]. At the final heat treatment (hardening and low tempering), defects in the crystal structure are inherited, which makes it possible to increase the resistance of a cold heading tool made of ШХ15 steel by 1.8-2.5 times [6].
It can be assumed (since there is no other data in all of the above works) that with such preliminary thermal cycling, due to the difference in the volume expansion coefficients of the matrix (ferrite) and the second phase (cementite), microplastic deformations develop in the matrix, accompanied by an increase in the defectiveness of the lattice. In the region of heating temperatures of 400-500°C, return phenomena occur and polygonal-type structures form.
This substructure is thermally stable and can be inherited upon final heating under quenching and upon quenching cooling.
Thus, judging by the literature, the use of heat treatment in the practice of heat treatment, including for cold deformation dies, seems very promising. However, in this case, significant technological disadvantages are seen. In addition, the physics of structural-phase transformations during TC remains largely unclear. As the authors of TC methods themselves admit [7], the choice of TC modes is still carried out empirically, and the drawbacks of these technologies are that the increase in ductility of steel is not accompanied by the necessary high level of its strength properties, as well as the long duration and laboriousness of TC in performance.
Firstly, it is impossible to establish any general modes of TC for parts of various sizes and weights;
Secondly, it is extremely difficult to implement the necessary heating-cooling modes that were obtained on the samples in real products due to the need for heating and cooling over the entire cross section of the product. In this case, isothermal exposure is required, which greatly reduces the positive effect of the TC.
The above drawbacks may not affect the final results (although all the above technological difficulties remain) during the technical and structural analysis of structural and tool steels, when the main goal is grinding grain, excess phase, relieving internal stresses, i.e. ensuring sufficiently high mechanical properties by obtaining a homogeneous structure with a uniform distribution of the excess phase [6].

V.CONCLUSION AND FUTURE WORK

Summing up the analysis of the creation and use of the most technologically advantageous hardening operations of a stamping tool for cold stamping, which at the same time could significantly increase its durability, we can say the following:
1. The main mechanism for the wear of cold stamping dies is multiple elastoplastic deformation and the subsequent separation of the metal particles of the stamp.
2. For the manufacture of cold stamping dies, the most widely used are carbon and low alloy tool steels of the type У8-У13, Х, 9Х1, ХГ, 9ХС, ХВГ, etc.
3. The main operation of hardening a cold forming tool from the above steels is quenching with low tempering. At the same time, the wear resistance of the tool very often turns out to be unsatisfactory.
4. Most of the methods for additional hardening of a cold forming die tool are unacceptable due to the lack of effect (increase in resistance by 1.5-2 times) while at the same time greatly complicating the hardening technology (chemical-thermal treatment - nitriding, boronation, laser hardening) or because the difficulties of implementing the developed modes on specific products (TC of tool steels).
5. The most promising way to increase the durability of cold stamping dies is the use of multiple hardening, when after each heat treatment operation, it is possible to study the properties of steel and introduce the necessary adjustments to the heat treatment technology.
For this purpose, it is necessary to study the mechanism of structure formation of high-carbon tool steels, both in the process of preliminary and final heat treatments. In this case, we have in mind to study the mechanism of formation of micro and fine structures depending on the heating temperature in the austenitic region, cooling rate (quenching or normalization) , temperature of intermediate tempering and inheritance of structural parameters after final heat treatment.
Thus, the aim of this work is to establish the structure formation mechanism of carbon and low alloy tool steels for cold deformation dies under the conditions of applying multiple hardening (normalization) in order to develop new, non-traditional, heat treatment modes that sharply increase the service properties of cold stamping dies.
To achieve this goal, it is necessary to solve the following tasks:
- establish the pattern of structure formation during preliminary heat treatment, when the temperature of heating under quenching (or under normalization) changes. Determine the nature of the change in the magnitude of the austenitic grain, the state of the fine structure and solid solution (martensite and residual austenite).

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- establish the regularity of the formation of the structure during the final heat treatment, depending on the conditions of the preliminary treatment. Determine the nature of the change in the magnitude of the austenitic grain for the manifestation of structural heredity, the state of the fine structure for the inheritance of its parameters after repeated phase recrystallization, the state of the carbon solid solution in the tetragonal lattice of martensite and residual austenite;
- establish the effect of multiple hardening on dimensional changes, wear resistance and strength of tool steels;
- to establish the most optimal modes of preliminary and final heat treatment of tool steels for cold deformation dies, which provide the best set of structural parameters and steel properties (wear resistance, strength, smallest dimensional change);
- conduct heat treatment according to the found, non-traditional, modes of the experimental batch of cold deformation dies and establish the level of growth of their resistance.

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