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SURFACE ROUGHNESS OF NEW SELF-LUBRICATING ANTIFRICTION COMPOSITES FOR PRINTING APPARATUS DURING BORAZON GRINDING

The article presents the experimental and theoretical results on the influence of fine borazon grinding modes on the formation of the roughness parameter R_a of cylindrical working surfaces of new antifriction composite parts based on utilized and regenerated R6M5 high-speed steel grinding waste with the CaF_2 solid lubricant additions, which are intended to equip units of printing machines' offset cylinders.

Keywords: antifriction composite part; steel waste; borazon grinding wheel; granularity; bond; grinding modes; roughness; units of printing machines.

Introduction

In modern conditions, the publishing and printing industry is undergoing fundamental technological changes and is in a stage of rapid development.

The widespread demand for various types of printed products, characterized by great variety, nomenclature and high product quality requirements, not only contributes to the development and improvement of classical and long-established printing methods, but also leads to the fact that great importance is attached to the reliability, durability and performance of the printing equipment itself. The quality of printed products directly depends on the stability of such equipment.

One of the main factors that determine the durability and productivity of printing equipment is friction parts, primarily antifriction parts, namely their ability to resist various types of contact interaction [1–5].

The development of printing machinery and the equipping of printing equipment with various kinds of complex mechanisms and devices adds great importance to the problem of increasing the wear resistance of parts in machine friction units.

Intensive wear of mating parts in friction units leads to a loss of mechanisms' kinematic accuracy, tightness violation of the machines' working space, violation of the normal lubrication mode, etc., resulting in a decrease in equipment productivity, which leads to a decrease in product quality.

The above applies to a wide variety of printing equipment, the operating conditions of which vary within a wide range of load factors — from light operating conditions at low speeds and loads to heavy operating conditions associated with high rotational speeds and loads, in particular, such machines as Heidelberg GTOZ-S52, MAN Roland 202, Komori GL 440, MAN Roland 205 E OB, Heidelberg SM 52-5+LX, etc.

In solving the problems of increasing the reliability and durability of printing equipment units, along with improving the design of machines and mechanisms, rational choice of materials for their parts, a significant place is given to the development of new technological processes for the manufacture of parts, ensuring the necessary operational properties of the material from which they are made, and technological aspects of improving the quality parameters of the parts' working surfaces that perceive the main load in the process of contact interaction and ultimately determine service life of both individual parts, units and the machine as a whole [1–5].

As a rule, the destruction of friction parts under operating conditions begins from their surface, especially if there are areas of stress concentrators on it. At the same time, the service life of antifriction parts, such as bearings, is affected by the type of external load, physical, mechanical, and antifriction properties of their material, operating speed and temperature, environment, geometry of the part and the condition of its surface layer, roughness of the working surface R_a, the magnitude and nature of residual stresses, and other factors [6–13].

One of the criteria for assessing the quality of antifriction parts for friction units of printing equipment is not only the dimensional accuracy and roughness of the working surfaces, but also the physical and chemical properties of the surface layer of the part material: the composition and properties of friction films (so-called secondary structures), the microgeometry relief, which are of primary importance for ensuring the reliability and durability of the part [1, 2, 10–17].

For this reason, the main tasks at the present stage, together with the continuous improvement of technological processes that ensure the accuracy of the size and shape of parts, are the creation of new and improvement of existing technologies for the synthesis of materials with subsequent fine processing of parts made of them to give the surface layer the necessary functional properties.

To significantly increase the antifriction parts' service life, primarily sliding bearing bushings in printing equipment' units, new self-lubricating sliding bearing bushings made of new composite materials synthesized from regenerated grinding wastes of different alloy steels with CaF_2 solid lubricant additives have been synthesized and recommended for production [1–3, 5, 16, 17].

The self-lubricating antifriction composites developed by the authors of [5] based on alloy steels grinding waste with CaF_2 solid lubricant additives have demonstrated high functional properties under severe operating conditions.

In addition, when using self-lubricating composite materials, there is no need for additional lubrication with liquid oil, and this is the direction of modern research in materials science.

It should also be emphasized that technology of contact surfaces' mechanical finishing and relevant quality parameters cause a direct influence on the wear resistance of printing equipment' antifriction parts.

This is due to the fact that high quality parameters of working surfaces are the determining prerequisite for the formation of antiseize lubricating films in the friction process. Therefore, the faster the formation of such antifriction films, the more stable and reliable the operation of the entire unit, and thus the entire printing machine, will be.

That is why it is extremely important to ensure high quality parameters of the working surfaces of such parts. This is usually achieved by using fine machining methods [1–3, 10–13].

Taking into account the above, the authors of the article paid great attention to the use of precision processing methods of new composites' surfaces. For this purpose, a series of experimental studies were performed using the methods of fine elbor, cubonite grinding, and precision machine finishing of the composite parts' surfaces [1, 2, 5–9, 16, 17].

The obtained data showed encouraging results in terms of surface quality parameters, which made it possible to recommend certain technological modes for fine machining of composite parts from some steels types grinding waste.

Unfortunately, the regularities of the purposeful and stable formation of surface quality parameters of new composite antifriction parts from waste intended for equipping printing machines still remain unclear. This leads to their rapid wear, failure of printing equipment, and requires the reserve parts large number.

At the same time, borazon grinding tools [18] are widely used in industrial enterprises of Ukraine, which are effectively applied in mechanical engineering and ensure the machined parts' high quality parameters.

Unfortunately, the processes of fine borazon grinding of new self-lubricating antifriction composite friction parts made from recycled materials, in particular, from regenerated steel grinding waste, remain unexplored.

Therefore, there is a need to perform wider experiments involving the use of different types of abrasive tools to be able to formulate specific recommendations for the use of the fine machining particular method for new types of composite parts.

This will make it possible to compare the effect of different tools on surface quality parameters and determine their advantages and disadvantages during machining of new composite parts to obtain the highest possible quality parameters.

The above arguments motivated the authors of the article to investigate the processes of fine borazon grinding of sliding bearing bushings made from new composite materials based on R6M5 tool steel grinding waste, and on this basis to create new technological processes for efficient fine machining of such parts for equipping high-speed printing equipment.

Objective of the work

The objective of the study is to determine the effect of borazon grinding technological modes on the quality parameters of cylindrical contact surfaces of self-lubricating composite parts based on R6M5 tool steel recovered industrial grinding waste with CaF_2 solid lubricant additives intended to equip offset cylinder units of printing apparatus.

The achievement of this purpose will make it possible to make generalizations about the use of the borazon grinding technological scheme for working surfaces fine processing of new composites from industrial grinding waste, which can be effectively used to manufacture new self-lubricating parts for printing machines' units. This will make a significant contribution to increasing the reliability of the above equipment, which will improve the stability of the printed products quality.

Experimental procedures and research methods

The objects of study were the fine borazon grinding processes and their influence on the quality parameters of the new antifriction composite friction parts' working surfaces.

The subject of the study included samples of self-lubricating composite parts based on R6M5 tool steel grinding waste with CaF_2 solid lubricant additives.

The samples for the experiments were obtained using the synthesis technology developed by the authors of this article [5] on the basis of pre-cleaned and reduced grinding powders of R6M5 steel waste, to which CaF_2 solid lubricant powders were added at the stage of manufacturing the initial charge in the amount of 4.0–8.0 wt.%.

Experimental studies on fine borazon grinding were performed on a high-precision machine FF-350 'Abawerk' (Germany).

Borazon wheels with rubber-bakelite GB1, bakelite B1, ceramic K1, and metal M1 bonds of different grain sizes Bo10GB1, Bo5GB1, BoM28B1, BoM28GB1, BoM20GB1, BoM14GB1, BoM10GB1, BoM7GB1, Bo5B1, Bo5K1, Bo5M1, and BoM28K1 were used in the experiments.

For comparison purposes, fine grinding experiments were also performed using green silicon carbide abrasive wheels 63SM14GI (foreign analogue — WGC14GI) and 63SM7GI (foreign analogue — WGC7GI).

The experimental results were processed using statistical methods, in particular, the Student's method [1, 2, 10, 13].

The analysis of the surface quality parameters of new antifriction parts after fine borazon grinding was carried out by optical profilometry using an optical profilometer ProfilControl 7S (Pixargus GmbH). This profilometer can work with a large array of data to measure the geometry of flat, round internal and external surfaces. The measuring field of the profilometer is up to 250 mm, the measurement accuracy is from micrometers to nanometers [6].

Research results and discussion

The list of tasks included studying the parameters of surface roughness during fine borazon grinding of new composite bearing bushings based on grinding waste of R6M5 steel with CaF_2 solid lubricant additives and determining the effect of grinding wheel granularity, tool bond type and main cutting modes on the quality characteristics of the machining surfaces of the studied parts samples.

The research results of the surfaces' fine borazon grinding of composites based on R6M5 steel waste have been presented in table 1.

Data analysis table 1 shows, that the roughness parameter R_a changes with the change of the processing factors, namely, the grinding depth t, the cross feed Scf and the longitudinal feed Vp.

The processing of the experiments using statistical methods, in particular, using the Student's method showed, that the studied aggregates are significantly different for the case of dependent variables of the processed samples at fixed values of two variables (e.g., Vp and t) and at a variable third variable (e.g., Scf).

Table 1

Roughness parameter R_a at fine flat borazon grinding of samples from the composite R6M5+6%CaF_2

Cross feed, Scf, mm/double stroke	Product speed (longitudinal feed), Vp, m/min	Grinding depth t, mm		
		0.002	0.01	0.05
		Roughness R_a, μm		
0.1	2	0.205	0.275	0.315
	5	0.257	0.284	0.337
	10	0.273	0.321	0.391
0.2	2	0.305	0.348	0.405
	5	0.337	0.373	0.485
	10	0.350	0.403	0.517
0.5	2	0.380	0.426	0.579
	5	0.407	0.480	0.629
	10	0.415	0.500	0.672
1.0	2	0.438	0.527	0.721
	5	0.473	0.545	0.773
	10	0.525	0.607	0.838

Note: Machine — FF-350 'Abawerek' (Germany), abrasive — borazon (Bo), granularity 14 μm on bakelite-rubber bond, wheel speed — 22 m/sec, processing — without cooling.

Similar results were obtained when comparing any samplings for cross feeds of 0.1–1.0 mm/double stroke and product speeds of 2–10 m/min.

It is to be noted, that as the difference between the compared samplings' feed rates and the difference between the product's speeds increases the difference between the tabular and calculated Student's distribution also increases.

This allows us to conclude that during fine borazon grinding there is a relationship between the surface roughness parameter R_a and the cutting depth t: $R_a = f(t)$, at $Scf = {}$ $= const$, $Vp = const$.

Using the mathematical statistics methods, it is easy to show, that there is a relationship between the parameter R_a and the cross feed Scf:

$$R_a = f\,(S_{поп.}),\ V_в = const,\ t = const.$$

A similar statistical relationship exists between the roughness parameters R_a and the product's speed Vp: $R_a = f\,(t)$ at $Scf = const.$ and $t = const.$

The study of the factual relationship between the surface roughness and the operating factors of borazon grinding by correlation analysis allowed us to establish quantitative correlations between the studied factors.

To obtain the multiple correlation equation, the correlation coefficients of pairwise dependencies were found on the basis of the experimental data R_a — t; R_a — Scf; R_a — Vp; Scf — Vp; Scf — t; t — Vp.

The calculations show there is a close linear relationship between the factors R_a, Scf, Vp and t. Formal mathematical analysis shows that between the factors Scf — t; t — Vp and Scf — Vp connection is absent.

The obtained correlation coefficients rc are far from 1. This indicates the roughness parameter R_a is influenced by other factors in addition to the factor for which r_c was determined.

The value of the correlation coefficients indicates the influence level of the studied factors on the surface roughness.

The greatest influence on the roughness parameter R_a is exerted by the cutting depth t and the cross feed Scf, and the least influence is exerted by the product's speed Vp.

The multiple correlation equation for the studied factors has the form:

$$R_a = 0.253 \times Scf + 5.21 \times t + {} \\ + 0.0053 \times Vp - 0.0437. \quad (1)$$

Analysis of formula (1) shows the cutting depth t and the cross feed Scf have the greatest effect on the roughness parameter R_a, the product's speed Vp has the least effect.

This model accuracy can be improved by dividing the entire range of plane grinding modes into two groups:

1st group:

— the cross feed Scf = 0.01–0.02 mm/double stroke;

— the grinding depth t = 0.002–0.100 mm;

— the product speed Vp = 2.0–4.0 m/min.

2nd group:

— the cross feed Scf = 0.5–1.0 mm/double stroke;

— the grinding depth t = 0.02–0.05 mm;

— the product speed Vp = 5.0–15.0 m/min.

After some transformations, equation (1) can be transformed and take the form:

1st group:

$$R_a = 0.2551 \times Scf + 5.21 \times t + 0.0049 \times Vp - 0.0038; \quad (2)$$

2nd group:

$$R_a = 0.2551 \times Scf + 5.21 \times t + 0.0049 \times Vp - 0.0533. \quad (3)$$

The R_a values calculated by formulas (2) and (3) differ from the experimental ones by 12–15 %, which allows us to use the formulas for practical calculations.

For example, knowing the specific values of Scf, t and Vp for a specific borazon tool, it is possible to approximately determine what the R_a parameter will be and evaluate the acceptability of the borazon grinding selected modes in terms of the requirements for antifriction composite parts.

It should be noted, the obtained conclusions are confirmed by fine borazon grinding with the wheels of different grain size M50, M28, M14 and M7. The corresponding experimental data have been shown in table 2 in comparison with green silicon carbide wheels.

Data in table 2 allows us to form important practical conclusions, that borazon wheels with a grain size of 7 μm provide minimal surface roughness R_a in the investigated range of 7–100 μm grain sizes for a borazon tool. These results can be explained by the grinding theory general positions [1, 2, 10–13, 17, 19].

It can be seen (table 2) that with an increase in tool grain size, the surface roughness increases due to an increase in the cross-

Table 2

Influence of tool grain size on the R_a surface roughness parameter at fine flat borazon grinding of composite workpiece based on R6M5+6%CaF_2

Abrasive wheel, foreign analogue (BS EN 12413, BS ISO 525)	Roughness R_a, μm
Bo10 GB1	0.907
Bo5 GB1	0.869
BoM28 GB1	0.261
BoM20 GB1	0.219
BoM14 GB1	0.205
BoM10 GB1	0.195
BoM7 GB1	0.163
63SM14GI (WGC14GI)	0.621
63SM7GI (WGC7GI)	0.358

Note: Machine — FF-350 ‘Abawerk’ (Germany); grinding modes: wheel speed —22 m/sec, longitudinal feed (product speed) — 2 m/min; cross feed 0.1 m/double stroke; cutting depth — 0.002 mm; processing — without cooling.

section a_z of the composite layer cut, and vice versa — the roughness parameter R_a decreases with a decrease in grain size.

The improvement in R_a roughness can also be explained by the fact, that the grains of the borazon tool have a sharper shape, i.e., a smaller angle of sharpness at the grain top and a smaller rounding radius of a single grain compared to other abrasive grains, such as electro-corundum (aluminium oxide) and green silicon carbide grains (table 3).

As a result of the experimental data mathematical processing, a correlation equation for the relationship between the roughness parameter R_a and the grain size A of the borazon tool was obtained, which has the following form:

$$R_a = 0{,}0052 \times A - 0.0069. \quad (4)$$

Thus, knowing the grain size A of the borazon grinding wheel, it is possible to calculate the roughness parameter R_a and make sure, that the selected tool will meet the quality requirements for the working surfaces of composite friction parts.

An important aspect of the study was to determine the effect of the borazon wheel's bond composition on the surface roughness parameter R_a (table 4).

Analyzing the data in table 4, it can be seen that roughness parameters R_a the best values of machined surfaces of parts made from a new antifriction composite based on high-speed steel R6M5+6%CaF_2 are provided by borazon wheels with a rubber-bakelite bond GB1.

This can be explained by its more elastic capacity and, thus, when grinding under the action of the cutting forces components, each grain seems to be dampened in the direction of the elastic environment of the rubber-bakelite bond. This causes the actual reduction of the

Table 3

Average values of cutting grain angle geometry for different abrasive materials [1, 2, 10–13, 17, 18]

Abrasive material	Abrasive wheel, foreign analogue (BS EN 12413, BS ISO 525)	Grain top geometry	
		Rounding radius, ρ, μm	Angle at the top, deg.
Borazon	Bo10/8	2.21	57.0
	Bo6/5	1.13	52.0
	BoM14/10	0.8–0.82	50.0
Green silicon carbide	63C10	7.5	95.1
	63CM28	2.3	92.1
	63CM14	2.0	90.6
Electro-corundum white	23A10	9.5	98.3
	23AM28	2.7	94.7
	23AM14	2.4	92.5

cutting depth. Thus, the conditions for forming the roughness of the machined surface change and, as a result, the roughness parameter R_a decreases, which is one of the main factors characterising the surface quality after fine borazon grinding.

It should be noted that these conclusions are based on the analysis of actual data obtained during an experimental study using different bonds (bakelite, ceramic, metal, rubber-bakelite) and different grain sizes of the borazon wheel (100, 28, 14, 10 and 7 µm).

Taking into account the fact, that physical phenomena in the cutting metals process are fundamentally similar for flat, external and internal circular grinding, the experimental study of the processes for fine external and internal circular borazon grinding of an antifriction composite based on R6M5 steel grinding waste was carried out taking into account the above results.

In particular, the experiments were carried out using Bo borazon tools with a grain size of 14–28 µm, which were formed into grinding wheels with a rubber-bakelite bond (GB1). It should be noted that the external fine borazon circular grinding was performed on a precision machine AS-250 ‘Werkzojt’ (Germany), and for internal grinding, a precision internal grinding machine of ultra-high accuracy SS-125 ‘Studder’ (Switzerland) was used. The main research results have been presented in figs. 1, 2.

Table 4

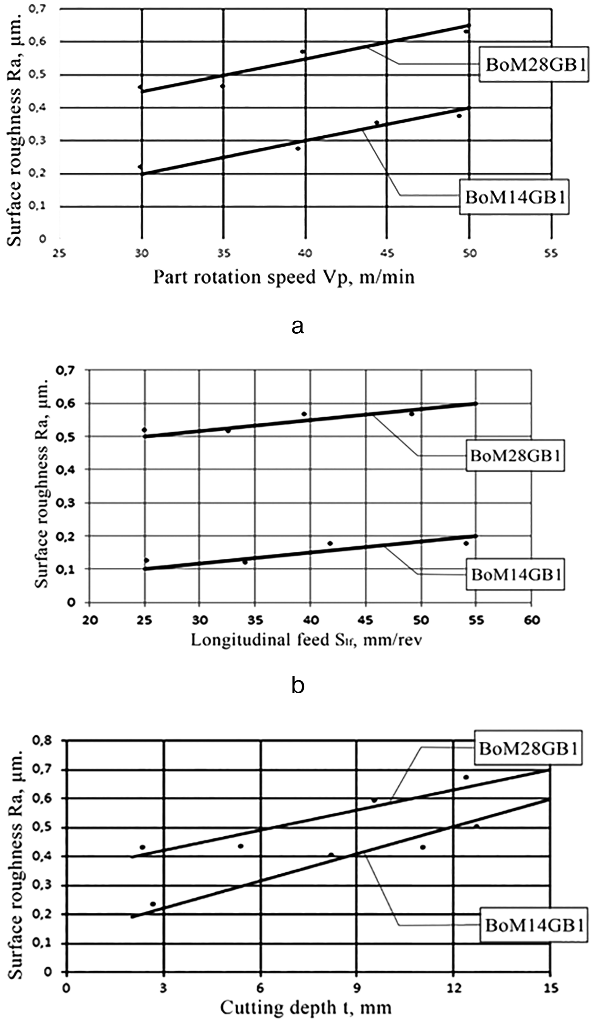
Effect of the borazon wheel’s bond on the surface roughness parameter R_a of R6M5+6%CaF_2 composite at flat grinding

Abrasive tool	Wheel’s bond material	Roughness R_a, µm
Bo5GB1	Rubber-bakelite GB1	0.273
Bo5B1	Bakelite B1	0.316
Bo5K1	Ceramic K1	0.409
Bo5M1	Metal M1	0.415
BoM28B1	Bakelite B1	0.282
BoM28GB1	Rubber-bakelite GB1	0.264
BoM28K1	Ceramic K1	0.298
BoM14B1	Bakelite B1	0.218
BoM14GB1	Rubber-bakelite GB1	0.207
BoM14K1	Ceramic K1	0.302
BoM10GB1	Rubber-bakelite GB1	0.198
BoM7GB1	Rubber-bakelite GB1	0.168

Note: Machine FF-350 ‘Abawerk’ (Germany); grinding modes: wheel speed — 22 m/sec, longitudinal feed (product speed) — 2 m/min; cross feed 0.1 m/double stroke; cutting depth — 0.002 mm; processing — without cooling.

The analysis of experiments (fig. 1) shows, that the surface roughness of parts made of new composites during fine external circular borazon grinding (as well as during flat borazon grinding) is significantly affected by the cutting modes: product speed Vp, longitudinal feed rate Scf and cutting depth t, as well as the grain size and bond material of the borazon tool.

Analogous to flat borazon grinding, the best quality of the machined



a

b

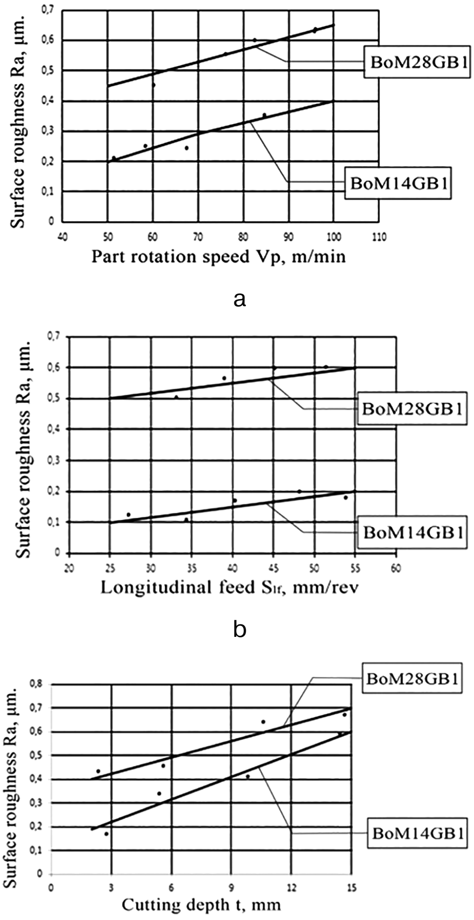
c

Fig. 1. Dependence of surface roughness parameters R_a of a workpiece made from R6M5+6%CaF_2 composite on the modes of fine borazon grinding Vp, Scf and t during external circular grinding (borazon wheel speed — Vw = = 30 m/s): a — Scf = 5 mm/rev; t = 2 μm; b — Vp = 30 m/min; t = 2 μm; c — Vp = 30 m/min; Scf = 5 m/rev

external surfaces of composite cylindrical parts (in terms of the R_a roughness parameter) with fine borazon circular external grinding is ensured by the use of tools based on borazon (Bo) on a rubber-bakelite bond (GB1), with a grain size of 14–28 μm (M14–M28) and the use of fine grinding modes (Vp $\rightarrow$ min; Scf $\rightarrow$ min; t $\rightarrow$ min).

Similar results were obtained during fine round internal borazon grinding of the friction surfaces of antifriction bushings made of new composites based on waste tool steel R6M5 (fig. 2).

Analysis of fig. 2 shows, that the depth of cut t, longitudinal feed Scf and workpiece rotation speed Vp have the greatest influence on the



a

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Fig. 2. Dependence of the surface roughness parameters R_a of a workpiece made from R6M5+6%CaF_2 composite on the modes of fine borazon grinding Vp, Scf and t during fine circular internal grinding (borazon wheel speed — Vw = 40 m/s): a — Scf = 30 mm/rev; t = 2 μm; b — Vp = 50 m/min; t = 2 μm; c — Vp = 50 m/min; Scf = 30 mm/rev

machining surface roughness parameter R_a, when using borazon wheels based on borazon Bo with a grain size of 14–28 µm on a rubber-bakelite bond for precision internal borazon grinding of parts made from a new composite based on R6M5 tool steel waste.

The best results in terms of the R_a quality parameter (i.e., minimum surface roughness) are achieved by fine borazon grinding modes, namely, the minimum possible (in terms of the machine's technical capabilities) cutting modes — grinding depth, longitudinal feed rate and workpiece rotation speed.

Summing up the series of the performed studies, important scientific and practical conclusions can be formulated.

Conclusions

1. For the first time, the fine borazon grinding processes of new self-lubricating antifriction composites have been studied on the example of R6M5+6%CaF_2 composite synthesised based on the utilised and regenerated R6M5 high-speed steel grinding waste. The results showed, that the use of a borazone tool for fine machining allows obtaining working surfaces' high quality parameters for parts made of such composites. This contributes to the stabilisation and reliability of the printing machine's friction unit.

2. It has been demonstrated, that the main regularities for fine borazon grinding of the studied composites coincide with flat, round external and internal grinding.

3. It has been found, that the surface roughness parameter R_a is significantly affected by the grain size, bond material of the borazon wheel, and modes of fine borazon grinding.

4. Minimisation of the surface roughness parameter R_a is ensured by using grinding wheels made of borazon Bo with a grain size of 14–28 µm on a rubber-bakelite bond and fine cutting modes, namely:

— for flat borazon grinding: wheel speed — 22 m/s, longitudinal feed rate — 2 m/min, cross feed rate — 0.1 mm/double stroke; cutting depth —2 µm;

— for external circular borazon grinding: abrasive wheel speed — 30 m/s, workpiece speed (product's speed) — 30 m/min, longitudinal feed rate — 30 mm/rev, cutting depth — 2 µm;

— for internal circular borazon grinding: wheel speed — 40 m/s, workpiece speed (product's speed) — 50 m/min, longitudinal feed rate — 30 mm/rev, cutting depth — 2 µm.

5. The obtained results open up opportunities for a significant improvement in the stability and reliability of the operation the printing equipment' heavily loaded friction units due to the lubricating films rapid formation on the parts' working surfaces and a run-in time reducing for the contacting parts. This is facilitated by the high quality parameters of the parts' surfaces after borazon fine grinding.

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Стаття представляє результати досліджень з впливу режимів тонкого боразонового шліфування на формування параметру шорсткості Ra циліндричних робочих поверхонь нових антифрикційних композитних деталей на основі утилізованих і регенерованих шліфувальних відходів швидкорізальної сталі Р6М5 з додаванням твердого мастила CaF_2, що призначені для оснащення вузлів офсетних циліндрів друкарської техніки.

Ключові слова: антифрикційна композиційна деталь; сталеві відходи; боразоновий шліфувальний круг; зернистість; зв'язка; режими шліфування; шорсткість; вузли поліграфічних машин.

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