Structural and mechanical maintenance of quality of the rolled stock for cold upsetting of metal articles

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Abstract. A widely spread and most productive way to obtain finished metal articles with high structural and mechanical properties are methods of cold heading out of rolled metal, which must have a certain quality - the required plasticity, uniform structure and process parameters along the full length, as well as soundness. In conditions of fierce competition in order to improve the quality of the upset metal articles, the enterprises are forced to find reserves at all the points of the process chain for transformation of the original rolled metal. The greatest effect is achieved by the excluding of energy-consuming and labor-intensive annealing in protective gas furnaces and control of surface defects by etching or mechanical operations. This paper is presenting an economical and environment-friendly technology for structural and mechanical maintenance of high quality of rolled stock for upsetting of metal articles. The rolled steel prepared by this technology has a highly dispersed equally spaced structure without a decarburized layer with increased plasticity, which enables to reduce the number of transitions in the process of upsetting of metal articles and to increase the tools service life.

1. Introduction
Against the background of environmental degradation and resources’ reduction [1, 2], the issues of resource and energy saving [3, 4] become highly relevant, with simultaneous quality improving and increasing of metal articles competitive ability [5, 6]. The most important factor in this direction is the cost saving on consumed metal and energy [7-10].

Widespread and most productive way to obtain finished metal articles with high structural-mechanical properties are methods of cold heading out of rolled metal, which must have a certain quality - the required plasticity, uniform structure and process parameters along the full length, as well as soundness. In the fierce competition in order to improve the quality of the upset metal articles the enterprises are forced to find reserves in all the points of the technological chain for transformation of the original rolled metal.
The required level of the set of structural and mechanical properties can be achieved by the large scale introduction of new materials and advanced technologies for their processing [11, 12]. Rolled steel for cold heading shall correspond to the highest standards of strength, plasticity and upsetting and on defining of special characteristics.

Thus, the necessity of labor and utility costs saving as well as the necessity of solving of the increasing environmental problems [13, 14] determines the relevance of this task.

Structural and mechanical properties of the material, providing high-quality heading [15, 16], are formed in the process of metal drawing through the die. The process capabilities of rolled stock are tested by the absence of cracks and tears on the surface after the upsetting test [17]. The optimal upsetting shall be up to 1/3 of the height. However, the results of this experiment correspond only to this particular coil of the rolled stock, and not to its entire batch.

The difference in drawing speeds at different stages of steel preparation significantly limits the drawing efficiency. The process transitions include:
- preparation;
- primary deformation;
- heat treatment in protective gas furnaces;
- re-deformation;
- heat treatment.

Warming up by high frequency currents (HFC) lasts only for up to 6 minutes (with further gradual cooling for about 6 h in the pits), while the electrical heating or warming up in the gas heaters lasts for 10-36 h. While doing so, it is very important to ensure the functional structural and mechanical properties of rolled stock by controlling the level of dispersion of the metal grains and phase components’ structure.

A widely spread method of the rolled stock annealing in bell-furnaces before the heading to granular perlite does not always ensure uniform properties along the length of the full strip, and the elements of unwanted lamellar perlite often appear in the structure of the rolled stock.

To ensure high quality of critical products (for example, bolts for gas transmission lines), unacceptable surface defects of hot-rolled steel, for example, such as a decarburized layer, scratches, notches, etc. [18-19] are removed by an expensive turning operation or a harmful pickling operation, which, in its turn, leads to an increase in the cost of finished products.

To ensure the quality of critical products (for example, bolts for gas transmission lines), unacceptable surface defects of hot-rolled metal, such as a decarburized layer, grooves, scores etc. [18-19] are removed by an expensive turning or a harmful procedure of etching, which, in turn, increase the cost of the finished articles.

In this work it is proposed to perform the annealing using induction blocks, which, due to the absence of a decarburized layer and high stable temperature, ensures the increase of the rolled metal quality, enables to increase the productivity and economic efficiency of the process, to implement its automation and ensures the lack of toxic discharges into the atmosphere.

2. Research methods
In this paper the hot-rolled 38XA steel with two diameters, standard chemical composition has been studied that is widespread in various sectors of the national economy for manufacturing of the reinforced fastening bolts:
- diameter 12.0 mm, %: C-0.39, Mn-0.62, Si-0.18, P-0.009, S-0.015, Cr-0.87;
- diameter 14.0 mm, %: C-0.40, Mn-0.64, Cu-0.19, P-0.021, C-0.017, Cr-0.9.

The initial microstructure of 38XA hot-rolled steel is a “perlite + ferrite”.

The effective technology used for 38XA rolled stock processing from diameter of 12.0 mm to 9.65 mm at production facilities is:
- annealing to granular perlite (protective gas furnaces 750°C, holding for 24 h);
- etching;
- drawing from 12.0 mm to 11.0 mm;
- annealing (protective gas furnaces 670°C, 12 h holding);
- etching;
- drawing from 11.0 mm to 10.2 mm;
- turning from 10.2 mm to 9.97 mm;
- drawing (from 9.97 mm to 9.65 mm).

In this technology, the removal of defects and decarburized layer from the surface of the strip may be performed by mechanical turning, resulting in not less than 55 kg of metal chips per each ton of metal. In case of scale removal by etching some additional time would be required, ecologically toxic solutions will be involved, requiring expensive utilization.

The authors have proposed two methods of rolled stock processing.

**Method 1.** Rolled stock diameter 12 mm:
- etching 12 mm;
- drawing 11 mm;
- annealing with high-frequency heating (760°-780°C);
- etching;
- drawing from 11.0 mm to 9.65 mm;
- annealing with high-frequency heating (760°-780°C);
- etching;
- calibration 9.65 mm.

**Method 2.** Rolled stock diameter 14 mm:
- etching 14 mm;
- drawing 13 mm;
- annealing with high-frequency heating (760°-780°C);
- etching;
- drawing to 12 mm;
- annealing with high-frequency heating (760°-780°C);
- etching;
- drawing to 11 mm;
- annealing with high-frequency heating (760°-780°C);
- etching;
- drawing to 9.65 mm.

### 3. Results and discussion

The 38XA steel structure with a final diameter of 9.65 mm for a workpiece of Ø 12.0 and 14.0 mm is “sorbitic pearlite”.

Statistical analysis of results of the existing process diagram of processing of the rolled stock showed increase in rolled stock hardness by 50% above the admissible HB>207, the decarburized layer of the rolled metal is higher than the norm (over 0.05 mm) by 20%. For major part of metal, Ψ<60%, which is below the admissible value. The surface quality parameter satisfies the GOST 14955-77 requirements only for 50% of the rolled stock. As a result only 50% of metal corresponds to the necessary requirements of standard.

It has been established that the rolled stock properties in the strip have not been uniformly distributed. It turned out that due to a higher speed of the strip external sides’ cooling comparing to the internal ones, the structure of external ends is more finely dispersed than that of the internal ends.

In case of rolled metal annealing a finely dispersed microstructure equally distributed along its full length is formed in the HFC inductor, which leads to the drop of hardness (HB by 30-31 units) and to the drop of strength (strength limit by 70-90 MPa; of yield strength – by 40-70 MPa), but leads to increase of plastic properties (contraction ratio – by 11-13%).

The increase of the number of HFC annealings causes a change of the microstructure as a result of further cold calibration.
For example, sorbitic pearlite acquires a less dispersed form. As such type of rolled stock Ø11.0 mm annealing leads to emerging of perlite with small grains, the Ø9.65 mm rolled metal already forms a uniformly distributed microstructure along the full scope of the rolled stock, which consists of dotted finely grained perlite with evenly distributed ferrite.

Furthermore, there is a high quality of the surface layer of the rolled stock, as evidenced by a non-high hardness (not more than HB 194), the absence decarburized layer, scale and ellipticity.

The value of the applicability factor of steel for deformation is rather high and amounts to \( \sigma_{0.2} / \sigma_{B} = 41/68 = 0.6 \).

Earlier [20] a process diagram for rolled stock preparation for upsetting had been patented, which included the coil annealing with HFC warming up, that guarantees a high (±3°C) accuracy of maintaining of the temperature conditions, and fractional deformation in dies.

The 10, 20, 20Г2П, 30Г1П, 38XГНМ steel bars of Ø8.0 mm have been subjected to drawing with different degree of drafting (8.00 mm – 7.6 mm – 6.88 mm – 6.23 mm – 5.10 mm – 4.39 mm).

It has been proven that using of HFC warming up during steel annealing in comparison with annealing in bell furnaces provides increase of the structure dispensability and absence of the decarburized layer. At the same time the strength and plasticity parameters do not practically differ.

However, in case of making deformations before the annealing with HFC warming up in unwound state, the microstructure is observed with full spheroidization.

However, this process diagram [20] differs from the one proposed by us by a considerably longer process cycle and is rather a labor and energy consuming.

For example, the process of unwinding of the coil upstream of the HFC induction box and its back winding requires availability of special equipment and is rather labor consuming. Besides, in case of the coils warming up, the uniformity of properties shall not be guaranteed for the full scope of rolled metal. In order to exclude this negative feature, the production engineers have to do an additional spheroidizing annealing in furnaces, which would not always lead to achieving of the uniformity of properties along the length of the rolled stock and leads to increasingly greater extension of the technological process.

4. Conclusions
It has been established that drawing with optimum level of drafting at each of the three stages after annealing with HFC ensures the absence of scale in the finished rolled metal and ellipticity. The available light oxide coating has been removed by etching during some seconds.

The rolled stock prepared according to this method has a finely dispersed uniformly distributed structure without a decarburized layer with the best capacity to form shaping. This enables to reduce the number of transitions in the process of cold heading of metal articles and to increase the service life of tools.

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