alfabuild

Researhe Article

ISSN 2658-5553

Received: January 16, 2021 *Accepted: March 15, 2022* *Published: March 16, 2022*

Increasing the strength of thin-walled stainless steel parts

Chibukhchyan, Hovhannes Surenovich[1*]

[1]National Polytechnic University of Armenia, Yerevan, Republic of Armenia; hovhannesch@gmail.com
Correspondence:* email hovhannesch@gmail.com; contact phone +37455302402

Keywords:

Strength; Ultrasonic treatment; Thin-walled part; Mathematical model; Microhardness; Mechanical properties

Abstract:

The object of research is the parts and assemblies of modern construction machines and mechanisms is important for reducing operating costs, increasing productivity, reducing downtime for repairs, improving their quality and competitiveness, which naturally imposes strict requirements on their mechanical properties, reliability, strength, and durability. The use of simple manufacturing technologies is also of great importance. One of the effective ways to increase the mechanical properties of thin-walled parts of surface-plastic deformation (PPD), among which a special place is occupied by methods of PPD using ultrasonic vibrations (UV). The purpose of the work is to improve the physical and mechanical characteristics of their thin-walled parts using the technology of bilateral ultrasonic smoothing of their working surfaces. **Method.** A new method of ultrasonic bilateral hardening of thin-walled sheet materials has been developed, which makes it possible to obtain blanks in the form of sheet materials hardened on both sides, from which thin-walled machine parts are obtained by pressure treatment methods. **Results**. Experimental studies have established simplified quadratic mathematical models of the dependences of the microhardness of the hardened layers and the depth of their penetration on the technological parameters of the ultrasonic smoothing process. It is shown that bilateral ultrasonic processing of thin-walled plates increases their axial stiffness by up to 49.6% with a simultaneous increase in their plasticity, which makes it possible to significantly improve the conditions for stamping complex machine parts from such plates. It is established that using the technology of bilateral ultrasonic hardening of sheet blanks for the manufacture of them by methods of processing materials by pressure allows up to 20...30% to improve the weight characteristics of manufactured thin-walled machine parts.

1 Introduction

With the growth of construction in various sectors of the economy, the demand for new and better construction machines and mechanisms has been increasing. The owner of the latest equipment wants to reduce the costs of operation, maintenance, and repair to increase the efficiency of its work, which dictates new requirements for construction machines and mechanisms:

- increase in reliability (increase in the operating time of the machine for failure) and durability (increase in the service life of the machine) [1];
- ensuring increased safety requirements,
- ensuring increased environmental requirements (reducing the negative impact on the environment) and ergonomics (creating comfortable conditions for efficient work of machinists-operators) with mandatory certification of machines according to these indicators.

The development directions of construction and road machines depend both on the scope of their application and the general trends of scientific and technical progress in mechanical engineering [2].

The most distinct areas of development of modern construction and road engineering include in particular:

1) increase in the economically justified limits of the unit capacity of machinery and equipment;

2) automation of control systems, control, and safety of machines based on the use of microprocessor technology and robots;

3) reducing the material and energy intensity of machines, increasing their resource and reliability based on improving calculation and design methods [1] and the use of new materials with the best physical and mechanical properties and characteristics;

4) increasing the requirements for ergonomics and technical aesthetics of machines and mechanisms, taking into account the entire complex of physical and functional capabilities of the human operator operating the machine;

5) increase in average operating speeds, which ultimately increases the productivity of machines;

6) wide unification and standardization of equipment to increase the pace of its production, reduce downtime associated with repair and maintenance,

7) improving the quality of manufacturing of machine components and parts, maintenance and repair work;

8) the use of high-quality operational materials.

It should be noted that the use of new technologies to reduce weight and improve the mechanical properties of parts, components and assemblies, in particular strength, is of particular importance. Improvement of mechanical properties requires the development and practical application of new technologies to improve the strength characteristics of thin-walled parts and parts with low weight.

The destruction of parts used in various fields of mechanical engineering, transport, chemical industry, construction machinery and mechanisms during operation begins mainly from the surface. The surface layers are exposed to the active influence of the external environment, being the most stressed. In this connection, there is a need to improve the physical and mechanical characteristics and geometry of the working surfaces of the parts.

The condition of the working surface of the part affects its operational properties such as operability, reliability, wear resistance, fatigue strength, corrosion resistance.

The creation of reinforced layers with submicro- and nanocrystalline structures on metal surfaces occupies a special place in solving the issues of increasing the strength and durability of engineering materials operating in difficult operating conditions.

One of the most effective and economical types of hardening is surface plastic deformation (SPD), which makes it possible to more fully realize the potential properties of structural materials in real parts, especially in parts of complex shape with stress concentrators [3].

As a result of the influence of high-intensity ultrasonic vibrations in the metal in the solid state, the densities of structural formations increase, which leads to a change in the physical and mechanical properties of the metal being processed and affects the process of plastic deformation. At the solid–solid phase interface, ultrasonic vibrations lead to a change in the state of the surface layer, reduce the forces of boundary friction when moving one body over another. Analysis of the research results shows that, regardless of the composition and initial mechanical properties of metals, the conditional yield strength decreases by 3.5...4 times and the coefficient of friction by 2...4 times during ultrasonic loading [4].

One of the main materials used in modern construction machines and mechanisms is stainless steel. Reducing the total weight and increasing the mechanical properties of stainless steel parts will improve construction machines and mechanisms: performance, reliability, strength, and performance and reduce production costs.

The environmental component is also of great importance since reducing the weight of parts directly reduces harmful emissions during metals production. However, this requires developing and applying new, more efficient, and practically uncomplicated technologies.

Stainless steel, which is resistant to temperature extremes, after chemical and mechanical influence, takes on its usual appearance and retains all its properties, and thus is widely used in the manufacture of various products for construction: profiles, nets, sheets, corners, beams, stair structures, etc.

The surface can be matte, colored, decorative, and this is why it is used as a decorative element in conjunction with other building materials such as wood and glass.

The reliability and performance of building structures, mechanisms, and machines is directly related to the quality of the surface layer of critical parts formed at the surface finishing stages. It is the surface layer that largely determines their service life.

Various methods are used for surface treatment of products. The most widely used are: hardening by high-frequency currents, chemical-thermal, electroerosive, electro-pulse, electron-beam, laser, magnetic, chemical, and others. However, applying these methods requires a large amount of thermal energy.

A significant role in surface treatment belongs to methods of surface plastic deformation, such as: smoothing, rolling, mandrel.

The works of scientists B.M. Askinazi, M. A. Balter, J. Y. Blumstein, S.A. Zaides, D. D. Papshev, and others are devoted to the issues of surface plastic deformation (SPD) and physical and technological foundations [5-15].

The analysis of the research results showed that current research in the field of ultrasonic SPD of machine parts is carried out to improve their operational characteristics and is carried out by ultrasonic hardening of their working surfaces on the one hand, in which, according to the known results of Alekhina V.P., a nanostructure is created at a depth of 25...40 microns, which contributes to a significant increase in the wear resistance of the working surfaces of such parts. Thus, if the part is thin-walled, its bilateral ultrasonic hardening can contribute to an even more significant increase in its mechanical characteristics, which is an urgent task for construction machines and mechanisms.

The use of the SPD method for processing and improving the quality indicators of parts with low hardness and stiffness requires an increase in the intensity of the stress-strain state, which requires the development of new technologies [16-28]. It is known that the main factors affecting the stress-strain state of parts are the shape of the part, the positions and coordinates of the deformable tool, and kinematics compared to the part [7-8,11-15]. As a result of ultrasonic treatment, deformable modified layers appear, harmful stress concentrations in the surface layers, and fatigue cracks' appearance sharply decrease. Thus, further development of fatigue processes is blocked.

The purpose of the work is to develop a method of two-sided ultrasonic processing of thin-walled stainless steel parts for subsequent practical application and to develop a general methodology for experimental research and a software package for machine processing of the results.

To achieve this goal, it is necessary to solve the following tasks.

- Investigate the dependence of microhardness on the depth of processing during ultrasonic processing.
- Determination of technological modes of obtaining the highest microhardness and depth of the processed sample.

2 Materials and Methods

2.1 Materials

Stainless steel grade 12X18N9T Russian state standart GOST 5949-75 [29] was adopted as the material. Experimental samples were made. One-sided and two-sided ultrasonic treatments of experimental samples were carried out on a machine using the equipment developed by us.

This steel grade is used in the manufacturing industry and construction. Stainless steel grade 12X18H9T is used to obtain the following products:

- welded structures of any type;
- metal products that come into contact with nitric acid;
- details of equipment operating under increased exposure to atmospheric factors;
- cryogenic technology;
- capacitive and heat exchange equipment.

The main advantage of this alloy is that the workpieces are easy to machine. To preserve the indicative characteristics of the metal, you do not need to resort to special metalworking technologies. Steel retains high strength, corrosion resistance, and ductility during mechanical and thermal processing.

2.2 Methods

Ultrasonic smoothing of stainless steel samples of the X18H9T brand was carried out on the ultrasonic machine of the 4772A brand, the power supply of the acoustic system (with a power of 2.5 kW) was connected to the output of the ultrasonic generator USG-10 with a power of 10 kW. The choice of the ultrasonic machine of the 4772A brand is because it can establish the necessary static pressure by balancing the pinhole of its acoustic system, and its table can move longitudinally and rotate around its vertical axis which is sufficient for carrying out the planned experiments.

Experimental studies were carried out using modern breaking machines of the Tira Test 2300 and HOUNSFIELD HKS5 breaking machine with a computer interface, which allow measuring and recording the yield strength, tensile strength, Young's modulus, and elongation of test samples before rupture in real-time and collecting experimental results in a separate file.

After ultrasonic treatment of the samples, samples with dimensions were cut out of them by electroerosion treatment for their subsequent tensile testing according to GOST 1497-84 [30].

The output parameters determined by the bursting machine are accepted: the modulus of elasticity, yield strength and strength limits, as well as the relative elongation of the samples before their rupture in accordance with GOST 7855-84 [31].

The experimental machine Tira Test 2300 allows, at given speeds of the traverse, to determine the deformations and loads on the samples during mechanical tests. The machine consists of a loading device, a control unit and a software technical complex. The microprocessor unit has analog and digital corresponding channels for power supply and processing of input signals from the corresponding sensors.

Stainless steel grade 12X18N9T was adopted as the material. Experimental samples were prepared. One-sided and two-sided ultrasonic processing of experimental samples was carried out on a machine using our equipment.

To study the microstructure of samples before and after hardening and their rupture, a ZEISS AXIO VERT A1 electronic microscope with a special optical eyepiece with 1000x magnification and a computer interface with the AxioVision LE software package was used.

3 Results and Discussion

Experimental studies were carried out in two stages. At the first stage, the dependences of microhardness on the depth of the hardened layer during USV treatment were investigated.

Based on the data obtained, the technological modes providing the highest microhardness and depth were determined at the second stage.

Machine processing of research results was carried out using a software package in the LabView environment. Constant coefficients of the regression equations of the mathematical model of the investigated parameter and technological modes providing the maximum and minimum values of this parameter are obtained. According to Fischer, the correspondence of the mathematical model with 95% accuracy of the border was checked.

Based on the experimental studies carried out at the first stage, mathematical models of the dependencies of the depth and microhardness of the hardened layer in code and natural values depending on the technological modes in the form of the following mathematical models are obtained:

$$h = 60.455 + 1692.361S + 0.521P_{st} + 1.641A + 9497.17S^2 - 8.944SPst - 0.001P_{st}{}^2 \\ -0.021A^2 + 58.335S^2P_{st} - 0.016SP_{st}{}^2 \tag{1}$$

$$H_{100} = 8589.049 - 28176.389S + 0.742P_{st} + 58.687A + 99375S^2 + 192.222SPst - 0.021P_{st}{}^2 \\ -0.16A^2 - 1000S^2P_{st} + 0.111SP_{st}{}^2. \tag{2}$$

The analysis of the mathematical models (1)-(2) obtained above, and the graphical dependencies of the output parameters on changes in all input parameters (Fig.1,2) showed the following generalized results: regardless of the type of visual dependencies of the studied parameters on the technological modes of the smoothing process, in all cases and for all processed materials, they are obtained at the highest static pressure and amplitude of the narrow indenter and the lowest flow of the smoothing process.

At the same time, the most significant depth of the hardened layer for stainless steel grade X18N9T reaches h = 194 microns. The highest microhardness of the hardened layer for stainless steel grade X18N9T- H100 = 9431.5 MPa.

The results of the study allowed us to obtain the dependencies of the depth of the hardened layer on the code values of the technological modes in the form of a mathematical model:

$$Y = 168.875 - 3X_1 + 12X_2 + 10.375X_3 - 0.875X_1^2 - 1.875X_2^2 - 1.375X_3^2 + 1.75X_1^2X_2 - 1.75X_1X_2^2. \quad (3)$$

and depending on the natural values;

$$h = 60.455 + 1692.36S + 0.521P_{st} + 1.641A + 9497.17S^2 - 8.944SPst - 0.001P_{st}{}^2 - 0.021A^2 + 58.335S^2P_{st} - 0.016SP_{st}{}^2. \quad (4)$$

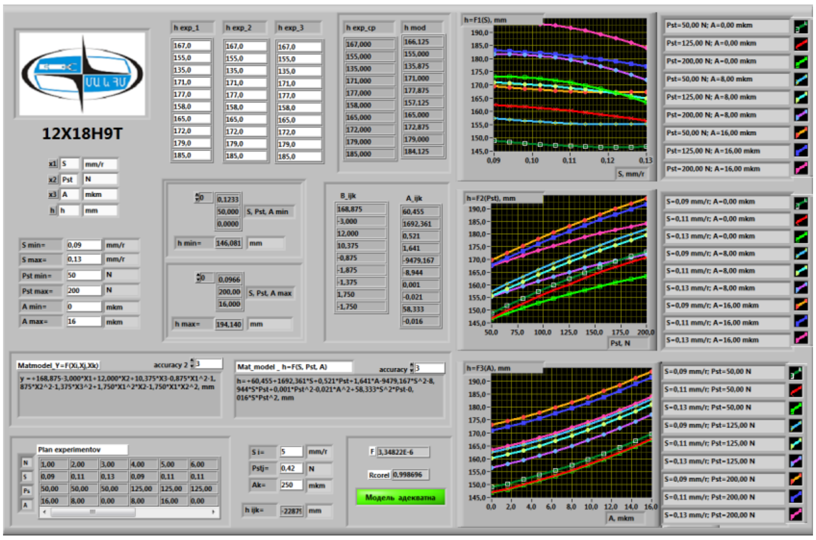

Fig. 1- Dependencies of the depth of the one-sided hardened layer of the X18H9T stainless steel sample on the technological modes

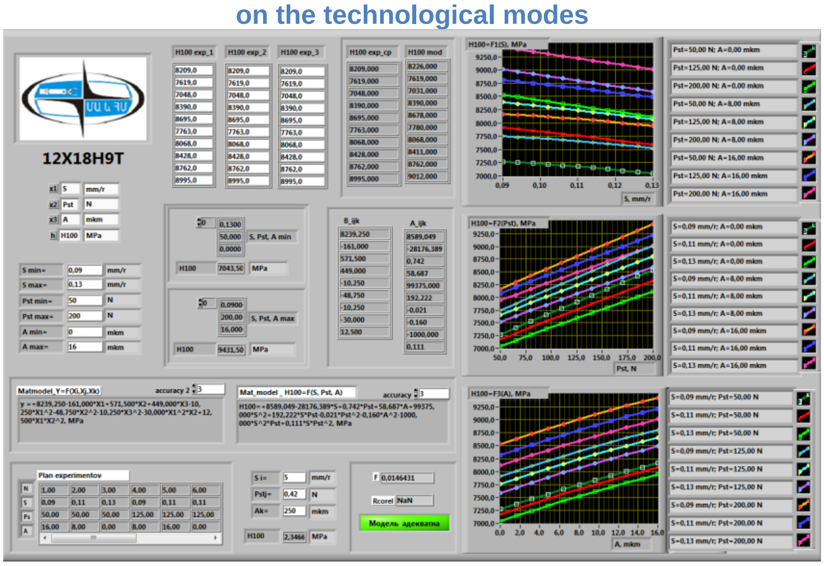

Fig. 2 - Dependencies of the micro-strength of the depth of the one-sided hardened layer of the X18H9T stainless steel sample on the technological modes

Fig. 3 - General view of the TIRA test 2300 breaking machine, Equipment manufacturer « VEB Werkstoffprufmaschinen», Germany

4 Conclusions

Analysis of the results of experimental studies of a sample of stainless steel grade X18H9T after ultrasonic treatment prove:

1. The dependencies of the micro-strength and depth of the one-sided hardened layer of the X18H9T stainless steel sample on the technological modes for a certain dimensionality are reduced;

2. The maximum depth of the hardened layer h=194.14 microns, observed with the following processing parameters S=0.0966 mm/rev, P_{st}=200 N and A=16 microns;

3. The minimum depth of the hardened layer h=146.08 microns, observed with the following processing parameters S=0.123 mm/rev, P_{st}=50 N and A=0 microns;

4. Maximum micro-strength of the hardened layer H100=9431.5 MPa, at S=0.09 mm/rev, P_{st}=200 N and A=16 microns;

5. Minimum micro-strength of the hardened layer H100=7043.5 MPa, at S=0.13 mm/rev, P_{st}=50 N and A=0 microns.

6. Experimental test results, on a tensile testing machine TIRA test 2300, of multilayer samples with double-sided ultrasonic treatment and without it showed that double-sided ultrasonic treatment made it possible to increase the axial stiffness coefficient by 1.315 times, depending on the plastic properties of the starting metal material, the higher the plastic properties of the starting material the higher the values of this coefficient, the higher the values.

References

1. Sogomonyan, V.K., Chibukhchyan, G.S., Chibukhchyan, H.S. Diagnostics of fatigue fractures of building structures elements. Magazine of Civil Engineering. 2018. 80(4). Pp.195-203. DOI: 10.18720/MCE.80.17

2. Panin, A. V., Klimenov, V. A., Pochivalov, Yu. I. i dr. Vliyaniye sostoyaniya poverkhnostnogo sloya na mekhanizm plasticheskogo techeniya i soprotivleniye deformatsii malouglerodistoy stali. [Influence of the state of the surface layer on the mechanism of plastic flow and deformation resistance of low-carbon steels] Fizicheskaya mezomekhanika. 2001. Vol. 4. No. 4. Pp. 85 –92. (rus)

3. Smelyansky V.M. Mexanika uprochnenya detaley poverkhnostnim plasticheskim deformirovaniem. M.: Mashinostroyenie 2002, Pp.300. (rus)

4. Krylova N.A., Shuvaev V.G. Otdelochno-uprochnyayushaya obrabotka poverkhnostey cilindricheskikh detaley s primineniem ultrazvukovikh prodolno-krutilnikh kolebaniy. Izvestiya Samarskogo nauchnogo centra Rossiskoy akademii nauk, vol. 20, no. 4(2),2018, PP.212-216. (rus)

5. Balasanyan, B.S., Agbalyan, S.G., Zakharyan, A.A., Balasanyan, B.A., Chibukhchyan, O.S. O vozmozhnosti povysheniya prochnosti i plastichnosti titanovoy folgi s ultrazvukovym uprochneniyem yeye poverkhnostey. [The possibility of increasing the strength and plasticity of titanium foil with ultrasound strengthening of its surface] Vesnik NPUA [National Poytechnic University of Armenia], Mekhanika, mashinovedeniye, mashinostroyeniye. Yerevan. 2018. No. 2. Pp.76 – 89.(rus)

6. Butenko, V.I., Zakharchenko, A.D., Durov, D.S., Shapovalov, R.G., Rybinskaya, T.A., Podnozhkina, V.N. Povisheniye prochnosti detaley, rabotayushchikh v ekstremalnykh usloviyakh. [Increasing the strength of parts working in extreme conditions] Izvestiya YuFU. Tekhnicheskiye nauki. Spetsialni vipusk. 2008. Pp.198 –202. (rus)

7. Aleksandrov, M.K., Papsheva, N.D., Akushskaya, O.M. Ultrazvukovoye uprochneniye detaley GTD// Aviatsionnaya i raketno-kosmicheskaya tekhnika. [Ultrasonic hardening of parts GTE] Vestnik Samarskogo gosudarstvennogo aerokosmicheskogo universiteta. 2011. No.3 (27). Pp. 271 – 276.

8. Askinazi, B.M. Uprochneniye i vosstanovleniye detaley mashin elektromekhanicheskoy obrabotkoy. Moscow, 1989. 200 p. (rus)

9. Zaytsev, K.V. Formirovaniye nanokristallicheskoy struktury v poverkhnostnom sloye konstruktsionnykh materialov. [Formation of nano crystal structures in the surface layer of structural materials] Trudy VI Vserossiyskoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiyem. Tomsk, 2008.Pp. 102–107. (rus)

10. Zaytsev, K.V., Aralkin, A.S. Primeneniye ultrazvuka pri obrabotke uglerodistykh staley i titanovykh splavov. [The use of ultrasound in the processing of carbon steels and titanium alloys] Sovremennyye problemy nauki i obrazovaniya. 2014. No. 3. Pp. 659 – 665. (rus)

11. Kazarinov, Yu. I. Prochnost elementov konstruktsiy s virezami i povrezhdeniyami: monografia. Tiumen: TIU, 2017. 188 p. (rus)

12. Solovyev, D. L. Deformatsionnoye uprochneniye sposobom statiko-impulsnogo nagruzheniya. [Deformation hardening by static-pulse loading method] Uprochniyaushchiye tekhnologii i pokrytiya. 2005. No. 10. Pp. 3 – 6. (rus)

13. Panin, A. V., Klimenov, V. A., Pochivalov, Yu. I. i dr. Vliyaniye sostoyaniya poverkhnostnogo sloya na mekhanizm plasticheskogo techeniya i soprotivleniye deformatsii malouglerodistoy stali. [Influence of the state of the surface layer on the mechanism of plastic flow and deformation resistance of low-carbon steels] Fizicheskaya mezomekhanika. 2001. Vol. 4. No. 4. Pp. 85 –92. (rus)

14. Klimenov V.A., Nekhoroshkov O.N., Uvarkin P.V., Kovalevskaya Zh.G., Ivanov Yu.F. Struktura, fazovyy sostav i svoystva stali 60, podvergnutoy ultrazvukovoy finishnoy obrabotke. [Structure, phase composition of ultrasonic finished 60 steel] Fizicheskaya mezomekhanika.-2006. Vol. 9. Spets. vipusk. Pp. 173 –176. (rus)

15. Minakov, A. P. i dr. Tekhnologicheskiye osnovy finishnoy uprochnyayushchey pnevmovibrodinamicheskoy obrabotki nezhestkikh detaley v mashinostroyenii. Mogilev: Belorus.- Ros. un-t, 2015. 251 p. (rus)

16. Mukhanov, I.I. Ultrazvukovaya uprochnyayushchechistovaya obrabotka stali i chuguna. [Ultrasonic hardening and finishing of steel and cast iron] Vestnik mashinostroyeniya. 1968. No.6. Pp. 64 –66. (rus)

17. Khertsberg, R. V. Deformatsiya i mekhanika razrusheniya konstruktsionnykh materialov. Per. s angl. A. M. Bernshteyna; Pod red. M. L. Bernshteyna, S. P. Yefimenko. Moscow, 1989. 575 p. (rus)

18. Brehl, D.E., Dow T.A. Review of vibration-assisted machining. Precision Engineering. 2008. Vol. 32. No. 3. Pp. 153 –172.

19. Kashif, K., Fitzpatrick, M., Wang Q., Pyoun, Y. Amanov, A. Effect of ultrasonic nanocrystal surface modification on residual stress and fatigue cracking in engineering alloys. Fatigue and Fracture of Engineering Materials and Structures. 2018. Vol. 41. Pp. 844 –855.

20. Lebedev, V.A., Kochubey, A.A., Kirichek, A.V. The use of the rotating electromagnetic field for hardening treatment of details. IOP Conference Series: Materials Science and Engineering. 2017. Vol. 177, Pp. 1–6.

21. Najafizadeh, N., Rajabi, M., Hashemi R., Amini, S. Improved microstructure and mechanical properties of sheet metals in ultrasonic vibration enhanced biaxial stretch forming. Journal of Theoretical and Applied Vibration and Acoustics. 2019. Vol. 5 (1). Pp.1-10.

22. Ross D., Ungar E., Kerwin, E. Damping of Plate Flexural Vibrations by Means of Viscoelastic Laminate, Structural Damping, ASME, New York. 1959, No. 2. Pp. 49 –88.

23. Long Y., Li, Y., Sun, J., Ille I., Li J., Twiefel J. Effects of process parameters on force reduction and temperature variation during ultrasonic assisted incremental sheet forming process , International Journal of Advanced Manufacturing Technology . 2018. Vol. 97, 2018/07/01, Pp. 13 –24.

24. Karimi A., Amini S. Steel 7225 surface ultrafine structure and improvement of its mechanical properties using surface nanocrystallization technology by ultrasonic impact. The International Journal of Advanced Manufacturing Technology Volume 83. 2015/08/07 Pp. 1127–1134.

25. Kashif Khan, Michael Fitzpatrick, Wang Q.Y., Pyoun Y.S., Amanov A. Effect of ultrasonic nanocrystal surface modification on residual stress and fatigue cracking in engineering alloys. Fatigue and Fracture of Engineering Materials and Structures. 2018. Vol. 41. Pp. 844 –855.

26. Lebedev V.A., Kochubey A.A., Kirichek A.V. The use of the rotating electromagnetic field for hardening treatment of details. IOP Conference Series: Materials Science and Engineering. 2017. Vol.177. Pp. 1–6.

27. Megson T.H.G. Aircraft Structures for Engineering Students. 6th edn. - Oxford: Butterworth-Heinemann. 2016. P. 910.

28. Caoa X.J., Pyounb Y.S., Murakamia R. Fatigue properties of a S45C steel subjected to ultrasonic nanocrystal surface modification. Applied Surface Science. 2010. Vol. 256. Pp. 6297–6303.

29. State Committee of Standards of the Council of Ministers of the USSR, GOST 5949-75 - Gauged corrosion-resistant, heat-resistant and high-temperature steel shape,1975, URL: https://www.russiangost.com/p-19708-gost-5949-75.aspx (date of application: 15.03.2022).

30. USSR State Committee for Standards, GOST 1497-88 - Metals. Methods of tension test,1984, URL: https://www.russiangost.com/p-16654-gost-1497-84.aspx (date of application: 15.03.2022).

31. Interstate Standard of Russian Federation GOST 7855-84 - Tensile-Testing Machines and Universal Machines for Static Testing of Metals and Structural Plastics. Types. The main parameters. General technical requirements ,1991, URL: https://www.russiangost.com/p-255207-gost-7855-84.aspx (date of application: 15.03.2022).