Formation of optimal structure and properties of automotive pearlite steel during cold processing

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Abstract. Special requirements for structural and mechanical properties are applied to core fasteners manufactured on cold-forming machines made of automotive pearlitic steel. Mill products come as an original unit to manufacture various fasteners of hot-rolled steel, which can not be used for forming hardware due to the poor quality of the structure and surface layer. Therefore, the calibration rod undergoes intermediate heat treatment before drawing. In addition, products of strength grade 8.8 and higher, obtained from alloy steels on cold-forming machines, are quenched during tempering, which often leads to decarburization, cracking and bending of finished products, which increases the labor intensity, energy intensity and, consequently, the final cost. The article suggests a method for producing rolled products from automotive pearlitic steel 35Cr and 38CrA, including an isothermal process that excludes full annealing, quenching when tempering rod-shaped products and preventing decarburization, risks and curvature. The design, caused by passing through the drawing die, strengthening the surface by reducing and rolling the thread, provides mechanical properties of bolts and studs M8 strength grade 8.8 and 9.8.

1. Introduction
In modern technical structures, threaded fasteners are widely used, which are hardened with tempering - hardened steel fasteners. A significant part of them is made in the form of long parts such as bolts, studs, stepladders, etc. Details are obtained from long products using various technological operations of cold deformation - drawing, upsetting, thread rolling.

The development of the production of hardened fasteners, which requires ensuring the competitiveness of products, along with an increase in structural strength and operational reliability, involves reducing costs along the entire production chain, from the receipt of rolled products to the manufacture of finished parts of the required quality. Of particular importance is this factor in the manufacture of fasteners intended for mass consumption, in particular in the automotive industry.

The most widespread and most productive method for producing finished products with high structural and mechanical properties of metal products is the methods of their cold upsetting from rolled metal, which should have a certain quality - the required ductility, uniform structure and parameters of technological properties along the entire length, and the absence of defects. With fierce competition, to improve the quality of planted metal products, enterprises are forced to seek opportunities at all positions of the technological chain of transformation of the initial metal rolling.
Reliable operation of metal products depends significantly on the nature of the metal [1-3], operating conditions [4-6] and its processing modes [7-9], which form the structure of the used materials [10-12] and which are provided by optimizing the modes of technological processes [13-15].

Special requirements are applied to rod bolted products made by cold forming from pearlitic steel [16, 17]. A very common and productive way to manufacture finished products with high properties of metal products is to produce them from rolled disembarkation metal, which must have evenly distributed plasticity, structure, manufacturability and soundness [18].

Calibrated steel before the technological operation of cold forging should have an optimal macro- and microstructure in order to successfully carry out further planting operations for the manufacture of fasteners from it. Obtaining the required ferrite grain number and hardness is the most important characteristic of the behavior of calibrated rolled products in the manufacture of parts by cold heading. For this, it is necessary to select the chemical composition of the steel within a narrower range (especially for carbon).

Various hardware (bolts, studs and screws), which special requirements for strength properties are not regulated, are made mainly of steel according to GOST 1050-2013, GOST 4543-2016, and GOST 380-2005. The above-mentioned standards do not regulate the structure parameters and metal surface, which are formed when they go through the drawing die and during the heading process. This creates certain risks of defects, such as strain cracks and deformations [19, 20] inside the product.

The mounting bolts of the motor group of cars are subject to increased requirements for the presence of surface defects, the depth of surface defects, the presence of a decarburized layer and the purity of the surface layer. In existing technologies for preparing critical fasteners before cold forming, hot-rolled steel is subjected to plastic deformation and the removal of unacceptable surface defects through an expensive turning operation. These technological operations lead to a significant increase in the cost of hardware products. The high cost of hardened fasteners seems to be a negative technical and economic indicator both for the hardware manufacturing manufacturing these products and for all areas of manufacturing manufacturing the design that uses high-strength hardware. For hardware production, this is an increased use of metal for the production of parts. For the rest, it is an irrational overestimation of the behavior of calibrated rolled products and, accordingly, a deterioration in their performance. As a result, all this can negatively affect the competitiveness of manufactured hardware and metal products.

The chemical composition and mechanical properties of the metal for fitting the main equipment on cars, tractors and other equipment are regulated by GOST 10702-2016. The mechanical properties of high-strength equipment are regulated by the current ISO 898-1:1999 standard. The required strength grade is provided by the choice of the steel [21, 22] and the mode annealing and finished products [23].

Hardware companies receive units to manufacture various fasteners of hot-rolled steel, which cannot be used for heading high-strength hardware due to poor-quality structure and surface layer. Hot-rolled metal from structural steels of the pearlitic class, which is purchased in raw condition from metallurgical suppliers, has a pearlitic structure with ferrite. Heat treatment and drawing before heading the main products should form the necessary surface and microstructure of rolled products [24, 25], which guarantee a high quality of product after cooling [26, 27].

GOST 1759.4-87 states that core-shaped products obtained from alloyed steels, which strength grade is 8.8 and higher, must be tempered. Unfortunately, the above-mentioned technological process causes decarburization, cracking and warping, negatively affecting the complexity, energy intensity and, consequently, the final cost of production.

This article discusses an alternative method of rolling preparation, which includes isothermal treatment of pearlitic steel 35Cr and 38CrA, excluding recrystallization annealing from the process and canceling quenching with the finished products output, which reduce the risks of their curvature and decarburization. This method allows one to obtain surface and mechanical properties of rolled products that fully comply with GOST 10702-2016.

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2. Research methods

Samples of rolled pearlitic steel of class 35Cr and 38CrA were studied, which are widely used for fixing the engine, body and other groups of automotive and special equipment. The process of thermomechanical preparation of rolled products was studied to obtain rod-shaped products with a low-formed head of strength grade 8.8 or more on cold-forming machines that exclude hardening and tempering. Isothermal and mechanical preparation of rolled products includes:
- heat treatment of the original coil;
- pickling;
- dragging;
- isothermal treatment (470° C);
- pickling;
- dragging;
- heading.

The microstructure of rolled products for bolts and spikes with a diameter of 7.8 mm was formed by isothermal treatment (annealing type 2). In [28], it was found that the transformation of austenite in the nitrate bath of these steels occurs in the range of conversion of sorbitol 650-470° C. The austenitic eutectoid type is obtained. The studied method of thermal cooling at 470°C after drawing is suggested for rolling short, medium and long studs and bolts with a volumetric molded head.

Taking into consideration a certain restriction on the length of saltpeter baths, the exposure of calibrated rolled products is carried out for no more than five to six minutes. Completion of austenitic transformation in rolling when cooling wire with a diameter of 8.2-8.6 mm at a temperature of 470°C goes on within 3.9 minutes. (234 s).

The samples of rolled metal were made by punching matrices with a diameter of 8.1; 8.2; 8.3; 8.4; 8.5 and 8.6 mm, followed by processing in a nitrate bath (470° C). The final drawing was made on a diameter of 7.8 mm. The bolts and studs M8 were ruptured in accordance with GOST 1759.4-87.

3. Results and discussion

The chemical composition, strength and plastic properties of steel 35Cr and 38CrA complied with GOST 10702-16. The microstructure of rolled products in the delivery state consists of pearlit with ferrite (Figure 1).

![Figure 1](image)

**Figure 1.** Microstructure of hot-rolled steel for steels: a - steel 35X; b - steel 38XA.

The mechanical properties of isothermally treated steel are shown in table 1.
Table 1. Mechanical properties of rolled units after isothermal treatment.

| Steel grade | Rolled product diameter. mm | Specifications |
|-------------|-----------------------------|----------------|
|             |                             | $\sigma_0$ | $\sigma_{0.2}$ | $\delta$ | $\psi$ |
|             |                             | MPa        | %              |        |        |
| 35Cr        | 8.0; 8.1; 8.2; 8.3; 8.4; 8.5; 8.6 | 828        | 670           | 20.5   | 57     |
| 38CrA       | 8.0; 8.1; 8.2; 8.3; 8.4; 8.5; 8.6 | 882        | 697           | 20.1   | 57     |

After isothermal treatment, samples of rolled steel 35Cr and 38CrA with diameter of 8.1 mm; 8.2 mm; 8.3 mm; 8.4 mm; 8.5 mm and 8.6 mm in a salt bath at a temperature of 470° C have the structure of sorbitol pearlite.

For samples made of 35Cr steel after the above mentioned treatment, the hardness is HB 249, and for samples made of steel 38CrA it is HB 254, respectively.

Mechanical properties of rolled products after isothermal (470° C) processing and drawing with various crimps are shown in Table 2.

Table 2. Strength and plastic properties of rolled steel 35Cr and 38CrA with various compression up to a diameter of 7.8 mm after isothermal and mechanical (470° C) processing.

| Compression rate. | Material | Specifications |
|-------------------|----------|----------------|
| %                 |          | $\sigma_0$ | $\sigma_{0.2}$ | $\delta$ | $\psi$ |
|                   |          | MPa        | %              |        |        |
| 4.9               | 35Cr     | 838        | 769           | 16     | 54     |
|                   | 38CrA    | 918        | 797           | 15.5   | 53.1   |
| 7.2               | 35Cr     | 896        | 791           | 15.8   | 53.8   |
|                   | 38CrA    | 922        | 807           | 15     | 53     |
| 9.5               | 35Cr     | 905        | 801           | 14.5   | 53     |
|                   | 38CrA    | 931        | 813           | 14.1   | 52.7   |
| 11.6              | 35Cr     | 916        | 810           | 14     | 52.5   |
|                   | 38CrA    | 959        | 835           | 13.5   | 52.1   |
| 14.2              | 35Cr     | 928        | 831           | 13.2   | 51.8   |
|                   | 38CrA    | 991        | 863           | 13.0   | 51.0   |
| 15.7              | 35Cr     | 944        | 862           | 13.1   | 51.1   |
|                   | 38CrA    | 1003       | 901           | 12.4   | 50.4   |
| 17.7              | 35Cr     | 971        | 887           | 12.5   | 50.0   |
|                   | 38CrA    | 1067       | 948           | 12     | 49.1   |

It is found that the strength characteristics of isothermal (470° C) treated rolled steel increase monotonously with the increase in compression deformation from 4.9 to 17.7%. Thus, the strength limit for rolling steel 35Cr for compression from 4.9 to 17.7% increases from 838 to 971 MPa, and for rolling 38CrA from 918 to 1067 MPa.

Tests of rolled steel 35Cr and 38CrA show that the conditional yield strength after the thermomechanical preparation is also increased. It was found that the conditional yield strength of rolled steel 35Cr with compression deformation increases from 4.9 to 17.7% from 769 to 887 MPa, and steel 38CrA from 797 to 948 MPa.

Isothermal and mechanical preparation of rolled products at a temperature of 470° C followed by drawing with compression deformation from 4.9 to 17.7% provides a monotonous reduction in elongation for steel 35Cr from 16 to 12.2% and for steel 38CrA from 15.7 to 12.2 %.

The relative contraction of isothermal and mechanically prepared rolled steel 35Cr with compression strain from 4.9 to 17.7% reduces from 54 to 52%, and for steel 38CrA from 53.1 to 50.4% (Figure 6).
After calibration of steel 35Cr and 38CrA, after thermomechanical preparation (470°C) of long studs and bolts with a low-cut M8 head, the products were tested for rupture. The results of their rupture tests are presented in table 3.

The results of their rupture tests are presented in table 3.

| Product | Material | Quantity, pcs. | σl, MPa | Ψ, % | δ, % | HB |
|---------|----------|----------------|---------|------|------|----|
| Bolt. M8 | 35Cr     | 21             | 840     | 44.5 | 10.7 | 254|
|          | 38CrA    | 17             | 950     | 44.5 | 10.7 | 286|
| Stud. M8 | 35Cr     | 18             | 838     | 44.5 | 10.7 | 248|
|          | 38CrA    | 25             | 938     | 44.5 | 10.7 | 277|

According to GOST 52643-2006, high-strength fasteners include products in which the tensile strength is more than or equal to 800 MPa. Therefore, bolts and studs made by thermomechanical method from steel 35Cr and 38CrA are considered high-strength fasteners by strength grade.

Result analysis of the table showed that rolled steel 35Cr can be used for bolts and studs with a strength grade of 8.8. Hardware in the form of bolts and studs for a strength grade of 9.9 can be recommended to be made by cold stamping from steel 38CrA after isothermal and mechanic process of the rolled product.

4. Results
The possibility of isothermal and mechanical preparation of rolled products with diameter 7.8 mm from structural pearlite steel 35Cr and 38CrA for stamping on studs and bolts obtained by cold stamping of strength grade 8.8 and higher without quenching and tempering is studied.

It is proved that the structure caused by going through the drawing dies, surface hardening during the restoration and knurling of the thread, provides mechanical parameters of bolts and M8 studs that meet the requirements of strength grades 8.8 and 9.8, according to the requirements of GOST 52643-2006.

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