Rolled stock structure and surface condition factor for quality of automobile fasteners insurance

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Abstract. Initial blank for the production of calibrated rolled stock is hot-rolled steel, ductility of which is largely determined by the structure and quality of the rolled stock surface. Hot-rolled steel should have a high degree of surface cleanliness and defect-free cross-section. In this paper, using the example of hot-rolled steel 40X, it is shown that the structural condition and quality of the rolled stock surface largely determine the further quality of calibrated rolled stock for automobile long length bolt products made from it. In this case, the mechanical characteristics, which are the most widely used indicators of the steel quality, are largely determined by plastic and heat treatment, which change the structure at the macro- and microscopic level.

1. Introduction

One of the types of mass-produced products is bolted rod products. A wide range and a large variety of metal products’ properties are dictated by the specifics of their use in various fields [1]. At the same time, up to 90% of bolts are made by cold forging [2]. The performance indicators of rolled stock intended for the manufacture of rod products are determined by structural and mechanical properties [3], that are formed at all stages of metallurgical processing, starting with the choice of charge materials for metal smelting and ending with the processing of finished wire [4, 5].

The material used for the manufacture of long length high-strength bolts should have [6] sufficient strength and ductility, uniform mechanical characteristics and chemical composition [7], and also should be free from surface and internal defects [8]: rolled gas blowholes, hair seams, tears and laps. The decarburized layer is formed due to the burning out of a part of carbon when the metal is heated, both at the rolling stage and during heat treatment before calibration. This leads to the decrease in mechanical properties, the formation of shatter marks, tears, scratches during rolling, calibration and cold heading.

2. Materials and test methods

For the manufacture of high-strength fasteners using cold heading, medium-carbon steel grades 35, 35X, 38XA, 40X are traditionally used. In terms of minimizing the cost, 40X steel is most preferred. This steel grade is standardized, traditionally it has most prevalent for reinforced fasteners and has proven itself to be easily mastered by hardware production of any degree of mass, and, finally, the
corresponding carbon content, and a fairly economical alloying with chromium simplifies the implementation of the technical solution in all its technological components [9].

In this work, studies have been conducted to identify surface defects in blanks for further rolling from steel 40X that affect the surface quality of the finished hot rolled steel. The quality control of the surface and the macrostructure of the blanks were carried out on templates etched at a temperature of 60–70 °C in a 50% aqueous solution of hydrochloric acid. The quality control of the hot-rolled surface was carried out on samples from one end of the coil of each batch of wire rod visually and on an optical microscope at x100 magnification.

3. Results and discussion

According to the results of studies conducted with samples of hot-rolled steel 40X, it is revealed that their chemical composition was within State Standard 10702-78, the macrostructure is homogeneous, without shrinkage porosity, delamination, has no cracks and other defects visible to the naked eye on transverse templates after etching. The samples of rolled stock pass shock crushing tests up to 1/2 of the initial height. The microstructure of rolled stock in the state in received is “perlite + ferrite”, in the structure there is no banding and Widmanstatten ferrite.

Hot-rolled steel can not be started up under the manufacture of bolts by the method of cold die forging (CDF) without technological processing, since it does not meet the requirements of the standards imposed by the accuracy of the profile size and surface quality and must be subjected to plastic deformation by the method of drawing. It is established that the forming during the drawing of rolled stock occurs as a result of plastic deformation of each grain. Before the drawing, the grain had a rounded, relatively equiaxed shape, after drawing, as a result of displacement along the slip planes, the grains are drawn in the direction of the acting forces, forming a fibrous structure.

When deformation of rolled stock by the drawing method, the principal strain scheme fully complies with the principal stresses scheme. As a result, the grains of the microstructure of calibrated rolled steel 40X acquire a strongly-pronounced orientation along the axis of tensile strain. In the paper [10], a grain of microstructure in which longitudinal size exceeds more than 20% transverse size was considered as oriented. At the same time, even in a hot-rolled state, about 15% of grains can be attributed to oriented ones. In the range of deformation degrees from 0 to 10%, the orientation of the grains occurred slowly.

When drawing of rolled stock with a degree of compression of 10%, the proportion of oriented grains was about 16–17%. At low degrees of compression (up to 15%), the deformation over the cross section of the samples is distributed very unevenly. When drawing with compressions, more than 25% deformation over the cross section of the samples throughout the volume is the same. The study of the structure of the samples in the longitudinal section shows that the most intensively the orientation of the structural components along the strain axis occurs at a compression degree of 20%. Because steel 40X refers to metals with a bcc lattice (body-centered cubic lattice), an axial texture is formed during cold drawing, which is characterized by a predominant crystallographic direction — the <110> axis [11].

Cold plastic deformation is accompanied by changes in micro and submicrostructures. At degrees of deformation of more than 15–20%, the appearance of a grain texture — elongation of grain is noted. With a degree of deformation of 40 and 60%, the granular structure is 100% of the structure, that is, when compressions of 40% or more, almost all components of the microstructure are oriented along the axis of deformation.

Cold plastic deformation is the result of the processes of movement and multiplication of dislocations, as well as the evolution of the dislocation structure. If in a hot rolled state the dislocation density \( \rho \) is the order of \( 10^3 \) cm\(^2\), then after drawing with a compression degree of 20–30%, the density increases to a maximum value of the order of \( 10^4 \) cm\(^2\).

The evolution of the dislocation structure develops according to the scheme: the Frank network (initial state) — the dislocation “chaos” (tangles, braids) — the cellular structure — the formation of a meso-structure. The increase in the dislocation density \( \rho \), and a rearrangement of the dislocation structure makes the main contribution to the strain hardening. From the results of the experiment, it
follows that the strength of hot-rolled steel increases from 770 MPa (compression $\varepsilon = 0\%$) to 950 MPa ($\varepsilon = 30\%$), and from 1050 MPa ($\varepsilon = 40\%$) to 1130 MPa ($\varepsilon = 60\%$).

With the increase in compression during its drawing, as a rule, strength properties increase and plastic characteristics decrease, and the achievable hardness is higher. The maximum permissible degree of deformation of hot-rolled steel 40X depends on the plastic characteristics and is determined by its microstructure. The reduction of plastic characteristics may be due to the accumulation of damage during CDF, which is associated with the increase in the number of vacancies, dislocations, micropores, submicrocracks [12].

Rolled stock has high plastic characteristics: contraction ratio $\psi = 57-59\%$, relative elongation $\delta = 20.5-20.8\%$, and is capable of undergoing cold plastic deformation by the method of drawing with compression up to 60%. With degrees of deformation from 5 to 60%, the hot-rolled steel tensile strength is increased from 900 to 1100 MPa, and the contraction ratio decreases from 60 to 38%.

In the study, the conditions and nature of the transformations were studied during patenting at the different temperatures of the nitre bath (370, 400, 425, 450, 500, and 550 °C). Previously, a calculation was prepared for the cooling curve for the 40X steel under study in a nitre bath with a given temperature at a bar holding time of 5 min. The cooling curves built from these data were combined with the S-curves of the time-temperature transformation of 40X austenitic steel having chemical composition under study. It was revealed that during patenting in a nitre bath at a temperature of 400 °C, the structure of lamellar sorbite (patenting sorbite) should be obtained, which was confirmed by the values of the hardness of rolled stock equal to 262 HB.

Reducing the temperature of the nitre bath, on the one hand, increases the difference between the free energies of austenite and ferrite, which accelerates the conversion, and on the other hand, causes a decrease in the rate of change in carbon diffusion. At bath temperatures of 370, 400, 425, 450 and 550 °C, excess ferrite does not have time to form, and the structure is quasi-eutectoid. Therefore, to obtain the required plastic and strength characteristics and hardness of rolled stock, patenting modes were studied in the temperature range of 370, 400, 425, 450, 500 and 550 °C.

Although the structure at all temperatures is called “patenting sorbite”, the hardness decreases with increasing temperature, since the higher dispersion, the lower the patenting temperature, that is, the temperature range of austenite transformation. After patenting at the temperature of 500 °C of the studied steel 40X, a “sorbite with martensite areas” microstructure appears.

Martensite in the structure of steel 40X, which is isothermally maintained at a temperature of 500 °C, was formed as a result of incomplete transformation of austenite during holding of 5 minutes and transformation of the remaining part of austenite into martensite during cooling in air. Such microstructure is not suitable for further deformation of 40X steel due to the presence of inclusions of hard and brittle martensite in it.

The structure of “sorbite with martensite areas” has a rather heterogeneous hardness of rolled stock (from 260 to 311 HB). Rolled stock with a microstructure “sorbite with martensite areas” has high strength characteristics (tensile limit $\sigma_t$ increases from 1000 to 1260 MPa, yield limit $\sigma_y$ increases from 760 to 940 MPa), but low plastic characteristics ($\psi$ reaches a minimum value of 23–25%). This is despite the fact that the requirements of GOST 10702-78 for calibrated rolled steel 40X by the value of contraction ratio are at least 40%.

The patenting of rolled stock at a temperature of 370 °C led to the formation of the “troostite” structure, which is shown. The microstructure of troostite is not suitable for further deformation of rolled stock by the CDF method, since it has high strength ($\sigma_t$ increased from 1050 to 1380 MPa, $\sigma_y$ increased from 970 to 1200 MPa), but low plastic characteristics ($\psi$ reaches a minimum value of 21–22%). Rolled stock with a microstructure “troostite” can be classified as difficult-to-form materials. This microstructure of steel 40X, which is used for the manufacture of long length bolts by cold heading, is not recommended.

The thermal operation of patenting hot-rolled steel at temperatures of 400–450 °C led to the increase in strength compared to the initial mechanical characteristics by 190–230 MPa, with a slight (1–4%)
decrease in plastic characteristics ($\delta$ and $\psi$). Patenting hot-rolled steel 40X at temperatures of 500 °C led to an even greater increase in tensile limit (by 370 MPa) and a significant reduction in its ductility.

4. Conclusion
Surface defects such as "laps" are obtained in the process of blanks rolling from a rolled-in foreign particle, undercuts, rough marks of cleaning the surface of the blank, and as a result of rolled gas blowholes on the surface of the blank. The elimination of these defects provides the increase in the quality of hardware products, a reduction in their cost and a reduction in metal consumption.

It is established that the determining factor in increasing the strength of finished long length bolts is the use of high-strength calibrated rolled stock, the mechanical characteristics of which are formed at the stages of thermal and plastic processing from hot-rolled steel.

At the same time, automobile long length bolt upset from rolled stock of steel 40X with the "patenting sorbite" microstructure and strengthened by surface plastic deformation during the process of reduction and thread rolling have a set of strength and plastic characteristics corresponding to the strength class 9.8 of the State Standard fastener 52643-2006.

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