Rolled metal electron plasma treatment for automotive hardware cold upsetting

Alexey Alesandrovich Fillipov[1], *German Vasilyevich* Pachurin[1], *Mariia Vadimovna* Mochalina[2*], *Nikolay Alexandrovich* Kuzmin[1], *Irina Gennadievna* Trunova[1], and *Olga Vladislavovna* Golubeva[2]

[1]Nizhny Novgorod State Technical University named after R.A. Alekseev, Minin Street, 24, 603950, Nizhny Novgorod, Russia
[2]Minin Nizhny Novgorod State Pedagogical University, Chelyuskintsev street, 9, 603138, Nizhny Novgorod, Russia

Abstract. One of the most important objectives of the modern car production development is to improve the quality of metal products and parts made from it, increase their efficiency, reliability, service life, bringing these indicators to the level of the world standards, ensuring the competitiveness of domestic products at the foreign market. The structural safety of motor vehicles is largely determined by the operational reliability of the constituent elements. Car fasteners made of high-carbon and alloy wire, including hardware items, are among the critical and widely used parts in mechanical engineering. The most common and progressive method of their manufacture is the cold upsetting from rolled bar material. The bar material surface condition has a significant impact on its quality. Hot rolled products from metallurgical plants are typically delivered to the processing facilities covered with scale and rust. To improve the surface quality of semifinished metallurgical products for rerolling at the stage of wire preparation for drawing, it is subjected to continuous mechanical or chemical cleaning. Traditionally, the technology of surface scale removing by etching is used in production. This method of scale removal provides a high level of cleaning, but there are problems with the disposal of spent acid solutions, reducing the steel ductility. Mechanical methods of scale removal have been widely introduced recently, although the use of mechanical scale removal devices also does not completely solve the problem. The paper considers the possibility of using advanced electron plasma treatment technologies for these purposes and the influence of traditional methods and this scale removing method from the rolled steel surface on the quality of metal preparation for upsetting. **Keywords**: Rolled metal, surface defects, hardware, cold upsetting, scale removal, electron plasma treatment

[*] Corresponding author: mariyamuhina@yandex.ru

1 Introduction

One of the most important objectives of the modern car production development is to improve the quality of metal products and parts made from it, increase their efficiency, reliability, service life, bringing these indicators to the level of world standards, ensuring the competitiveness of domestic products at the foreign market [1-3].

The structural safety of motor vehicles is largely determined by the operational reliability of the constituent elements [4-6]. Car fasteners made of high-carbon and alloy wire are among the critical and widely used parts in mechanical engineering. The most common and progressive method of their manufacture is the method of cold upsetting from rolled bar material [7-11].

The wire quality is usually characterized by the level of standard mechanical properties (ultimate tensile strength, relative reduction of area and ultimate elongation) and the uniformity of their distribution along the length of the coil [12-13]. The latter indicator is of no small importance, since it serves as characteristics of its structural regularity and the level of inherent flaws [14-16], on which, in turn, the process of cold upsetting of fasteners depends. This phenomenon is objective, characteristic of wire from different manufacturers, but manifested in these to varying degrees, which is determined by the specifics of the technology of hot-rolled products preparation for drawing.

The bar material surface condition has a significant impact on its quality [17-19]. The causes of surface defects of hot-rolled and calibrated rolled metal are defects in metallurgical production: rolling gas bubbles, hair cracks, flaws and rolling laps. At the same time, due to the burning out of part of the carbon during heating of the metal, both at the rolling stage and during heat treatment before calibration, the formation of a decarbonized layer is an invariable surface defect. Decarburization and scale formation significantly reduce the mechanical properties in the rolled metal surface layers. The surface becomes susceptible to the formation of notches, scorings and scratches during rolling, calibration and cold upsetting.

The hot rolled products from metallurgical plants are typically delivered to the processing facilities covered with scale and rust. To improve the surface quality of semifinished metallurgical products for rerolling at the stage of wire preparation for drawing, it is subjected to continuous mechanical or chemical cleaning, which is not an easy task.

Traditionally, the technology of surface scale removing by etching is used in production. This method of scale removal provides a high level of purification. In the production process, with this type of cleaning, problems arise with the disposal of spent acid solutions, a decrease in the steel plasticity. Etching in a salt bath leads to the diffusion of atomic hydrogen and saturation to a greater extent of the surface layers of hot-rolled products.

The subsequent distribution of hydrogen in the wire is determined by residual stresses during pressure treatment operations [20], which adversely affect the stages of wire processing.

Presently, every company engaged in the wire and rod processing is striving to introduce the environmentally friendly technologies for preparing the rolled surface for drawing.

Mechanical methods of scale removal have been widely introduced recently. In practice, surface treatment with monolithic tools (cutters, milling cutters, scale breakers, abrasive wheels, brushes) and abrasive powder (shot blasting) cleaning and others are used. The use of mechanical scale removal devices does not completely solve the problem. There are several reasons as follows:

- 100% scale removal is not provided;
- due to the lack of a sub-lubricating layer, the drawing process is difficult;
- drawing tool durability is lower than when using etched metal;
- due to the low durability of the drawing tool and increased drawing efforts, the range of produced wire is limited.

 https://doi.org/10.1051/e3sconf/202337601106

The most important technological trend when cleaning the surface of hot-rolled products from scale is the use of plasma technologies.

The physical essence of electron plasma treatment (EPT) consists in the reduction of oxides on the surface of the product and the sublimation or evaporation of other types of contaminants as a result of interaction with particles of low-temperature plasma, which is created by various physical sources [21].

The essence of the technology is to treat the surface with a low-temperature plasma with a degree of discharge in the range of 10-0.01 mm Hg. In this case, a plasma-forming element of a special design is used [21].

The studies of Giprometiz ("Lengiprometiz" OJSC) show the possibility of implementing this technology by creating not only single-line rod cleaning units with a capacity of 1.5-2 t/h, but also a multi-line (6-12 lines) forming heavy coils for their subsequent processing at mills under the same drawing modes as after etching. Two Units of this type are capable of replacing an etching line with a capacity of 150 thousand tons/year at a cost of 4-5 times lower than that for etching [22].

Metals recovered from oxides create strong protective films on the cleaned surface that protect this surface from further corrosion for a long time [21].

Interest in this technology is explained by the fact that a wide range of steels are used in hardware production: from carbon, spring to alloy steels, which behave differently after EPT.

2 Materials and analysis of coating methods used in production

"Krasnaya Etna Plant" OJSC (Nizhny Novgorod) has carried out experimental work on cleaning hot rolled products of various grades of steel at "Plasmakar" LLC facilities in St. Petersburg. Rolled metal of the following steel grades was subjected to electron plasma treatment: 10kp, 51XFA and 35X.

The rods have been examined: two rods from each steel grade. One rod of each of these steel grades was processed according to the existing technological mode (etching in a solution of sulfuric acid), and the second one - at an electron plasma unit. The micro-hardness, microstructure and structure of the rod surface layer have been studied.

The micro-hardness of the hardened layer was measured at a load of 100 g and an increase of x500. Washers with a diameter of 10 mm were cut out and polished sections were made from them. For the reliability of the results obtained, micro-hardness was determined on 5 washers from each rod.

In order to obtain a reasonable opinion on the quality of metal treatment using the EPT method, the results obtained were compared with the requirements of GOST 10702 "High-quality structural carbon and alloy steel for cold extrusion and upsetting", GOST 14959 "Spring carbon and alloy steel. Specifications" and GOST 14963 "Alloy spring steel wire"

3 Experiment results and the discussion of these

3.1 Steel grade 10kp

A visual inspection of the rod after EPT indicates the uniformity of the surface, there are no noticeable roughness and dark spots. No traces of scale were found. The measurement results are stable and with virtually no variation in values. The measurement results are provided in Table 1.

Table 1. Surface quality, microstructure and presence of hardened surface layer of the hot rolled products made of steel grade 10kp.

Steel grade	Surface quality	Microstructure	Presence of layer	Micro-hardness HV100
10kp	Existing mode Rippling, scallops Rz 2,8	Existing mode Ferrite + tertiary iron carbide	Existing mode Hardened layer missing	Existing mode 217
10kp	After EPT Rippling, scallops Rz 3,4	After EPT Ferrite + tertiary iron carbide	After EPT Hardened layer missing	After EPT 221

The microanalysis showed that the structure of the surface layer of samples processed using the existing technology and after EPT does not differ from the core. This corresponds to the results of the micro-hardness measurement.

The surface of the hot-rolled product sample that has been treated by EPT meets the requirements of GOST 10702.

3.2 Steel grade 51XFA

A visual inspection of the 51XFA steel sample surface that has been treated by EPT method showed that it is worse than that of the sample that was processed using existing technology: there are traces of looseness, craters and pits. No traces of scale were found. The measurement results are provided in Table 2.

Table 2. Surface quality, microstructure and presence of hardened surface layer of the hot rolled products made of steel grade 51 XFA.

Steel grade	Surface quality	Microstructure	Presence of layer	Micro-hardness HV100
51XFA	Existing mode Rippling, scallops Rz 2,7	Existing mode Sorbitic pearlite + ferrite	Existing mode Hardened layer missing	Existing mode 272
51XFA	After EPT Traces of looseness, pits Rz 80	After EPT Sorbitic pearlite + ferrite sections	After EPT Hardened layer available (over 0.1mm)	After EPT 401

There is no decarburized layer in both examined samples. Microanalysis showed that there is a pronounced layer of reduced etchability on the surface of the sample after EPT, which corresponds in size to the hardened layer. Figure 1 shows the change in the micro-hardness of the hot-rolled product surface made of steel grade 51XFA treated according to the existing technology and after the EPT.

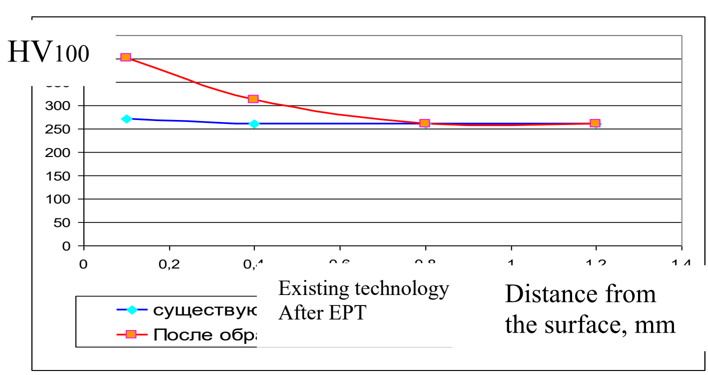

Fig. 1. Steel 51XFA hot rolled product surface micro-hardness change after EPT and using the existing technology. Compiled by the author.

The surface of the hot-rolled product surface made of steel grade 51XFA after the EPT does not meet the requirements of GOST 14959 and GOST 14963

3.3. Steel grade 35X

Visually, the surface of a 35X steel sample that has been treated by EPT method is worse than a sample that was treated in an etching solution of sulfuric acid. No traces of scale were found. The measurement results are provided in Table 3.

Table 3. Surface quality, microstructure and presence of hardened surface layer of the hot rolled products made of steel grade 35X.

Steel grade	Surface quality	Microstructure	Presence of hardened layer	Micro-hardness HV100
35X	Existing mode Rippling (individual sections), scallops Rz 4,4	Existing mode Sorbitic pearlite + ferrite	Existing mode N/A	Existing mode 245
35X	After EPT Cavities and small craters Rz 50	After EPT Sorbitic pearlite + ferrite	After EPT Present	After EPT 361

There is no decarburized layer in both examined samples. In the structure of the sample that has undergone the EPT, there is a weakly etched layer on the surface of the rod. The hardness of this layer is overestimated (Fig. 2).

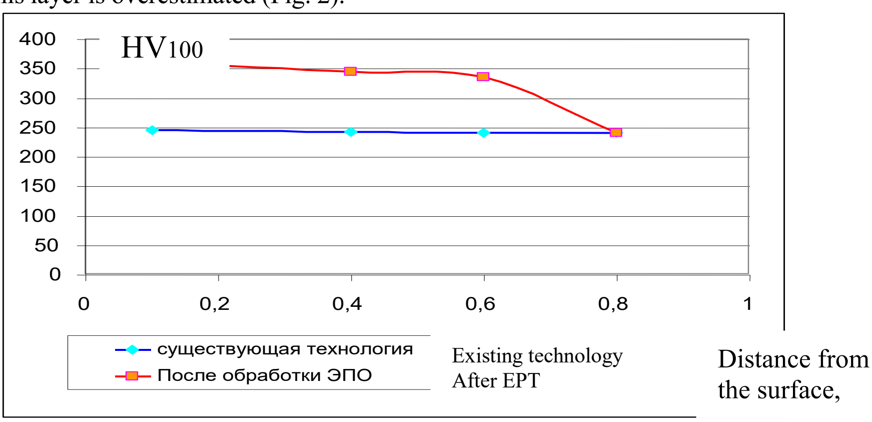

Fig. 2. Steel 35X hot rolled product surface micro-hardness change after EPT and using the existing technology. Compiled by the author.

The surface quality meets the requirements of GOST 10702, but the hardness of the surface layer does not meet the standard requirements.

Thus, a layer of reduced etchability is present in samples of 35X and 51XFA steel grades after treatment by the electron plasma method, which corresponds in size to the hardened layer.

4 Conclusions

1. No traces of scale were found in all samples of hot-rolled products after the electron plasma treatment.
2. No decarbonized layer was found in all samples of hot-rolled products after electron

plasma treatment;

3. Samples of steel grade 10kp, after treatment by electron plasma method, meet all the requirements of GOST 10702;

4. The surface of the 51XFA steel sample, after treatment by electron plasma method, does not comply with GOST 14959 and GOST 14963 norms;

5. The hardness of the surface layer has been increased in samples of 35X and 51XFA steels treated by the electron plasma method, which does not comply with GOST 10702 and GOST 14959 norms.

References

1. V.F. Terentyev, *Fatigue of high–strength metal materials* (IMET RAS - CIAM, Moscow, 2013)
2. V.F. Terentyev, A.N. Petukhov, *Fatigue of high–strength metal materials* (IMET RAS - CIAM, M., 2013)
3. V.F. Terentyev, S.A. Korablev, *Fatigue of metals Institute of Metallurgy and Materials Science named after A.A. Baykov of RAS* (Nauka, M., 2015)
4. A.A. Filippov, G.V. Pachurin, V.I. Naumov, N.A. Kuzmin, Metallurgist **59(9-10)**, 810-815 (2016)
5. Y. Estrin, A. Vinogradov, Acta Materialia **61**, 782–817 (2013)
6. P. Lukas, L. Kunz, L. Navratilova, et al., Materials Science and Engineering **528**, 7036–7040 (2011)
7. Y. Furuya, Mater. Lett **112**, 139–141 (2013)
8. I.O. Leushin, A.Yu. Subbotin, I.V. Geiko, Ferrous metals **10**, 48-53 (2017)
9. M. Sartor, M. Wunde, A. Lemke, M. Roth, S. Boem, K. Ovrazhek, N. Napirkovsky, T. Rod, Ferrous Metals **11**, 46-51 (2016)
10. T. Kohl, M. Bretschneider, T. Klingberg, F. Luther, B. Maas, Ferrous metals **8**, 44-48 (2017)
11. G. Parma, T. Wuttke, M. Norden, Ferrous metals **1**, 45-48 (2018)
12. D.Yu. Kozinov, A.A. Filipov, G.V. Pachurin, Russian Metallurgy (Metally) **13**, 1806–1808 (2022)
13. D.Yu. Kozinov, A.A. Filipov, G.V. Pachurin, M.V. Mukhina, Zh.V. Smirnova, In book: Safety in Aviation and Space Technologies, 311-321 (2022) DOI:10.1007/978-3-030-85057-9_27
14. V.V. Rogozhin, Bulletin of the Nizhny Novgorod University named after N.I. Lobachevsky **4**, 140-147 (2012)
15. Yu.N. Bekish, *Electrochemical deposition of nickel-boron films in the presence of amine-boranes and boron hydrides* (Bulletin of BSU., Minsk, 2008)
16. A.A. Gerasimova, A.G. Radyuk, CIS Iron and Steel Review **1**, 33-35 (2014)
17. E.S. Senokosov, "Metalurg" **4**, 17-20 (2006)
18. A.D. Baeshov, Corrosion: material, protections **5**, 1–6 (2013)
19. G.V. Pachurin, M.V. Mukhina, A.N. Kuzmin, Trans Tech Publications, Ltd., Apr. **316**, 899–904 (2021) DOI: 10.4028/www.scientific.net/ssp.316.899
20. L.M. Poltoratsky, V.E. Gromov, V.L. Chinokalov, V.Ya. Zellermayer, Ferrous metallurgy **4**, 56-58 (1991)

21. E.S. Senokosov, A.E. Senokosov, Metal Supply and Sales **4**, 50-51 (2001)
22. Yu.S. Heydarov, V.S. Yerofeyev, Association of hardware. Hardware. Specialized magazine **1(02)**, 28-32 (2003)