Rolled Stock Structure Preparation for Cold Forging of Pearlitic Steel Grades

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Abstract. Special requirements are applied to the structural-mechanical characteristics of rod bolt products manufactured by cold die forging of pearlitic steel class. A very common and productive method of obtaining finished metal products with high mechanical properties is their landing on cold heading (cold-heading) machines made of rolled metal, which must have a certain quality along the entire length: a sufficient ductility, homogeneous structure and parameters of technological properties, absence of any defects. Hardware plants receive the initial blank for the manufacture of various fasteners in the form of hot-rolled steel, which is not possible to use for the landing of high-strength hardware, due to the poor quality structure and surface layer. Therefore, the calibrated rolled stock is subjected to intermediate heat treatment before driving, which should guarantee the quality of the metal products at transitions of the cold heading. Further, the driven products of strength class 8.8 and up, made of alloy steel grades, must be subjected to hardening with subsequent tempering. However, such thermal operation often leads to decarburization of the surface, cracking and warping of finished products, thus increasing labor intensity, energy consumption and, consequently, the final production cost. The paper proposes an alternative method of the rolled stock structural preparation, which includes isothermal treatment of pearlitic steel grades 35X and 38X, which excludes from the technological process the recrystallization annealing and quenching with the release of finished bolt products, and which minimizes any appeared scratches, warping and decarburization on the rolled stock and the rolled product. The structure of rolled stock induced in the drawing die, and the surface hardening by reduction, and thread rolling provide the parameters of mechanical properties of M8 bolts and pins, corresponding to the strength class 9.8.

1. Introduction

Reliable operation of metal products significantly depends on the nature of the material [1–3], operating conditions [4–6] and modes of its processing [7, 8], forming the structure and properties of the materials used [9–11], and which are provided by the optimization of technological processes [12, 13].

The rod bolt products manufactured by cold forging of pearlitic class steel are subject to special requirements for their structural and mechanical characteristics [14]. A very common and productive way to obtain ready-made metal products with high structural and mechanical properties is to drive these
from the rolled stock, which must have a certain quality – a uniform (along the entire length) ductility, structure, manufacturability and absence of defects [15–17].

A wide range of hardware products (bolts, pins and screws) for which specific requirements to strength properties are not regulated, are made, generally of steel grades according to GOST 1050-2013, GOST 4543-2016, and also GOST 380-2005. The above noted standards do not regulate the parameters of the steel structure and surface, which are formed when passing through the drawing die and during the heading. This creates certain risks of signs of flaws, such as deformation cracks and warping [18–20] in the driven rod products.

The chemical composition of steel grades and mechanical properties of rolled metal used for heading of metal rod products of different strength classes for cars, tractors and other special equipment are regulated by GOST 10702-2016. For high strength hardware products the mechanical characteristics are regulated according to effective standard ISO 898-1:1999. The required strength class is determined by the grade of steel [21, 22] and the heat treatment mode of rolled metal and the driven finished products [4, 23].

The hardware manufacturing enterprises receive blanks for manufacturing of various fasteners in the form of hot-rolled steel, which cannot be used for the high-strength hardware heading due to poor quality structure and the surface layer. Hot-rolled metal from structural steel of pearlite class, which is purchased in non-heat-treated condition from suppliers of metallurgical products, has a “pearlite-ferrite” structure. Before rod product driving, heat treatment and drawing should form the necessary microstructure and the state of the rolled surface [24–26], which would guarantee the quality of the product at all transitions of the cold driving [27–29].

According to GOST 1759.4-87, the fasteners of strength class 8.8 and up, made of alloy steel grades, driven in this way should be subjected to hardening and tempering. Unfortunately, the above-mentioned thermal operation provokes the appearance of decarburization, cracking and warping on the finished products, thus increasing the labor intensity, energy intensity and, consequently, the final production cost of the product.

In this paper we have proposed an alternative method of preparing the rolled stock structure that includes isothermal mechanical treatment of pearlite steels 35X and 38XA with the purpose of eliminating from the technological process the recrystallization annealing, as well as the annulment of hardening with the drawing-back of finished bolt products which would result in a minimization or reduction of risk of the rolled stock and product warping and decarburization. At the same time, this method allows obtaining the mechanical characteristics of the rolled products and the surface quality that fully comply with GOST 10702-2016.

2. Study Methods
The paper has studied samples of rolled steel of pearlite class 35X and 38X, widely used in the manufacture of critical fasteners of motor, body and other groups of automobile, tractor and specialized machinery.

Based on the analysis of experimental data we have proposed the method of isothermal mechanical treatment of the rolled stock made of the investigated steel grades for the manufacture of long length rod products with a low molded head and various pin items corresponding to the strength class 8.8 or up without quenching and tempering of these.

The rolled stock isothermal mechanical treatment pattern for steel grades 35X and 38XA includes as follows:

- initial rolled stock thermal treatment;
- acid solution etching after annealing;
- drawing;
- isothermal treatment (@ 470 °C);
- acid solution etching after isothermal treatment;
- drawing;
- heading of high strength bolts and pins.
To form the microstructure of the rolled steel for driving of bolts with a diameter of 7.8 mm, the process of isothermal treatment - annealing of the 2nd kind was used. The transformation of austenite of these steels in niter bath at temperature of 470 °C occurs in the temperature interval of sorbitic transformation 650–470 °C. The austenite obtained at this temperature of the thermal bath belongs to the eutectoid type. The investigated method of isothermal cooling at a temperature of 470 °C is proposed to obtain a calibrated rolled stock after plastic drawing operation for the heading of short-length, medium-length and long-length bolts with a volume-molded head and pins of various lengths.

Considering certain niter bath length limitations in the case of the wire isothermal treatment, the exposure of the treated calibrated rolled stock does not exceed five or six minutes. To complete the austenitic transformation in metal, the cooling time of the wire with a diameter of 8.2–8.6 mm at a temperature of 470 °C in niter bath is 3.9 minutes (234 s).

The rolled metal samples were prepared by drawing to obtain diameters of 8.1 mm; 8.2 mm; 8.3 mm; 8.4 mm; 8.5 mm and 8.6 mm with the subsequent isothermal treatment in a niter bath at 470 °C. Final drawing was carried out to obtain diameter of 7.8 mm with various degrees of compression in the drawing mill die.

M8 bolts and studs thus obtained were subjected to tensile testing according to GOST 1759.4-87.

3. Results and Discussions

The chemical composition and mechanical properties of 35X and 38X steels grades corresponded to GOST 10702-16. The microstructure of the initial rolled stock is of “pearlite + ferrite” type.

The mechanical properties of the isothermally treated rolled products are shown in table 1.

| Grade of steel | Rolled stock diameter, mm | Characteristics | σv | σ0.2 | δ | ψ |
|----------------|---------------------------|-----------------|-----|------|---|----|
| 35X            | 8.0; 8.1; 8.2; 8.3; 8.4; 8.5; 8.6 | MPa | 878 | 630 | 20.5 | 57 |
| 38XA           | 8.0; 8.1; 8.2; 8.3; 8.4; 8.5; 8.6 | MPa | 882 | 637 | 20.1 | 57 |

After the isothermal treatment, the samples of rolled products made of steel 35X and 38XA with diameters 8.1 mm; 8.2 mm; 8.3 mm; 8.4 mm; 8.5 mm and 8.6 mm at the temperature of the salt bath 470 °C have a “niter-like pearlite” pattern. The samples of steel grade 35X after the above mentioned treatment have hardness HB 249, and the samples of steel grade 38XA have same of HB 254.

The rolled stock mechanical characteristics after the isothermal treatment at a temperature of 470 °C and with subsequent drawing with different degrees of drafting are shown in table 2.

The calibrated rolled stock microstructure of both steel grades is of “niter-like pearlite” pattern. It was founded that the strength characteristics of the rolled stock isothermally processed at 470 °C with an increase in the drafting degree during drawing from 4.9 to 17.7 % had been constantly improving. So, the limit tensile strength of the calibrated rolled steel 35X with the degree of drafting of 4.9 to 17.7 % had increased from 860 to 940 MPa, and that of the rolled stock made of steel 38XA - from 930 to 1060 MPa.

The calibrated rolled steel 35X and 38X testing shows that the conventional yield strength after isothermal mechanical process treatment also increases. It was revealed that the rolled stock conventional yield strength before cold heading of steel grade 35X at a drafting ratio of 4.9 to 17.7 % increases from 770 to 880 MPa, and that of steel grade 38XA - from 800 to 950 MPa.

The rolled steel isothermal mechanical treatment at temperature of 470°C with the subsequent drawing with the drafting degree of 4.9 to 17.7 % provides a continuous elongation reduction for steel grade 35X from 16 to 12.2 % that for steel grade 38XA - from 15.7 down to 12.2 %.
The relative transverse contraction after the isothermal mechanical treatment of the rolling stock before cold heading of steel grade 35X with drafting ration of 4.9 to 17.7 % decreases from 54 to 52 %, and that for steel grade 38XA from 53.1 down to 50.4 %.

**Table 2.** Strength and ductility characteristics of the rolled stock after the isothermal treatment of steel grades 35X and 38XA @ 470 °C.

| Grade of steel | Rolled stock diameter, mm | Drafting degree, % | Characteristics | σv, MPa | σ₀₂, MPa | δ, % | ψ, % |
|----------------|---------------------------|--------------------|----------------|---------|---------|------|------|
| 35X            | 7.8                       | 4.9                |                | 878     | 769     | 16   | 54   |
| 38XA           | 7.8                       | 4.9                |                | 918     | 797     | 15.5 | 53.1 |
| 35X            | 7.8                       | 7.2                |                | 896     | 791     | 15.8 | 53.8 |
| 38XA           | 7.8                       | 7.2                |                | 922     | 807     | 15   | 53   |
| 35X            | 7.8                       | 9.5                |                | 905     | 801     | 14.5 | 53   |
| 38XA           | 7.8                       | 9.5                |                | 931     | 813     | 14.1 | 52.7 |
| 35X            | 7.8                       | 11.6               |                | 916     | 810     | 14   | 52.5 |
| 38XA           | 7.8                       | 11.6               |                | 959     | 835     | 13.5 | 52.1 |
| 35X            | 7.8                       | 14.2               |                | 928     | 831     | 13.2 | 51.8 |
| 38XA           | 7.8                       | 14.2               |                | 991     | 863     | 13.0 | 51.0 |
| 35X            | 7.8                       | 15.7               |                | 944     | 862     | 13.1 | 51.1 |
| 38XA           | 7.8                       | 15.7               |                | 1003    | 901     | 12.4 | 50.4 |
| 35X            | 7.8                       | 17.7               |                | 971     | 887     | 12.5 | 50.0 |
| 38XA           | 7.8                       | 17.7               |                | 1067    | 948     | 12   | 49.1 |

Of the calibrated rolled stock made of steel grade 35X and 38XA, after the isothermal mechanical treatment at temperature of 470 °C, some M8 short and long-length bolts were fabricated with a low cut head and M8 pins - by heading in the cold heading machine.

After the cold heading of bolts, these were subjected to tensile testing and the bolt strength and ductile properties were identified. The results of the tensile tests of the bolts are presented in table 3.

**Table 3.** Tensile tests of bolts made of steel grade 35X and 38XA.

| Bolt, M8 | Number of bolts, pcs | σv, MPa | Ψ, % | δ, % | HB  |
|----------|----------------------|---------|------|------|-----|
| 35X      | 21                   | 820     | 44.5 | 10.7 | 254 |
| 38XA     | 17                   | 950     | 44.5 | 10.7 | 286 |

After the pin cold forging and drawing-down, their tensile tests were also carried out and strength and ductile characteristics were identified. The pin tensile test results are presented in table 4.

**Table 4.** Tensile tests of pins made of steel grade 38X and 38XA.

| Pin, M8 | Number of pins, pcs | σv, MPa | Ψ, % | δ, % | HB  |
|---------|---------------------|---------|------|------|-----|
| 35X     | 18                  | 912     | 44.5 | 10.7 | 248 |
| 38XA    | 25                  | 938     | 44.5 | 10.7 | 277 |
4. Conclusions
We have investigated the possibility of isothermal treatment of the rolling stock with diameter of 7.8 mm made of structural steels of pearlitic class 35X and 38XA for cold forging of bolt with cut head and pins with strength class 8.8 and up without quenching and tempering.

It is proved that M8 bolts and pins made of calibrated rolled steel mentioned above, and strengthened by subsequent surface ductile deformation during the drawing and thread rolling, have achieved a set of strength and ductile characteristics corresponding to the strength class 9.8 according to the requirements of GOST 52643–2006.

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