РОЗДІЛ І. ПРИКЛАДНА МЕХАНІКА, МАТЕРІАЛОЗНАВСТВО ТА МАШИНОБУДУВАННЯ

DOI: 10.25140/2411-5363-2021-4(26)-7-14
UDC 621.7:544.56

***Sergiy Kovalevskyy*[1], *Olena Kovalevska*[2]**

[1]Doctor of Engineering, Professor, Head of the Department of Innovative Technologies and Management
Donbass State Engineering Academy (Kramatorsk, Ukraine)
E-mail: kovalevskii@i.ua. **ORCID:** https://orcid.org/0000-0002-4708-4091

[2]Candidate of Technical Sciences, Assistant Professor,
Associate Professor of the Department of Metal Processing in a Vise
Donbass State Engineering Academy (Kramatorsk, Ukraine)
E-mail: olenakovalevskaya@gmail.com. **ORCID:** https://orcid.org/0000-0001-5884-0430

NEW OPPORTUNITIES FOR PROCESSING MATERIALS IN STRONG MAGNETIC FIELD

The article shows the most important results of new studies concerning the possibility of influencing the physical and mechanical indicators of the hardness of steel and carbide materials, presented in the form of dimensional samples and non-sharpened cutting tool inserts. The main differences in the process of volumetric hardening of articles made of magnetically permeable materials are presented - resonant vibrations with amplitudes commensurate with the subatomic dimensions of the hardened materials. Some results of metallographic studies confirming the structural changes in the material of steel samples are presented. The efficiency of resonant processing of materials in a uniform magnetic field of neodymium magnets has been confirmed.

Keywords: *volumetric hardening; uniform magnetic field; resonance; vibrations; piezoelectric elements; metallography.*
Table: 1. Fig.: 6. References: 12.

Urgency of the research. The problem of increasing the efficiency of technological processes of forming the working surfaces of machine parts remains relevant for mechanical engineering, since a targeted change in the physical and mechanical characteristics of critical surfaces is traditionally accompanied by significant expenditures of resources such as time, materials, energy and labor [1; 2]. This is especially important since virtually all of these resources are non-renewable. Therefore, a multiple reduction in the consumption of these resources makes it possible to make tact technological processes innovative, and products with their use competitive.

Target setting. The most effective effects of technological impact on materials are observed under subatomic and subcrystalline impact with strong interactions for such scales. Well-known thermal and power processes are widely used: heat treatment, plastic deformation [2; 5; 6; 7]. But the cost of resources for such well-known processes with a constant increase in tariffs for their use make the products uncompetitive. It is necessary to find new reserves for creating innovative processes, which are distinguished by high efficiency in the use of the above-mentioned resources.

Actual scientific researches and issues analysis. As already mentioned, the concentration of thermal and power energy aimed at shaping or changing the structure of a material and its physical and mechanical properties in the manufacture of machine parts requires the use of special machines and installations that activate such high-cost energy sources as thermal furnaces, multi-ton presses, etc. [2]. A volumetric change in the properties of the material can be achieved, in particular, by heat treatment, due to which the structure is rearranged throughout the entire volume of the product. At the same time, this type of processing has a number of disadvantages, including large internal stresses and deformations due to uneven cooling over the section of the part. The use of external energy fields (electric, electromagnetic, ultrasonic and microwave) can qualitatively affect the structure and mechanical properties of materials. Many publications are devoted to the study at the atomic-molecular level of the mechanisms of action of electric and magnetic fields on plastic deformation processes. It was found that under the action of pulses of electric current and magnetic flux, electroplastic and magnetoplastic effects appear in the material [2; 4]. Special installations, in which the magnetic pulse treatment of metals is carried out, is a source of energy. The installations are equipped with a special tool with which all processes are carried out.

For many years, the special attention of scientists has been attracted by the behavior of structural materials in strong magnetic fields in a wide temperature range. The peculiarity of such a combined method of influencing the structure consists in using the energy of an external magnetic field (constant, alternating or pulsed) to influence the thermodynamics, mechanism and kinetics of phase transitions in order to obtain stable changes in structure and properties useful for operation [2; 5; 6].

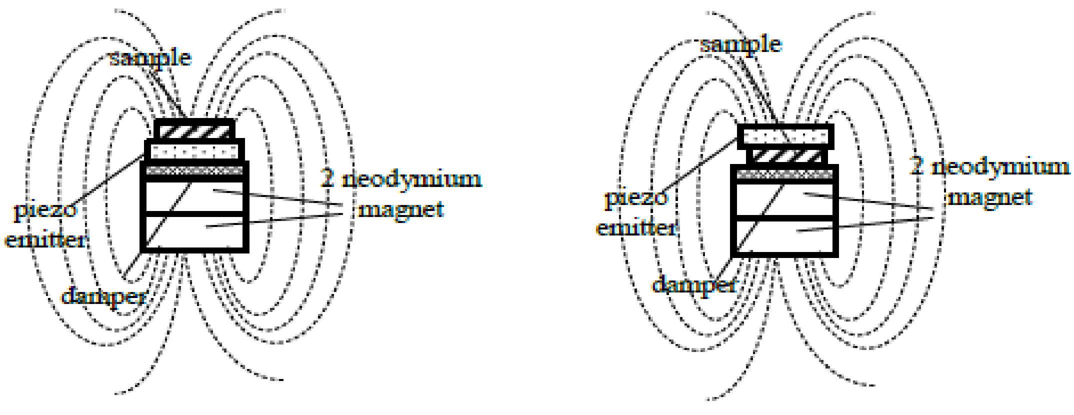
It is known that in the process of magnetic treatment, a metal exposed to an alternating magnetic field changes the operational properties of the surface layer. The improvement in the properties of ferromagnetic parts during pulsed magnetic processing is explained by the directional orientation of free electrons of a substance in an external magnetic field [7].

Uninvestigated parts of general matters defining. A key aspect of the process under consideration is to achieve a three-dimensional effect: this is important because the presence of a gradient of mechanical properties leads to internal stresses in the material, which negatively affects the reliability of the product. Therefore, treatment in a strong magnetic field by weak amplitude vibrations is required: large amplitudes bring the process closer to magnetic pulse processing, ie the volumetric effect is lost. The increase in the hardness of steel samples as a result of the influence of microamplitude oscillations in a constant (homogeneous) strong magnetic field has been experimentally proven. The effect spread throughout. In addition, it was found that the formation of reinforcing mesh of lamellar perlite was observed in the volume of the material during the processing of eutectoid steel samples. The dependences of the value of hardness and the time of reaching its constant value on the amplitude of oscillations of the piezoresonator and, accordingly, the samples were extreme.

Magnetic fields allow to realize direct non-contact influence on dynamics of structural defects of various level, on their behavior and, as a result, to change macroproperties of material and operational characteristics of details. They can significantly change the kinetics of the crystallization process, initiate phase transitions, affect the final structure and other properties in the processing of materials. Under certain processing modes, pulsed magnetic fields can be used like intense plastic deformation to create the desired microstructure, but retain the original size and shape of the product [2; 8].

The research objective is new opportunities for processing materials in a strong magnetic field.

The statement of basic materials. The study of the effect of a constant magnetic field on samples of quick-change cutting tool inserts vibrating in the microamplitude range was carried out for the schemes shown in Fig.1a and 1b.



a *b*

Fig. 1. Arrangement of samples above (a) and below 1b) a source of vibration "white noise"

Resonant microvibrations of the samples make it possible to increase the hardness of the samples at a rate of 5 ... 6 HB per minute. However, it was found that in the range of microvibration amplitudes received from a vibrating exciter based on a piezoelectric element with a diameter of 30 mm. The exciting signal was generated by a "white noise" generator.

Table shows options for the mutual arrangement of samples, as well as vibration exciters based on piezoelectric elements and neodymium magnets, which form a constant uniform magnetic field, which were subjected to experimental verification in order to confirm the proposed idea of the prospects of magnetic resonance processing of materials in a strong constant magnetic field.

Table

Options of technological adjustments of piezoelements for experimental samples

№	Piezoelectric Elements - Emitters and Sensors	Loading scheme
1	2	3
1.	PD-1; PV-2	NM-PD-S-PV-NM
2.	PD-1; PV-1	
3.	PD-2; PV-2	
4.	PD-1; PV-1	PD-S-PV-NM

Table 1 shows setup options for investigating the best positioning of specimens in the form of non-regrind cutting tool inserts. The designation “1” refers to a piezoelectric element with a diameter of 30 mm and a weight of 10 mm. The designation "2" refers to deposited on a substrate with a diameter of 30 mm, a layer with a diameter of 20 mm and a thickness of 0.5 mm. The designation PD refers to the sensory role of piezoelectric elements “1” and “2”. Accordingly, PV refers to the role of piezoelectric elements as causative agents of “white noise”. The designation NM-PD-S-PV-NM reflects the layout of the experimental setup: neodymium magnet-sensor-sample-vibration source-neodymium magnet. The designation PD-S-PV-NM reflects the layout of the experimental setup: sensor-sample-vibration source-neodymium magnet. Figure 2 shows the results of the magnetic resonance treatment of the sample.

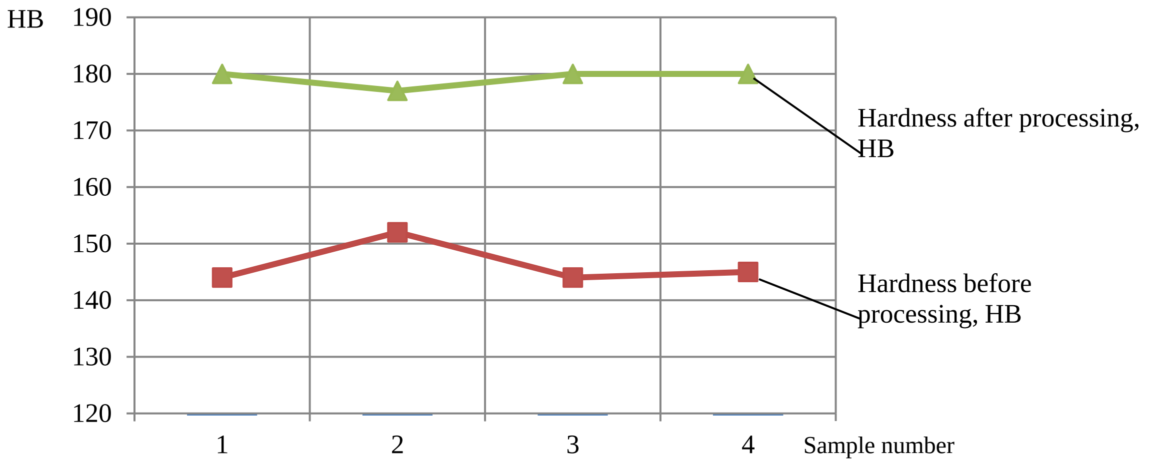
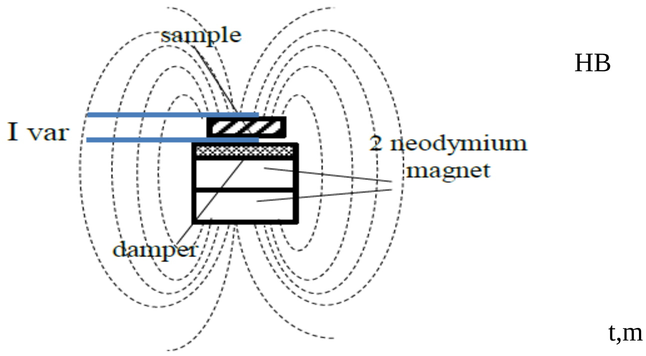


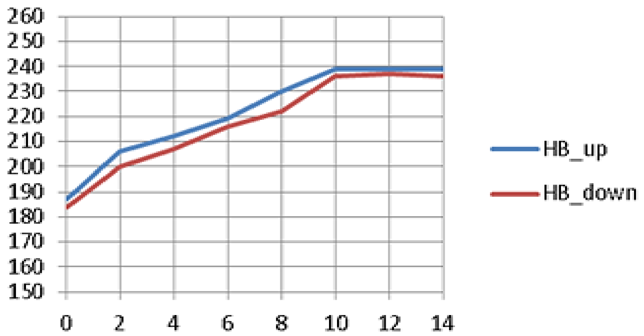
Fig. 2. The results of the magnetic resonance treatment of the sample

Microvibrations of the samples in a magnetic field created by strong neodymium magnets, in the resonant mode, first lead to an increase in hardness, followed by stabilization of their hardness.

Of particular interest is the possibility of local strengthening of a part of the samples (parts) by using the interaction of the magnetic field created by the poly-frequency packet of electric current and the local field of a constant strong magnetic field, using the Biot-Savart-Laplace law [2; 9; 10]. In this scheme, there is no microvibration exciter, but the hardening effect will be present (Fig. 3a and 3b).



a

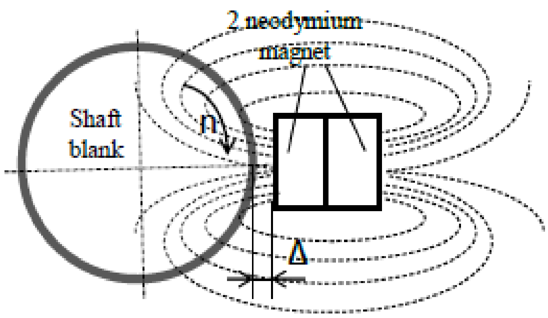


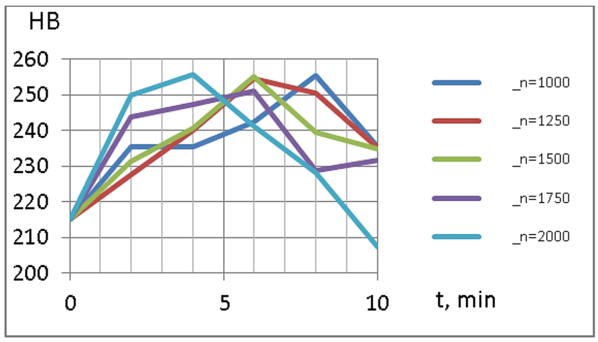
b

Fig. 3. Diagram of the layout of the experimental setup for studying the volumetric hardening of an unregulated cutting tool insert under the action of a current modulated by an alternating broadband current of small amplitude (a) and the results of changing the hardness of the sample along its upper and lower surfaces (b)

The increase in hardness of the sample material also increased by 30-40 % over a period of 10-12 minutes. The consumed power did not exceed 2-3 watts.

Surface plastic deformation or heat treatment of shaft journals requires significant energy consumption to increase the hardness of the working surfaces of machine parts within 1-3 kW [2; 11; 12]. The results of experimental studies of non-contact surface treatment of machine parts according to the scheme in Fig. 4a are shown in Fig. 4b.





a *b*

Fig. 4. The layout of the experimental setup to study the non-contact effect of a strong uniform magnetic field on the surface hardening of a rotating shaft installed in the centers of the lathe at a distance of 0.1 mm from the surface of a neodymium magnet (a) and the change in the hardness of this shaft for 10 minutes (b)

Device for magnetic reinforcement of the work surface of the axes: a) schematic diagram; b) the dynamics of the work surface armature HB from time t to the influence of the magnetic field for different values of the machine spindle speed; Δ = 0.1 mm.

Experimental verification of the performance of the proposed scheme for processing a shaft with a diameter of 79 mm revealed the effect of increasing the hardness of the contactless surface treatment of a sample made of Ck45 steel. An increase in the hardness of the treated surface with a decrease in the gap between the neodymium magnet and the surface to be hardened was quite predictable. Also, an increase in the hardness of the treated surface with an increase in the rotation frequency of the workpiece is explained by an increase in the rate of intersection of a uniform magnetic flux by the rotating part of the sample.

However, the nature of the influence of microvibrations of a neodymium magnet on the nature of the hardening effect on the surface and volume of the sample completely coincided with the results of microvibrations of the samples with a frequency of 20…20000 Hz in a uniform magnetic field of permanent magnets.

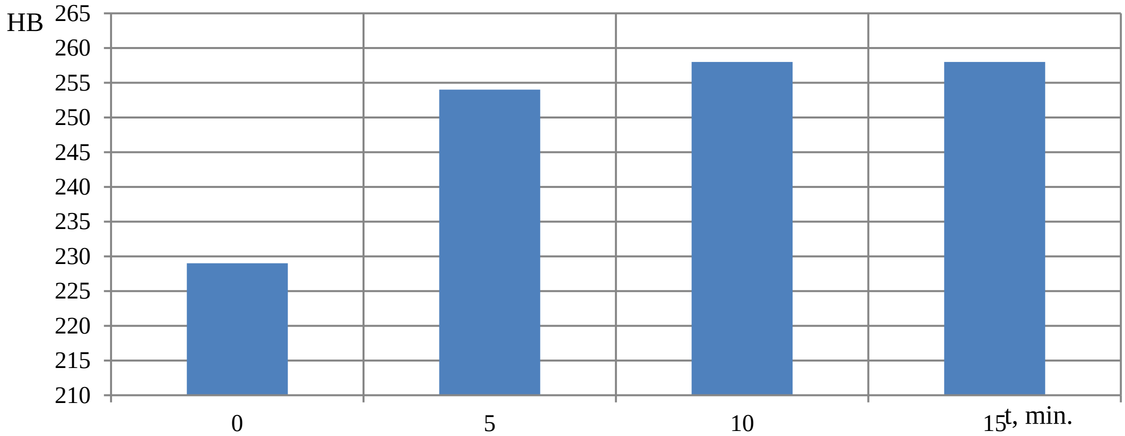
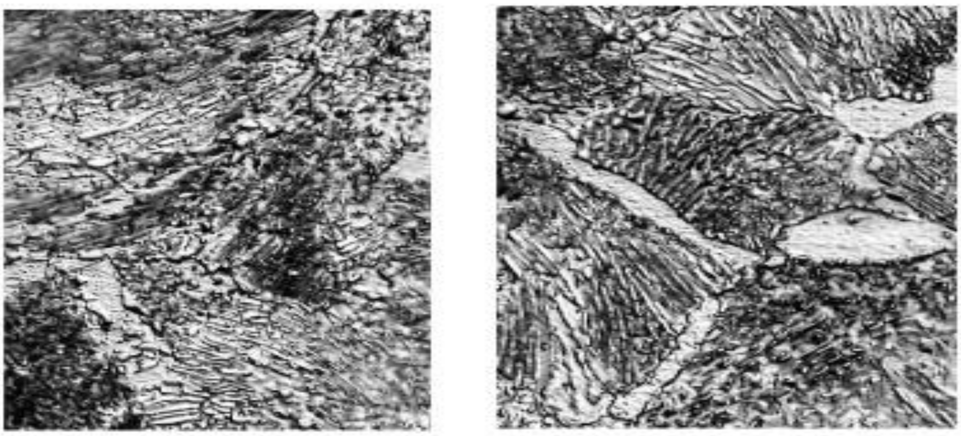


Fig. 5. The results of a broadband resonance effect for 15 minutes of a strong magnetic field of a neodymium magnet on a shaft mounted on a lathe and rotating at 2000 rpm

The results of studying the microstructure of samples before and after magnetic resonance treatment are presented in Fig. 6.



a *b*

Fig. 6. Structure of steel samples (eutectoid steels: C = 0.8 %; Si = 0.15 %; Mn = 0.15 %; P = 0.012 %; S = 0.017 %; Cr = 0.10 %; Al = 0.009 %; Cu = 0.10 %):
a – before magnetic resonance treatment, HB = 145;
b – after magnetic resonance imaging treatment, HB = 197

Photos of microsections were obtained using standard processing of microsections - etching with an alcoholic solution of nitric acid. The developed grain boundaries made it possible to establish the features of the pearlite structure of the reinforcing nature. The influence of microvibrations of the sample in a uniform magnetic field created by one or two neodymium magnets has been established. Moreover, in the course of research, an extreme influence of the magnitude of the amplitude of microvibrations in a constant magnetic field was found. In addition, microvibrations generated in the resonant frequency range of the sample not only contribute to the volumetric hardening of the material, but also increase the ability of the samples to deform. This explains the difference between the bulk hardness of the sample and the density of the material, which also changes, representing four options for reducing or increasing the density of the material of the samples with an increase or decrease in their hardness (in some cases, a decrease in the hardness of the samples was observed with an increase in the density of their material). However, these features of the processes of magnetic resonance processing have yet to be further investigated.

Conclusions. Expanding the list of technological effects on various materials possessing the properties of magnetic conductivity of a uniform magnetic field makes it possible to significantly increase the variety of technological operations of volume hardening of machine parts and technological tools. Achieved results of magnetic resonance processing convincingly confirm this conclusion. Rational modes of magnetic resonance treatment of materials with extreme effects of microamplitude vibrations with a broadband spectrum of oscillations of the hardened sample were found. Prospects of piezoresonators application for formation of pearlite mesh in the volume of steel products processed in the magnetic field are shown. This is confirmed by metallographic studies.

References

1. Sidorchuk, O.M., Hohaiev, K.O., Radchenko, O.K., Mironyuk, L.A., & Mironyuk, D.V. (2020). Termichna obrobka shtampovoyi stali pidvishenoyi stijkosti [Thermal processing of die steel with increased resistance]. *MOM*, (2), 29–37. doi:10.15407/mom2020.02.029.

2. Kovalevskyy, S.V., Kovalevska, O.S. (2021). *Nanoamplitude resonance vibrations of samples in a strong uniform magnetic field*. http://www.savremenimaterijali.info/sajt/doc/file/SM2021/Poster/2.pdf.

3. Minko, D.V. (2020). Analiz perspektiv primeneniya elektroplasticheskogo effekta v processah obrabotki metallov davleniem [Analysis of the prospects for the use of the electroplastic effect in metal forming processes]. *Literatura i metallurhiia – Literature and metallurgy*, (4), 125-13.

4. Hohaiev, K.O., Radchenko, O.K., Sidorchuk, O.M., Mironyuk, D.V. Shtampova stal [Stamped steel]. Pat. 141447 Ukraine: MPKS22S38 / 00 201u2019 09670.

5. Su Eun Chung, Wook Park, Sunghwan Shin, Seung Ah Lee, Sunghoon Kwon (2008). Guided and fluidic self-assembly of microstructures using railed microfluidic channels. *Nature Materials, 7*, 581.

6. Eliseev, A.A., Lukashin, A.V., Tretyakov, Yu.D. (Ed.). (2010). *Funktsionalnye nanomaterialy [Functional nanomaterials]*. Fizmatlit.

7. Miyazawa, S., Mukaida, M. (1996). Formation of stacking-faults in atomic graphoepitaxial alpha-axis YBa2Cu3Ox, thin films on (100) SrLaGaO4 substrates. *Jap. J. Appl. Phys*., (35(9B)), L1177–L1180.

8. Kovalevskii, S.V., Kovalevska, O.S. (20320). Sposib zmini fiziko-mehanichnih vlastivostei zrazkiv z magnitnih ta nemagnitnih materialiv [Method of changing the physical and mechanical properties of samples of magnetic and non-magnetic materials]. Patent 143057 Ukraina MPK B23H 7/38 (2006.01).

9. Onufriyenko, V.M. (1999). Physical and Geometric Interpretation of Electromagnetic Field's Characteristics. *Telecommunication and Radio Engineering, 53*(4-5), 136-139.

10. Onufriienko, V.M. (2004). Potentsialy fraktalnykh shariv zariadiv i strumiv u shtuchnomu seredovyshchi [Potentials of fractal layers of charges and current to the artificial environment]. *Radioelektronika. Informatika. Upravlinnya – Radioelektronika. Computer Science. Management,* (1(1)), 18-21.

11. Kovalevskyi, S., Kovalevska, O., Dasych, P. (2020). Vibratsiino-impulsna obrobka [Vibration-pulse processing]. *Neiromerezhni tehnolohii ta yikh zastosuvannia NMTiZ-2020: zbirnik naukovih prats XIX Mizhnarodnoyi naukovoyi konferentsii «Neiromerezhni tehnolohii ta yikh zastosuvannia NMTiZ-2020» – Neural limit technologies and their application NMTiZ-2020: coll. Science. works of the XIX International. Science and Technology Conf.* (pp. 82–84). DDMA.

12. Kovalevskii, S.V., Borovoi, I.B. (2020). Obiemna obrobka materialiv v rivnomirnomu magnitnomu poli [Volume processing of materials in a uniform magnetic field]. *Novi i netradytsiini tehnolohii v resurso- i enerhosberezhenii: materialy mezhdunarodnoi naukovo-tehnichnoi konferentsii,* (pp. 80–85). ONPU.

Список використаних джерел

1. Термічна обробка штампової сталі підвішеної стійкості / О. М. Сидорчук, К. О. Гогаєв, О. К. Радченко, Л. А. Миронюк, Д. В. Миронюк // МОМ. – 2020. – № 2. – С. 29–37.

2. Kovalevskyy S.V. Nanoamplitude resonance vibrations of samples in a strong uniform magnetic field [Electronic resource] / S. V Kovalevskyy, O. S. Kovalevska. – Accessed mode: http://www.savremenimaterijali.info/sajt/doc/file/SM2021/Poster/2.pdf.

3. Минько Д. В. Анализ перспективы применения электропластического эффекта в процессах обработки металлов давлением / Д. В. Минько // Литература и металлургия. – 2020. – № 4. – С. 125-130.

4. Штампова сталь: пат. 141447 Україна: МПКС22С38/00 №u2019 09670 / К. О. Гогаєв, О. К. Радченко, О. М. Сидорчук, Д. В. Миронюк; заявл. 05.09.2019; опубл. 10.04.2020. Бюл. № 7. 2020. – 2 с.

5. Guided and fluidic self-assembly of microstructures using railed microfluidic channels / Su Eun Chung, Wook Park, Sunghwan Shin, Seung Ah Lee, Sunghoon Kwon // Nature Materials. – 2008. – Vol. 7. – R. 581.

6. Елисеев А. А. Функциональные наноматериалы / А. А. Елисеев, А. В. Лукашин ; под ред. Ю. Д. Третьякова. – Москва : Физматлит, 2010. – 456 с.

7. Miyazawa S. Formation of stacking-faults in atomic graphoepitaxial alpha-axis YBa2Cu3Ox, thin films on (100) SrLaGaO4 substrates [Electronic resource] / S. Miyazawa, M. Mukaida // Japanese Journal of Applied – 1996. – Physics 35(9B): September. – L1177-L1180.

8 Патент 143057 Україна МПК B23H 7/38 (2006.01). Спосіб зміни фізико-механічних властивостей зразків з магнітних та немагнітних матеріалів / С. В. Ковалевський, О. С. Ковалевська ; власник Донбасу. держ. машинобуд. акад. – № u202000120; заявл. 08.01.2020; опубл. 10.07.2020, Бюл. № 13.

9 Onufriyenko, V.M. Physical and Geometric Interpretation of Electromagnetic Field's Characteristics / V. M. Onufriyenko // Telecommunication and Radio Engineering. – 1999. – Vol. 53; № 4-5. – Pp. 136-139.

10 Онуфрієнко, В. М. Потенціали фрактальних шарів зарядів і струму штучному середовищі / В. М. Онуфрієнко // Радіоелектроніка. Інформатика. Управління. – 2004. – № 1(1). – С. 18-21.

11 Ковалевський, С. Вібраційно-імпульсна обробка / С. Ковалевський, О. Ковалевська, П. Дасич // Нейромежні технології та їх застосування НМТіЗ-2020 : зб. наук. праць XIX Міжнар. наук-тех конф. – Краматорськ : ДДМА, 2020. – С. 82-84.

12 Ковалевський, С. В. Об'ємна обробка матеріалів у рівномірному магнітному полі / С. В. Ковалевський, О. С. Ковалевська, І. Б. Боровой // Нові і нетрадиційні технології в ресурсо- і енергозбереженні : матеріали міжнар. наук.-тех. 25 наук. конф. – Одеса : ОНПУ, 2020. – С. 80-85.

Отримано 08.12.2021

УДК 621.7:544.56

***Сергій Ковалевський*[1], *Олена Ковалевська*[2]**

[1]доктор технічних наук, професор, завідувач кафедри інноваційних технологій і управління
Донбаська державна машинобудівна академія (Краматорськ, Україна)
E-mail: kovalevskii@i.ua. **ORCID:** https://orcid.org/0000-0002-4708-4091
ResearcherID: S-7619-2019. **SCOPUS Author ID:** 57201214151

[2]кандидат технічних наук, доцент, доцент кафедри обробки металів тиском
Донбаська державна машинобудівна академія (Краматорськ, Україна)
E-mail: olenakovalevskaya@gmail.com. **ORCID:** https://orcid.org/0000-0001-5884-0430
ResearcherID: S-8871-2019. **SCOPUS Author ID:** 57201211726

НОВІ МОЖЛИВОСТІ ДЛЯ ОБРОБКИ МАТЕРІАЛІВ У СИЛЬНОМУ МАГНІТНОМУ ПОЛІ

Використання магнітного поля як основної сили впливу призводить до значної економії енергоресурсів. Значний інтерес викликає можливість розширення переліку технологічних впливів на робочі поверхні деталей машин, поряд із поверхневим пластичним деформуванням та термообробкою.

Однією з основних проблем є підвищення зносостійкості пластин ріжучого інструменту, підвищення довговічності елементів механічних деталей і конструкцій.

Магнітно-імпульсна обробка металів є ефективним методом, тому він дуже популярний серед сучасних виробників; це підвищує такі показники, як стійкість, міцність та корозійна стійкість [2; 6].

На основі проведеного аналізу було виявлено, що треба дослідити вплив наноамплітудних коливань сталевих зразків у постійному та однорідному сильному магнітному полі на деякі їхні фізико-механічні характеристики.

Завдання - виявити нові можливості для обробки матеріалів у сильному магнітному полі.

Розглянуто різні технологічні схеми, в яких застосовується широкосмугове збудження зразків за допомогою п'єзоелектричних збудників, що перетворюють електричний сигнал постійної амплітуди в діапазоні від 20 Гц до 20 кГц у вигляді "білого шуму" резонансний спектр власних механічних коливань. зразків. Результати таких впливів на зразки в лабораторних умовах підтверджуються стандартними випробуваннями на твердість зразків, їхній хімічний склад та металографію.

Для зразків з евтектоїдної сталі з вмістом вуглецю 0,8 % магнітно-резонансна обробка зразків джерелом електричного сигналу потужністю всього 3 Вт протягом 50 хвилин дозволила домогтися зміни твердості Брінеллю до 35 %. Збільшення амплітуди коливань п'єзорезонатора приводить до збільшення твердості матеріалу.

Ключові слова: *об'ємне загартовування; однорідне магнітне поле; резонанс; вібрації; п'єзоелектричні елементи; металографія.*

Табл.: 1. Рис.: 6. Бібл.: 12.

Kovalevskyy, S., & Kovalevska, O. (2021). New opportunities for processing materials in strong magnetic field. *Technical sciences and technologies*, 4(26), 7-14.