

Розроблено комплексну технологію зміцнення друкарських циліндрів утворенням на поверхні регулярного мікрорельєфу з наступним хромуванням.

Проведеними дослідженнями впливу комплексної обробки друкарського циліндра на якість поліграфічної продукції встановлено механізм одержання високих параметрів якості робочої поверхні друкарських циліндрів. При застосуванні вібраційного інструмента з радіусом $R=2$ мм, при навантаженні $P=550$ Н шорсткість поверхні спостерігається по середньоарифметичному відхиленню Ra 0,63 мкм, що в 7,6 разу менше без застосування поверхнево-пластичного деформування. Комплексна обробка друкарського циліндра включає поєднання вібраційного накатування з утворенням повністю нового регулярного мікрорельєфу та наступним хромуванням.

Вібраційне накатування проводилося при зусиллі вдавлювання інструмента 50–600 Н; частоті обертання шпинделя 25–2000 об./хв.; ексцентриситеті деформувального інструмента 0,2–1,0 мм; частоті осциляцій деформувального інструмента 1000–2000 подв.х./хв.; подачі деформувального інструмента 0,08–12,5 мм/об. При хромуванні застосовували електроліт $\text{CrO}_3 \approx 290$ г/л і $\text{H}_2\text{SO}_4 \approx 3$ г/л; температура електроліту 57 °С; час хромування – 20 хв; густина струму 80 А/дм², час активації 20 с. Завдяки цьому стало можливим одержання розвиненої поверхні циліндра з високими експлуатаційними характеристиками. Експериментальними дослідженнями підтверджено, що за рахунок режимів обробки суттєво змінюються шорсткість поверхні, твердість, мікротвердість. Це посилює поверхневе зміцнення друкарського циліндра. Зокрема, встановлено, що завдяки комплексній технології твердість підвищується у 1,2–1,6 разу порівняно з твердістю основного металу та у 2,7–3,3 разу порівняно із хромованою поверхнею. Це дозволяє стверджувати, що виявлений механізм формування відповідає заданим властивостям.

Таким чином, є підстава стверджувати, що можна подовжити експлуатаційний термін друкарських циліндрів, забезпечити стабільну роботу обладнання, поліпшити якість поліграфічної продукції завдяки застосуванню комплексної технології з наступним хромуванням

Ключові слова: поверхнево-пластичне деформування, хромування, мікрорельєф, шорсткість поверхні, дюрOMETричні властивості поверхні, друкарський циліндр

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EFFECT OF THE INTEGRATED TREATMENT ON THE MANUFACTURING OF PRINTING CYLINDERS

S. Zyhulia

PhD, Associate Professor*

E-mail: s.zygulya@gmail.com

O. Barauskiene

PhD, Associate Professor*

E-mail: oksanalotototska@gmail.com

*Department of Printing Technology

National Technical University

of Ukraine "Igor Sikorsky Kyiv

Polytechnic Institute"

Peremohy ave., 37,

Kyiv, Ukraine, 03056

1. Introduction

The quality of printed products depends on parts, separate nodes, components of the printing equipment. The operational characteristics and stability of machinery performance are affected by the technological features of their fabrication, which are based on the processes of surfaces treatment, specifically by the methods of surface strengthening [1].

Well known are the traditional methods for manufacturing parts. Currently, specialized technological procedures are common – the integrated technology of spark and laser doping followed by nitriding [2], dynamic methods of surface-plastic deformation [3], cold and shot blasting machining [4], combined types of treatment [5], etc.

At present, stability of operation of printing cylinders using conventional technologies of fabrication does not meet the modern needs of printing production. This is due to the influence of an aggressive environment (inks, wetting solutions, washing substances, anti-set-off powders, etc.), which causes extensive corrosion at the surface of the cylinder. Therefore, it is a relevant task to address the issues related

to increasing the durability of a printing cylinder by using various technological measures.

Today, there is not enough information about the application of comprehensive technological influences, which combine both the mechanical and electrochemical treatment methods. It is known that certain technological methods, aimed at the improvement of operational properties of equipment components, are actually used for surface treatment. Thus, paper [6] considered an integrated technology that combines the finishing-strengthening surface treatment, implying the formation of a partial regular microrelief, and hard chromium-plating with the thermal or electrothermal treatment.

However, a combination of these methods has not been investigated enough, which is why it is necessary to undertake comprehensive theoretical and experimental studies. This illustrates the relevance of the chosen field of research.

Addressing the issue on improving the operational characteristics, as well as the stability of a printing process, is not only of scientific but also of practical interest. This would significantly increase the quality and durability of printing cylinders, and, therefore, the quality of printed products.

2. Literature review and problem statement

The main device in a printing machine is the cylinder, which ensures reliable operation of the equipment and the steady flow of technological process for reproducing word-illustrative information with high quality parameters. Its failure would terminate the process of products manufacturing and incur essential financial losses.

In paper [7], authors reported an analysis of applying the ionic-plasma strengthening, nickel plating, chromium-plating. The authors analyzed those production and other factors that affect wear processes. The list of factors included additional parameters for the surface treatment of parts that wear out, the types of materials and treatment, surface coating, change in operating modes, parameters for loading the printing technique, the actual work duration, etc. However, the work gives only an analytical review of the application of each type of coating for the manufacture of cylinders for offset printing machines.

The authors of paper [8] consider increasing the efficiency of friction nodes in printing machines by the technological modes of manufacturing composite materials based on copper, as well as their influence on the physical-mechanical and antifriction properties. However, the paper does not describe the durometric properties and roughness of the surface, which are important in the manufacture of parts.

Article [9] examined the methods of surface-plastic deformation, thermal treatment, diffusion saturation, treatment in a magnetic field, electrophysical treatment, finishing-strengthening treatment, and the application of functional coatings. The authors propose using, as a technological process of the manufacture and repair of parts, a high-speed gas-flame coating, but only based on literature sources without providing a clear argumentation substantiated by experimental research.

One of the promising areas of surface strengthening is the surface-plastic deformation, which is widely used in the printing industry [10]. The study was aimed at identifying common patterns in applying different means for the implementation of strengthening methods. There are some experimental data, based on literary sources, which is not enough to make a decision on applying the chosen technology for the manufacture of parts.

The quality of printed products depends on the quality of a surface layer of the printing cylinder, which can be enhanced through additional machining using the plastic deformation [11]. Formation of a regular microrelief at the surface contributes to an improved contact with a metallic plate, which acts as protection of the cylinder against corrosion. The author uses the methods of systems analysis, a mathematical apparatus for determining a contact area after the deformation of the surface at formation of the tetragonal microrelief, as well as an algorithm to manage the technological process of finishing-strengthening treatment within a control system. The author reports the full cycle of studies starting at manufacturing an offset cylinder of the printing machine to controlling the technological indicators for printed products. Note, however, that this work does not provide any experimental research into the application of a given type of microrelief. This means that the author did not define the way in which the finishing-strengthening treatment affects the geometric and operational properties of a printing cylinder. To overcome one of those problems, paper [12] reported a study of the influence of treatment

modes at vibration knurling followed by chromium-plating on the geometric parameters of the surface. It was shown that owing to the variation in indentation efforts and the radius of a deformative tool it becomes possible to adjust the width and depth of irregularities, as well as the height of inflows. Despite the practical significance of such results, the authors failed to consider in detail the regularities in the process of applying a microrelief of the sinusoidal type; no mathematical notation was given.

Feasibility of the chromium-plating of treated surfaces has been confirmed by the protective capability to corrosion, chemical, erosion resistance, as well as by the improved operational properties of parts that operate under conditions of high wear [13]. The formation of a partial regular microrelief increased wear resistance by 1.5–2 times compared to polished surfaces. Note, however, that a given work does not report any experimental study that could have justified this claim. That means that the authors did not define the influence of technological factors in the process of vibration knurling and the selected type of chromium-plating on durability. From a practical point of view, it could lead to difficulties related to determining the influence of optimal machining modes on performance of parts fabrication.

Paper [14] considered the way in which machining influences the operational properties of cylinders, and discovered that the machining modes largely affect the roughness, microhardness, corrosion resistance of surfaces. The study conducted by the authors suggests that the machining improves the resistance to fatigue and hardness, as well as the microhardness of the machined surface. Note, however, that the paper did not provide the conditions for forming a completely new microrelief of the hexagonal type on parts of cylindrical shape. The authors did not consider the treatment of parts of complex shape and did not study the effect of surface plastic deformation on the printing cylinder.

The technological features of machining lead to difficulties in predicting the modes of treatment for obtaining qualitative parameters of the surface layer. The specified factor is related to the fact that the choice of modes for forming a microrelief depends to a large extent on the properties of a material of the machined surface. To overcome this problem, paper [15] examined the influence of processing technology of surface plastic deformation on the quality parameters for a surface layer. It was shown that the wear resistance of the surface depends on the treatment modes with the smallest wear observed at deforming by a force when a low surface roughness and a high microhardness are ensured; other parameters almost do not affect the durability of the surface.

However, the above treatment methods are not efficient enough to improve the durability of the cylinders' surface; therefore, the operation of the equipment cannot be stable. The result is that the quality parameters for products cannot be steady.

The above is a scientific and technical task, one of the ways to solve which is to apply a comprehensive approach that includes the combination of a vibration knurling method and the subsequent surface chromium-plating.

According to authors of [16], the process of chromium-plating that followed machining the surface has significantly improved microhardness, wear resistance, and corrosion resistance, compared with a coarse-grained sample.

The influence of chromium-plating modes on operational characteristics was described in [17]. It was experimentally determined that high critical loads and good adhesion

indicators are achieved due to the formation at the chromium-plated surface of the denser phase $(Cr, Fe)_2N_{1-x}$. Meanwhile, this finding has not been confirmed by a proper experimental study into the influence of a chromium-plated surface on the operational properties of parts following the formation of a regular microrelief by plastic deformation under the predefined treatment modes.

Thus, there is reason to believe that the lack of certainty on the impact of technological modes of the surface treatment process followed by chromium-plating on the properties of printing cylinders necessitates conducting this research.

3. The aim and objectives of the study

The aim of this study is to establish regularities in the influence of the comprehensive finishing treatment of a printing cylinder, which includes the methods of vibration knurling and surface chromium-plating, on operational properties.

To accomplish the aim, the following tasks have been set:

- to substantiate the application of a comprehensive technology of treating the cylinders of printing machines;
- to conduct an experimental study into the surface-plastic deformation using the processes of vibration knurling and the galvanic chromium plating of surface in order to obtain the maximally developed topography of the working surface of a cylinder;
- to define quality parameters for the surface following the comprehensive treatment of the cylinder, as well as their influence on the durability of the printing cylinder.

4. Technological modes, materials and methods to study samples

We performed experimental research into vibration knurling at the lathe-screw-milling machine 16K20 and a device for knurling external surfaces, fixed in a tool carrier of the machine 16K20 using a special lath. The device has an autonomous electric motor, which enables the oscillations of a deformative tool (DT).

DT materials must have high physical and mechanical properties: hardness, resistance to abrasion, limit strength for compression, low coefficient of friction against a metal, large thermal conductivity and heat capacity, the capability to machine a surface to a minimum roughness [18]. The working parts of indenters-smoothers use a synthetic diamond of spherical surface with a rounding radius from 0.5 to 4 mm. In terms of its characteristics for hardness, strength, elasticity module, thermal conductivity and thermal stability, the technological modes for burnishing can be intensified to improve the performance of treatment [19].

A microrelief was applied by vibration knurling. Treatment modes were selected based on analysis of the scientific literature [15, 18] for different materials: the effort of tool indentation – 50–600 N; spindle rotation frequency – 25–2,000 r/min.; DT eccentricity – 0.2–1.0 mm; DT frequency of oscillations – 1,000–2,000 double step per minutes; DT feed – 0.08–12.5 mm/rev, which corresponds to the technical specifications of equipment that was employed in the research.

To achieve roughness $R_a=0.63\text{...}1.25\ \mu\text{m}$, we polished, prior to vibration knurling, at the circular grinding machine 3M150.

Galvanic chromium-plating was carried out at a manual galvanic installation for solid chromium-plating made by AT Anlagen Technik Service Engineering GmbH (Austria).

Galvanic chromium-plating was conducted under the following modes: electrolyte $CrO_3\approx 290\ \text{g/l}$ and $H_2SO_4\approx 3\ \text{g/l}$; the electrolyte temperature – 57°C ; duration of chromium-plating – 20 min; a current density – $80\ \text{A/dm}^2$, activation duration – 20 s. Following the specified modes of chromium plating, the chromium thickness was $75\ \mu\text{m}$. Hardness was measured by the Brinell's method in line with a standard procedure.

The study was carried out using samples made of structural steel 45 with a carbon content of 0.3–0.5 (premium steel), which is mainly used to produce printing cylinders.

To study the structure, we cut microsections from the samples of a printing cylinder and treated them first with grinding, using the fine grain abrasives, followed by polishing. The abrasives used were powders M20, M14 with grain size from 500 to 2,500. We applied to the surface of a polishing circle a layer of paste, which consists of small particles ($1.0\text{--}7.0\ \mu\text{m}$) of chromium oxide (green), silica gel, stearic and oleic acids, sodium hydrogen carbonate and kerosene. After machining, the microsections were exposed to chemical processing. To etch the surface, we used a 5 % solution of nitric acid in a 96 % ethanol alcohol.

The structure of the sample of a printing cylinder was investigated at the photomicroscope of reflected light Neophot-32 (Carl Zeiss, Jena, Germany) using the methods of optical metallography.

5. Results of studying the structure of printing cylinder, durometric properties, geometric parameters of microrelief and roughness of the surface

Experimental research to determine the influence of an integrated technology on the surface hardening of printing cylinders was carried out for two groups of samples. The first sample (Fig. 1) shows the structure of a printing cylinder. The second sample shows the structure of the printing cylinder after vibration knurling with the formation of a microrelief of the hexagonal type with a concave shape. The next stage was chromium-plating to determine the thickness of chromium (Fig. 2).

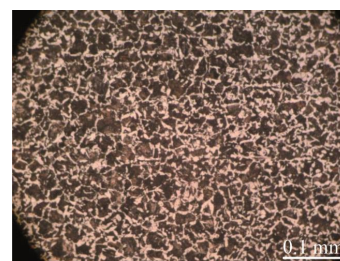


Fig. 1. Structure of the sample of a printing cylinder

The developed technological measures for the integrated treatment of cylinders ensured obtaining the durometric characteristics that are given in Table 1.

Comparison of results of durometric characteristics (Table 1) of the cylinder's surface layer indicates that the durometric indicators without treatment are below than

the similar indicators following the integrated technological process. This is due to the formation of the developed surface, which forms by the method of vibration knurling. The application of chrome unto the formed regular microrelief of the hexagonal type with a concave shape predetermines the strength of adhesion between chromium and the surface of the cylinder due to its netted microtopography. This reduces the abrasive phenomena and improves corrosion resistance.

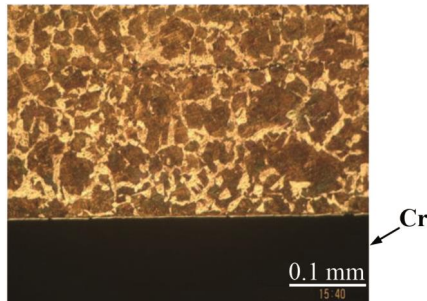


Fig. 2. Structure of samples following the integrated treatment

Table 1

Durometric properties of the material for a printing cylinder

Sample number	Starting hardness HB, MPa	Hardness after integrated treatment HB, MPa	Microhardness after integrated treatment HV, MPa
1	2,270	6,720	8,640
2	2,290	6,560	8,600
3	2,290	6,490	8,630

High ductility of steel in a combination with a significant hardness of the surface ensures high operational properties of the printing cylinder under severe operating conditions. Such conditions include a high rotation frequency of the printing cylinder (250–680 rpm), enhanced loading (1–2 MP) and the aggressive environment: inks, moisturizing and washing solutions, etc.

The results obtained suggest an increase in the surface strengthening, by 1.2–1.6 times, compared with the hardness of the base metal, and by 2.7–3.3 times compared with a chromium-plated surface.

Our durometric research, which produced the positive results, confirms the appropriateness and effectiveness of the application of the integrated technological process, which includes the method of vibration knurling and chromium-plating.

The largest impact on geometric parameters is exerted by such technological modes as the effort of deformation and the radius of DT. To determine the influence of treatment modes, we conducted a series of experiments, some of which are given in Tables 2, 3. All results were processed and visualized in the form of 3D charts that characterize the impact of effort of deformation and the radius of DT on the geometric parameters of a microrelief. Fig. 3 shows the dependence of width (*a*) and depth (*b*) of a groove in the microrelief on a printing cylinder on the effort of deformation and the radius of DT at integrated technological process.

Table 2

Experimental data on the width of a microrelief's groove

Deformation effort <i>P</i> , N	Radius of deformative tool <i>r</i> , mm	Depth of microrelief's groove <i>b</i> , mm
100	2	0.2
150	2	0.23
200	2	0.25
250	2	0.27
300	2	2.95
350	2	0.32
400	2	0.345
450	2	0.37
500	2	3.39
100	2.5	0.215
150	2.5	0.245
200	2.5	0.275
250	2.5	0.32
300	2.5	0.345
350	2.5	0.39
400	2.5	0.42
450	2.5	0.45
500	2.5	0.48
50	3	0.17
100	3	0.22
150	3	0.26
200	3	0.31
250	3	0.34
300	3	0.395
350	3	0.435
400	3	0.48
450	3	0.53
500	3	0.575

Table 3

Experimental data on the width of a microrelief's groove

Deformation effort <i>P</i> , N	Radius of deformative tool <i>r</i> , mm	Depth of microrelief's groove <i>h</i> , mm
50	1	0.00225
100	1	0.0037
150	1	0.005
200	1	0.0062
250	1	0.0074
275	1	0.008
100	1.5	0.0016
150	1.5	0.0027
200	1.5	0.00385
250	1.5	0.005
300	1.5	0.006
350	1.5	0.0072
100	2	0.00075
150	2	0.0018
200	2	0.00285
250	2	0.0039
300	2	0.00495
350	2	0.006
400	2	0.007
450	2	0.008
150	2.5	0.00125
200	2.5	0.00215
250	2.5	0.0032
300	2.5	0.004
350	2.5	0.005
400	2.5	0.0059
450	2.5	0.0068
500	2.5	0.00775

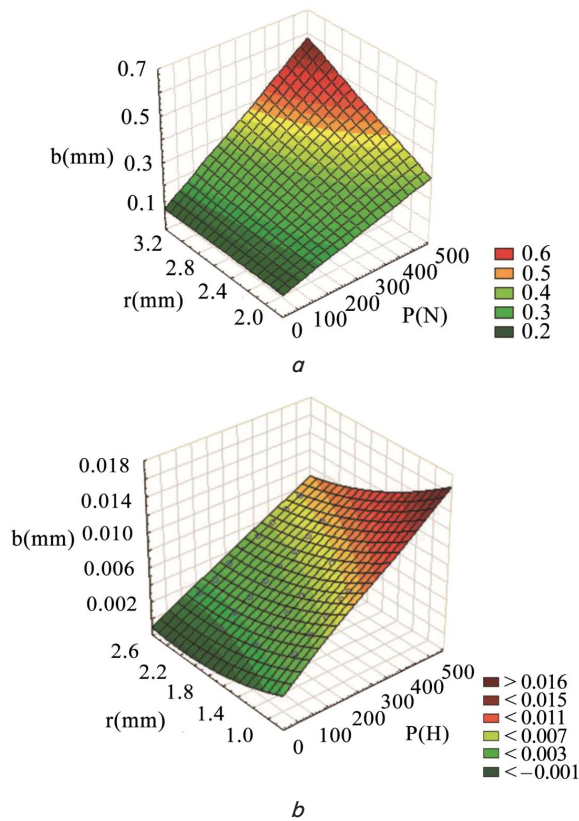


Fig. 3. Impact of indentation effort on the geometric parameters of surface’s microrelief: *a* – width of irregularities; *b* – depth of irregularities

Considering the charts of the surface, one can draw the following conclusions:

- the impact of DT radius and the indentation effort on the width and depth of a microrelief is linear;
- both the width and depth of irregularities increase with an increasing indentation effort at the same DT radius;
- the width of irregularities increases, and the depth of irregularity decreases, with an increasing DT radius if the same indentation effort is applied. In this case, the decrease in the depth of irregularities can be explained by a decrease in specific pressure.

Our study confirms that the geometry of a microrelief depends on the modes of technological process of vibration knurling and the geometrical parameters of DT.

Results from studying the roughness of surface are given in Table 4 and shown in Fig. 4.

Table 4
Surface roughness of specimens of steel 45

No. of entry	Type of surface treatment	Mean arithmetic deviation of profile, $R_a, \mu\text{m}$	Height of profile’s irregularities at ten points, $R_z, \mu\text{m}$
1	Polishing	4.83	27.89
2	Vibration knurling	2.88	16.48
3	Integrated technological process: $P=550\text{ N}, R=2\text{ mm}$	0.63	5.22
4	Integrated technological process: $P=300\text{ N}, R=3\text{ mm}$	1.98	11.86
5	Integrated technological process: $P=450\text{ N}, R=2.5\text{ mm}$	1.21	10.14

Fig. 4 shows profilograms of the surface roughness after vibration knurling with the use of the integrated technology.

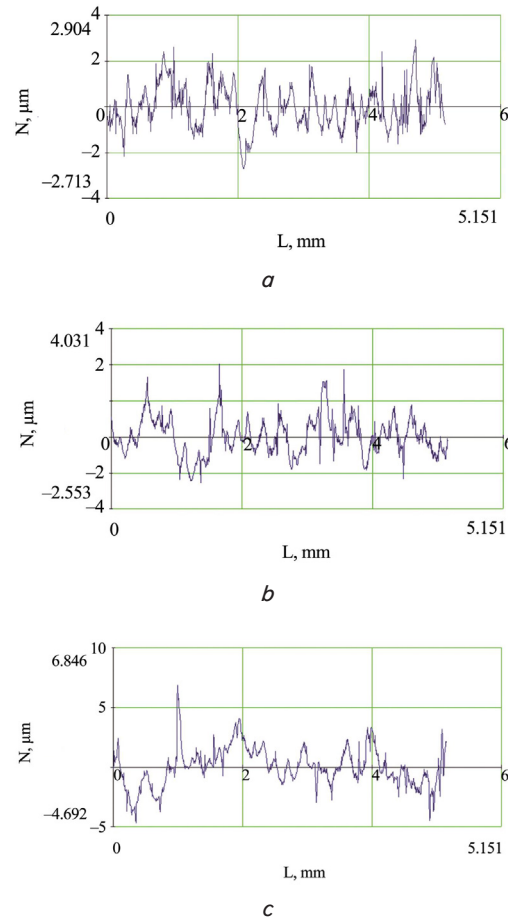


Fig. 4. Profilograms of the printing cylinder’s surface following the integrated technological process: *a* – at $P=300\text{ N}, R=3\text{ mm}$; *b* – at $P=550\text{ N}, R=2\text{ mm}$; *c* – at $P=450\text{ N}, R=2.5\text{ mm}$

We processed the results from experiments to determine the roughness parameters using the methods of mathematical statistics and the theory of probability.

The results from treating the data in Table 2 and Fig. 4 are: if we apply a vibratory tool with a radius of $R=3\text{ mm}$, under a load of $P=300\text{ N}$, the arithmetic mean deviation is observed, $R_a=1.98\ \mu\text{m}$. In this case, the height of irregularities at 10 points – $R_z=11.86\ \mu\text{m}$. If we apply a vibratory tool with a radius of $R=2\text{ mm}$, under a load of $P=550\text{ N}$, the arithmetic mean deviation is $R_a=0.63\ \mu\text{m}$. In this case, the height of irregularities at 10 points is $R_z=5.22\ \mu\text{m}$. If we apply a vibratory tool with a radius of $R=2.5\text{ mm}$, under a load of $P=450\text{ N}$, the arithmetic mean deviation is $R_a=1.21\ \mu\text{m}$ and the height of irregularities at 10 points is $R_z=10.44\ \mu\text{m}$.

The results obtained demonstrate that it is most appropriate to apply a tool with a radius of $R=2\text{ mm}$ under a load of $P=550\text{ N}$, which ensures the best parameters $R_a=0.63\ \mu\text{m}$.

Owing to these parameters, it is possible to obtain the working surface of a printing cylinder with a reduced roughness, due to increasing the smoothness and regularity of heights. It ensures a tight contact between the cylinder and a metallic plate, which is used in the technological process of printing, and prevents the penetration of an aggressive environment.

6. Discussion of results of studying the integrated technology for manufacturing printing cylinders

Our study has proven that the developed integrated technology for manufacturing printing cylinders makes it possible to obtain a surface with the high level of properties. This is illustrated by the fact that the completely new regular microrelief, formed by vibration knurling, is $R_a=0.63 \mu\text{m}$ and depends on the technological modes of treatment: indentation effort of the tool and the radius of DT (Fig. 4).

Such a technology, which at the first stage implies the creation of a completely new microrelief under the following treatment modes: a tool indentation effort – 50–600 N; spindle rotation frequency – 25–2,000 rpm; the eccentricity of a deformative tool – 0.2–1.0 mm; the frequency of DT oscillations – 1,000–2,000 double step per minutes; DT feed – 0.08–12.5 mm/rev, and at the second stage – galvanic chromium-plating (electrolyte $\text{CrO}_3 \approx 290 \text{ g/l}$ and $\text{H}_2\text{SO}_4 \text{ g/l}$; the electrolyte temperature – 57 °C; chromium-plating duration – 20 min.; a current density of 80 A/dm², activation time – 20 s), ensured an increase in the operational properties of the printing cylinder. In particular, hardness increases by 1.2–1.6 times compared with the hardness of the base metal and by 2.7–3.3 times compared with the chromium-plated surface.

However, at present, there are difficulties in the manufacture of printing cylinders. This is predetermined by the large size of the cylinders and the lack of specialized devices for applying vibration knurling. In addition, to apply the integrated technology, it is necessary to know the treatment modes for the application of the proposed microrelief. It is not always possible because the variation of treatment modes changes the shape of a microrelief. However, studies reported in [5, 6, 11, 12, 15] demonstrated that different shapes (type II with the irregularities that partly intersect; type III with the irregularities that completely intersect) make it possible to obtain stable operational properties in parts.

The further research will aim to comprehensively analyze the impact of treatment modes of vibration knurling and chromium-plating on geometric and operational properties, namely, forming the geometric parameters for the working surface and its physical-mechanical properties that could ensure an increase in the durability and reliability of printing cylinders.

The obtained results on geometric parameters of the surface (Fig. 4, Table 2) make it possible to devise recommendations on the effective use of the examined integrated technology for manufacturing printing cylinders for sheet and roll printing machines:

1. In the manufacture of printing cylinders, the finishing operations should involve the following modes of vibration knurling: a tool indentation effort – 50–600 N; a spindle rotation frequency – 25–2,000 rpm; the eccentricity of a deformative tool – 0.2–1.0 mm; the frequency of DT oscillations – 1,000–2,000 double step per minutes; DT feed – 0.08–12.5 mm/rev. That would ensure the surface with roughness parameters $R_a=0.63 \mu\text{m}$.

2. Following the vibration knurling treatment, it is necessary to perform the operation of galvanic chromium-plating under such modes as: $\text{H}_2\text{SO}_4 \approx 3 \text{ g/l}$; the electrolyte temperature – 57 °C; chromium-plating duration – 20 min.; a current density – 80 A/dm², activation time – 20 s when applying the electrolyte $\text{CrO}_3 - 290 \text{ g/l}$, which would increase the hardness by 1.2–1.6 times compared with the hardness of the base metal, and by 2.7–3.3 times compared with the chromium-plated surface.

3. Application of the integrated technology will make it possible to ensure a 2–3-time increase in the service life of printing cylinders.

7. Conclusions

1. Our research has shown that the use of the integrated technology for treating the printing cylinders, which includes a combination of vibration knurling that forms a completely new regular microrelief, followed by chromium-plating, ensures obtaining high quality parameters of the working surface. The surface layer, following the application of the integrated technology, demonstrates an increase in hardness, a decrease in roughness, with the formation of the favorable stressed-strained state of the surface layer. The integrated technology extends operational term of printing cylinders. This in turn prolongs durability of the printing cylinder operation, thereby providing stable operation of the equipment. In addition, it contributes to stable progress of the technological process and improves quality of the printed products. Application of the integrated technology when manufacturing printing cylinders makes it possible to prolong durability of the cylinders by 2–3 times in contrast to the printing cylinders that are not treated with the proposed integrated technology.

2. Comparison of experimental results (Table 2) revealed that following the vibration knurling and galvanic chromium-plating of the surface the roughness parameters of $R_a=0.63 \mu\text{m}$ are better than those after polishing where $R_a=4.83 \mu\text{m}$. This is due to the formation of the developed surface, which is created by the method of vibration knurling. The application of chrome onto the formed regular microrelief of the hexagonal type with a concave shape ensures the high density of alignment between the cylinder and a metallic plate. This prevents the penetration of aggressive environment (inks, wetting and washing solutions, anti-set-off powders, etc.). This technology makes it possible to avoid the spread of corrosion.

3. Our study has shown that the use of a vibratory tool with $R=2 \text{ mm}$ under a load of $P=550 \text{ N}$ makes it possible to obtain high characteristics of the surface roughness, namely $R_a=0.63 \mu\text{m}$ and $R_z=5.22 \mu\text{m}$. This reduces by 7.6 times the cylinder's surface roughness without treating with the surface-plastic deformation. The geometry of a microrelief is significantly affected by the modes of the technological process of vibration knurling and the geometric parameters of DT. Thus, to increase the depth of strengthening, it is necessary to reduce the DT radius and to increase the indentation effort.

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