Thermal Treatment of Cemented Alloyed Steels for the Cold Plastic Deformation

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Abstract. Disclosed is a method of thermal treatment of blanks from alloyed cement steels for cold volumetric stamping and extrusion. The technology ensures the formation of a ferritic-pearlitic structure in steel with a minimum microhardness of individual structural components. Examples of manufacturing of toothed parts by the method of cold wrapping and thin-walled tubular articles during cold extrusion are given. It is shown that cyclic resistance of parts made by cold plastic deformation and hardened by method of chemical-thermal treatment is increased by three or more times. According to the results of metallographic analysis, the ability of steel to cold plastic deformation and the ability to obtain high-quality machine parts are predicted.

1. Introduction

In the XXI century, the attitude of the machine-building complex to the production of automotive equipment changed significantly. The automotive industry focuses on the production of competitive products that meet the requirements of European and world standards for reliability, durability, ecological properties and deadweight coefficient. An important condition at the stages of technological conversion of metal into a part is the saving of fuel-energy and material resources. The most promising area of simultaneous solution of these problems should include the development and implementation of low-waste and high-efficiency processes for forming parts. Such processes are various methods of cold plastic deformation: extrusion, stamping, landing, reduction, etc., which are increasingly used in mechanical engineering plants. Thanks to these technologies, the metal utilization rate reaches 90% or more [1–3]. It is significantly reduced, and in some cases, there is no need for subsequent machining of such metal products. In addition, in the process of forming parts by this method, and especially parts of complex geometry, a favorable deformation texture is created in metal products, which contributes to improving their performance. Low carbon steels [4–7] are known to have high processing properties in cold pressure treatment. However, the use of such steels in the automotive industry is limited by their reduced strength and the heavy operating conditions of many parts. For products that simultaneously experience static and dynamic loads in operation, high-strength alloy steels are recommended and often used, which in turn have an insufficient level of ductility at room temperature, which makes them difficult to deform in a cold state. This is especially noticeable in the manufacture serration toothed and thickwalled tubular parts.

The main condition for the implementation of cold plastic deformation technologies in the manufacture of high-tensile-strength steel products is to ensure homogeneity of the structure and properties of the alloy over the entire volume of the semi-finished product [8–9].
The purpose of the work is to create a favorable structure in alloyed cement steels for cold plastic deformation of metal products.

2. Research materials and methods
Studies were carried out on widely used in the automotive industry structural cement alloyed steels of 20HGNMTA and 12HN3A grades used for the manufacture of toothed parts and piston pins of the internal combustion engine (ICE).

For metallographic studies, optical microscopes “Neofot-21” (Germany) and IM-7200 (Japan) with the licensed software product “Trixomet-PRO” of the Video Test-M system were used. The hardness was determined in accordance with the standards on certified instruments TSh-2M and TK-2M. Microhardness of structural components was estimated by means of the Durimet microhardness gage (Germany) at a load of indenter 9.8N. Heat treatment of samples and full-scale parts was carried out in laboratory and production conditions in electric furnaces M-12 and in gas-heated mod furnaces 34898 “Heat Project,” respectively. Plastic deformation of steel semi-finished products was carried out on mod presses. KB 0034.

The bending cyclic durability of the gear parts as part of the KAMAZ car assemblies was evaluated during tests of the driving bridges on the AV-604 model bench. The chemical composition of metal semi-finished products, blanks and parts was determined according to GOST 18895-97 on the SPEKTROLAB emission spectrometer, on the MFS-51 microphotometer and AFS-51 spectrograph, as well as on fashion devices. AN-7529 and AN-7560 for the determination of carbon and sulphur.

3. Results of work
The main criteria of structural state of steels characterizing high ductility of alloy is dispersion of grain structure, quantity and morphology of structural and phase components, degree of contamination and concentration with non-metallic inclusions [4,10].

The first parameters of the structure are formed during the heat treatment of the semi-finished product and primarily as a result of prolonged (40 hours or more) spheroidizing annealing. But even after such long exposure in the structure of alloyed steels, there are areas with traces of non-diffusion decay of austenite (Figure 1).

Figure 1. Products of diffusion-free conversion to steel after annealing of blanks.

The presence of microparticles with martensitic (Figure 1) or bainite structure in steel having a ferritic-perlitic base creates a stress state between gradient structural components and reduces the plastic properties of alloys. In order to increase technological ductility of structural steel it is necessary to have structure of granular, rather than plate pearlite, which increases isotropicity of alloy, reduces its hardening during deformation and improves stamping [11–12].

It was established that the chemical composition of the studied steels for all elements is within the permissible limits of GOST 4543 and technical regulation TU 14-1-5509. At the same time, fluctuations in individual chemical elements in steel 20HGNMTA ranged from 1.19 to 4.0 times, and in steel 12HN3A – from 1.31 to 2.80 times.
Widely used methods of heat treatment of such steels do not provide stable production of the recommended structure and hardness of blanks for cold plastic deformation. This is strongly evidenced by the significant fluctuations in hardness of the steel 12HN3A after annealing, which varied from 176 to 197 HB. Therefore, when developing the steel softening technology, it is necessary to take into account not only the fluctuations of the chemical elements, but also the structural heterogeneity in micro-volumes (Figure 1).

We investigated the influence of temperature-time parameters of heating, cooling and diffusion decay of undercooled austenite on the resulting structure, hardness and size of steel grains. Table 1 shows the results of analysis of such properties in steel 12HN3A after various treatments. The most favorable parameters in terms of structure and hardness for cold plastic deformation are this steel after thermal treatment, which includes austenitization at a temperature of 880°C with subsequent diffusion isothermal γ-α conversion at temperatures of 650°C and 620°C (Table 1 mode No. 4).

**Table 1. Steel properties 12XH3A after various types of heat treatment.**

| Mode number | Scheme of heat treatment | Microstructure | Size of grain, mm | Hardness, HB |
|-------------|--------------------------|----------------|-------------------|--------------|
| 1.          | P+F                      | P < 80%        | 0.017–0.026       | 187 (159)    |
| 2.          | P+F                      | P < 80%        | 0.017–0.028       | 159          |
| 3.          | P+F                      | P > 80%        | 0.016–0.022       | 149–153      |
| 4.          | P+F                      | P > 85%        | 0.014–0.021       | 146–149      |
| 5.          | P+F                      | P > 85%        | 0.017–0.038       | 146–149      |

*Designation: Cooling with furnace (OP), in water (OP), in the air (HIA), P – perlite, F – ferrite.*

The introduction of this technology of heat treatment of steel 12XH3A in the manufacture of piston fingers ICE has shown its economy and processability. High-quality parts with minimum allowance for mechanical treatment (Figure 2) are obtained from preheated blanks by cold extrusion method.

The developed annealing technology can be used as a softening heat treatment for steel blanks 20HGNMTA. To intensify the process of recrystallization of steel and provide a fine-grained structure
in it, the austenization temperature can be increased to 900–920 °C. This is confirmed by the stability and growth of the grain when heating this steel to a temperature of ~ 950°C, which can be explained by the presence of alloying refractory elements in it - molybdenum and titanium [13–22].

Heat treatment according to the proposed technology of steel blanks 20HGNMTA showed that their hardness does not exceed 163 HB, the microhardness of perlite is in the range of 227–286 HV, ferrite – 179–210 HV at the difference between these structural components less than 80 HV. This state of steel made it possible to obtain parts with high tooth accuracy by cold stamping (COS) (Figure 3).

Figure 2. Diagram of production of ICE piston pins and interoperative annealing of billet from steel 12HN3A. O – annealing; F – phosphatizing.

Figure 3. Satellite made by cold stamping (steel 20HGNMTA).

Bench tests of wheel gears of driving axles with satellites manufactured by the XOS method showed the bending durability of parts within 1070–1150 thousand loading cycles, which is about three times higher than the resistance of mating parts included in the mechanism link.

4. Conclusions
1. Disclosed is a method of heat treatment of steel 12HN3A and 20HGNMTA for cold plastic deformation, involving austenizing and decay of supercooled austenite at temperatures of 650 and 620°C.
2. Three-fold increase of cyclic resistance of cemented toothed parts made by method of cold hoop forging was revealed.
3. The technology of annealing blanks is recommended for use at enterprises in the manufacture of parts by cold plastic deformation.

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