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RESEARCH

The Factor of Structure and Mechanical Properties in the Production of Critical Fixing Hardware 38XA

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A B S T R A C T

Fixing hardware made of carbon, high-carbon, and alloyed wires is one of the widespread critical parts in mechanical engineering. The characteristics of fixtures and fasteners and their performance figures are assessed at all stages of steel-making operation, from the choice of burden stock for metal smelting to the method of preparing calibrated rolled metal parts and upsetting end products. Material used for producing long high-duty bolts must be both sufficiently strong and ductile, have homogeneous mechanical properties and chemistry, and no inner or surface defects. When manufacturing fasteners, hot-rolled metal is often plastically deformed by drafting before cold upsetting, and all unacceptable defects are removed by the expensive procedure of lathe-turning. Moreover, this technology of metal processing entails losses of up to 5.5 % in chips. This paper suggests a resource-efficient and environmentally friendlier fabrication method for calibrated rolled metal items made of steel 38XA, 9.65 mm diameter, for cold die-forging of high-duty bolts used in automotive engines, which helps spare expensive lathe-machining processes. Moreover, rolled steel produced using this technology is characterized by high resistance to plastic deformation when cold, which leads to increase n wear-resistance of tools in cold die-forging of bolts.

1. INTRODUCTION

Increasing quality of steel products and parts made of steel, improving their capacity, reliability, raising these parameters to international standards, and ensuring the competitiveness of domestic products while adhering to the requirements of resource saving in the design of manufacture processes are some of the crucial goals and tasks in the development of modern mechanical engineering [1-4].

2. RESEARCH OBJECTIVES

Widespread critical parts in mechanical engineering include fixing hardware made of carbon, high-carbon, and alloyed wires [5,6].

The wide range of wire products and versatile properties required of fastening items are occasioned by the specific character of their application in different areas of mechanical engineering [7]. The characteristics of fixtures and fasteners and their performance figures are assessed [8] at all stages of steel-making operation, from the choice of burden stock for metal smelting to the method of preparing calibrated rolled metal parts and upsetting end products [9]. The fabricability of calibrated rolled metal processing and, eventually, the performance parameters of finished fastener products obtained by cold upsetting are to a great extent subject to the properties of the steel: its chemistry, mechanical properties, macro- and microstructure, presence or absence non-metallic inclusions, etc. [10,11].

When manufacturing fasteners, hot-rolled metal is often plastically deformed by drafting before cold upsetting, and all unacceptable defects are removed by the expensive procedure of lathe-turning.

The material used for producing long high-duty bolts must be both sufficiently strong and ductile, have homogeneous mechanical properties and chemistry, and no inner or surface defects [12]. Provided these requirements are met, the use of calibrated rolled metal in manufacturing bolts allows the 95–98 % metal utilization factor.

Surface defects have practically no impact upon the results of static load mechanical tests [13,14]. On the other hand, surface defects of hot-rolled metal (such as backfins, slivers, scratches, hair seams, etc.) because a crack, tears, pores at the subsequent plastic deformation by drawing. They are left on the surface of the metal after its squeezing when being drawn through the die. All the above-mentioned types of defects may manifest themselves in stamping and thermal treatment as a crack, which leads to the rejection of many of end product items. For this reason, when too many surface defects are found, calibrated rolled metal made according to different technology options, even if boasting high levels of mechanical properties and the optimal structure, can still turn out to be absolutely unsuitable for further manufacturing bolts through cold upsetting.

In the most effective manner, the plastic deformation capacity of cold steel is customarily assessed by the ratio of conventional yield limit to ultimate strength $\sigma_{0,2}/\sigma_в$. Steel is regarded as suitable for cold die-forging, if $\sigma_{0,2}/\sigma_в < 0.6$. With the values of the ratio $\sigma_{0,2}/\sigma_в > 0,8$ we observe high resistance of steel to plastic deformation when cold, which leads to overloads in cold-upsetting equipment and a poorer wear-resistance of tools. Unacceptably high values of the conventional yield limit and ultimate strength and, therefore, of the ratio $\sigma_{0,2}/\sigma_\varepsilon$, are occasioned by the high level of work hardening during lathe-turning and calibration. This causes the formation of improper microstructure in metal and is unacceptable for cold upsetting of high-load bolts for automobile engines. In addition to this, when lathing the surface of calibrated rolled metal, the other unwanted surface defects can occur. Since for this type of processing rounded-edge cutters are used, temperature in the thin surface layer of rolled metal rises high. The depth of the hardened skin is within 0.15–0.3 mm. Screw-shaped cuts and cracks are formed on the surface of the rolled metal. Because precise rod-centering is a very difficult procedure, the circumferential surface removal of metal is uneven and the decarbonized layer of metal on the surface remains unacceptably thick (over 0.1 mm). Moreover, this technology of metal processing entails losses of up to 5.5 % in chips.

It was established that calibrated rolled metal of 38XA, fabricated in accordance with the currently adopted technology, in the absolute majority of cases has $\sigma_в$ higher than 700 MPa (the average value being $\sigma_в$ = 780 MPa) and unacceptable values of $\sigma_{0,2}$ > 640 MPa (the average value being $\sigma_{0,2}$ = 680 MPa), while the difference of $\sigma_{0,2}$ and $\sigma_в$ in testing rises up to 100–120 MPa; half of the tested rolled metal demonstrates hardness values above the acceptable level (according to the National state standard GOST 10702-78 — NV) > 207; in most cases $\Psi < 60\%$, i.e. below the permitted value; ≈ 20% of rolled metal has a decarbonized layer of over 0.05 mm, which is in excess of the allowable norm; more than 50% of calibrated rolled metal has surface quality not meeting the requirements of the GOST 14955-77 standard; due to uneven heating of metal charge in the furnace, only half of the metal after annealing meets the standard requirements for microstructure.

To address these shortcomings, we propose an engineering process for fabricating calibrated rolled metal of this sort of steel, by cold upsetting with end-product diameter 9.65 mm, from initial hot-rolled metal, diameter 14.0 mm, without lathe operations.

Table 1 presents a comparison of technologies of preparation of calibrated rolled metal, steel 38XA, diameter 9.65 mm, for fabricating critical engine bolts by the method of cold upsetting.

When using the suggested method, the value of full drafting reaches 65 %. For sample etching, hydrochloric acid at a temperature of 63–67 °C was used. It was revealed that after high frequency current (HFC) annealing, an insignificant oxidation coating is formed on the rolled metal surface easily removed by hydrochloric acid in a couple of seconds.

Table 1. Comparison of technologies for preparing calibrated rolled metal 38XA, diameter 9.65 mm, for fabricating critical engine bolts.

Manufacturing operation	Current technology (variant 1)	Proposed technology (variant 2)
1	2	3
Heat treatment of hot-rolled metal	Hot-rolled metal annealing, parameters: heating temperature is 750 ºC, hold time in furnace is 3 hours, furnace cooling down to 610 ºC, hold time is 3 hours, furnace cooling	Hot-rolled metal annealing by HFC, parameters: heating temperature is 760…780 ºC, hold time in furnace is 3 hours, furnace cooling down to 700 ºC, hold time is 3 hours, furnace cooling
Scale removal from the surface of rolled metal	Etching in a hydrochloric acid solution	Etching in a hydrochloric acid solution
Rolled metal calibration	Pre-calibration: from diameter 12.0 mm to diameter 10.55 mm (reduction rate is 19.1 %)	Pre-calibration: from diameter 14.0 mm to 12.5 mm (reduction rate is 20.0 %)
Lathing the surface of calibrated rolled metal	Lathing of calibrated rolled metal from diameter 10.55 mm to 9.97 mm	no
Heat treatment of calibrated rolled metal	Recrystallization annealing of calibrated rolled metal, parameters: heating temperature is 670 ºC, hold time in furnace is 3 hours, hold time is 3 hours, furnace cooling	Recrystallization annealing of calibrated rolled metal, parameters: heating temperature is 720 ºC, hold time in furnace is 3 hours, hold time is 3 hours, furnace cooling
Scale removal from the surface of rolled metal	Etching in a hydrochloric acid solution	Etching in a hydrochloric acid solution
Rolled metal calibration	Final calibration: from diameter 9.97 mm to 9.65 mm (reduction rate is 6.0 %)	Pre-calibration: from diameter 12.5 mm to 10.0 mm (reduction rate is 22.0 %)
Heat treatment of rolled metal	no	Recrystallization annealing of calibrated rolled metal, parameters: heating temperature is 720 ºC, hold time in furnace is 3 hours, hold time is 3 hours, furnace cooling.
Scale removal from the surface of rolled metal	no	Etching in a hydrochloric acid solution
Rolled metal calibration	no	Pre-calibration: from diameter 11.0 mm to 9.65 mm (reduction rate is 23.0 %)
Heat treatment of end-product fixing hardware	no	Recrystallization annealing of calibrated rolled metal, parameters: heating temperature is 720 ºC, hold time in furnace is 3 hours, hold time is 3 hours, furnace cooling.
Rolled metal calibration	no	Final calibration: from diameter 9.65 mm to 9.65 mm (within elastic deformation)

3. METHODS

The mechanical properties of the metal in its initial, hot-rolled state and later at all stages of technological conversion were assessed using a tensile-test machine ZDM-100. The tests were carried out on four 300-mm-long samples; the obtained results were averaged. The rupture testing of the bolts, with measuring the applied rupture loads, was carried out on the MUP-50 machine. The appearance of the bolts' fractures was studied after destruction.

Microstructure of the metal was studied on transverse micro-sections using an optical microscope with a 600x zoom. Hardness was measured using a Rockwell machine on scale C, on parallel ground flat patches. The testings were carried out on 4 samples, all data were averaged. Microstructure and hardness of the steel were studied in a hot-rolled state and at technological conversions.

4. RESULTS

It was revealed that hot-rolled steel Ø 38XA as received is characterized by inhomogeneous mechanical properties, scratches on the surface and partial decarbonization.

The more annealing runs the metal is subjected to at the temperature of 760–780 °C by the HFC method after cold plastic deformation (calibration), the bigger changes in its microstructure are. Thus, sorbitic perlite becomes less disperse; after annealing by HFC in the intermediate size of Ø 11.0 mm, fine-grained perlite occurs in the microstructure. In the final size of Ø 9.65 mm and after the fourth annealing by HFC, the formation of homogeneous microstructures of fine-grained and point perlite is obtained, with evenly distributed ferrite. The hardness of calibrated rolled metal with this sort of microstructure is not in excess of NV 194. There are changes in mechanical properties of calibrated rolled metal: its strength properties deteriorate, while its plastic properties improve.

Triple calibration and no scale after annealing by HFC lead to a significant improvement of surface quality of calibrated rolled metal. It is also important that this rolled metal has no ovality in its final size.

Unlike the currently accepted technology, the method proposed in this paper allows getting the calibrated rolled metal 38XA with a considerably smaller plastic stress resistance, better plasticity and lower hardness. There is no decarbonized layer on this rolled metal. At the same time, the drawability of this rolled metal ($\sigma_{0,2}/\sigma_в$) is as much as 0.6.

Consequently, such calibrated rolled metal can be regarded as suitable for cold die-forging.

For the design of state-of-the-art energy-saving technologies needed to fabricate fixing hardware, strength grade 8.8 and higher, we have to draw on additional quality improvement reserves at all stages of technological conversion. The material used for cold die-forging has to possess sufficient plasticity properties, homogeneous mechanical properties and chemistry, and be utterly devoid of any surface or internal defects.

The potential reduction rate of rolled metal depends on the plastic properties of the steel and is largely determined by its microstructure [15-17]. The optimal combinations of properties are reached with a homogeneous fine-globular microstructure and an even distribution of cemented carbide in the ferrite. To obtain this, one has to correctly define the heat treatment conditions. By way of interim heat treatment, annealing is usually used, after which there must be no large-size free ferrite precipitation in the microstructure. Otherwise, due to a quick building up of hardened ferrite spots, the rolled metal will not be capable of resisting high degrees of reduction.

In order to determine the optimal rate of rolled metal's reduction which would ensure the required mechanical properties for calibrated rolled metal and end products, while ruling out the necessity for quenching and tempering operations, we considered three processing options for fabricating bolts out of calibrated hot-rolled steel 38XA (diameter 11.0 mm) for cold upsetting [18]: one of the three is the currently adopted and the other two are what we propose. The chemical composition was conforming to the GOST 10702-78 standard "Quality Engineering Steel, Carbon Steel, and Alloyed Steel for Cold Pressing and Upsetting". The mechanical properties of the hot-rolled metal complied with the requirements of the GOST 10702-78 standard without heat treatment. After calibrating the rolled metal for the purposes of cold heading, we also checked the microstructure and mechanical properties $б_в$, $б_{0,2}$, δ, ψ.

Table 2 presents a comparison of calibrated rolled metal preparation technologies for fabrication of fixing hardware.

5. DISCUSSION

It was revealed that the microstructure of rolled metal when hot-rolled is sorbitic and thin-plate perlite + ferrite in the form of a torn network over the boundaries of perlite grains. Hardness rate is 90–96 HRB.

The calibrated rolled metal prepared according to var. 2 has rupture strength rate at a slightly higher level than calibrated rolled metal made according to var. 1 (by 120 MPa). The values of relative elongation and relative contraction are practically identical. Therefore, calibrated rolled metal prepared in accordance to var. 2 can be used for upsetting bolts by the cold method.

With calibrated rolled metal prepared according to var. 3, the rupture strength rate is higher than in var. 1 (by 290 MPa), and therefore it can be recommended for cold upsetting of bolts with the strength grade of 10.9. However, in cold die-forging of bolts from calibrated rolled metal prepared according to var. 3, the wear resistance of tools is reduced.

Table 2. Comparison of calibrated rolled metal preparation technologies.

Manufacturing operation	Current technology (variant 1)	Proposed technology (variant 2)	Proposed technology (variant 3)
1	2	3	4
Heat treatment of hot-rolled metal	Hot-rolled metal annealing, parameters: heating temperature is 730 ºC, hold time in furnace is 3 hours, furnace cooling down to 650 ºC, hold time is 3 hours, furnace cooling	Hot-rolled metal annealing, parameters: heating temperature is 780 ºC, hold time in furnace is 3 hours, furnace cooling down to 700 ºC, hold time is 3 hours, furnace cooling	Heat treatment of hot-rolled metal in a salt bath at the heating temperature of 880 ºC, cooling in nitrate at 400 ºC, holding for 3 minutes, final cooling in water
Scale removal from the surface of rolled metal	Etching in a hydrochloric acid solution	Etching in a hydrochloric acid solution	Etching in a hydrochloric acid solution
Rolled metal calibration	Final calibration: from diameter 11.0 mm to 9.45 mm (reduction rate is 26.5 %)	Pre-calibration: from diameter 11.0 mm to 9.7 mm (reduction rate is 22.0 %)	Final calibration: from diameter 11.0 mm to 9.45 mm (reduction rate is 26.5 %)
Heat treatment of calibrated rolled metal	no	Heat treatment of calibrated rolled metal in a salt bath at the heating temperature of 880 ºC, cooling in nitrate at 400 ºC, holding for 5 minutes, cooling in the ambient air for 2 minutes, final cooling in water.	no
Scale removal from the surface of rolled metal	no	Etching in a hydrochloric acid solution	no
Rolled metal calibration	no	Final calibration: from diameter 9.7 mm to 9.45 mm (reduction rate is 5%)	no
Heat treatment of end product fixing hardware	Fixing hardware hardening at 860 ºC, tempering at 540 ºC. Quenching compound is machine oil IS-20.	Not required. After cold die-forging, the bolts' strength grade is 8.8.	Not required. After cold die-forging, the bolts' strength grade is 10.9.

6. CONCLUSION

The calibrated rolled steel 38XA produced by processes not implying expensive lath machining operations, demonstrates a high resistance to cold plastic deformation.

The proposed processes are material- and resource-saving and environmentally friendlier if compared with the currently adopted technology. It is reasonable to apply the results of the development survey in the production [19].

The rolled metal produced in accordance with the process option 3 at the reduction rates (after heat treatment) of 20–26.5 % demonstrates a higher resistance to plastic deformation in comparison with variants 1 and 2 and thus can be recommended for fabrication of strength grade 10.9 bolts.

The upsetting of bolts having these mechanical properties leads to deterioration of power efficiency and reduces wear resistance of tools due to high specific loads on the instruments.

The calibrated rolled metal prepared in accordance with var. 2 can be used for the fabrication of fixing hardware by cold upsetting with the thread diameter 10–12 mm with no subsequent hardening and tempering, with the strength grade of 8.8.

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