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Effect of Surface Treatment on the Wear of Spindle-Neck Coating with a Collapse Balloon Crown

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Abstract
The paper presents test results of the effect of the surface treatment type on the wear of spindle-neck coating with a collapse balloon crown of ring spinning frames within industrial conditions of mating with yarn. The tests comprised measurements, using the optical method, of spindle-neck coating produced from EN AW-2024 (AlCu4Mg1) alloy, and subjected to, in the first variant, the operation of burnishing, and in the second variant – the burnishing operation followed by hard anodic oxidation and grinding with abrasive paper having a grain size of 600. Moreover, to be able to do it, the circularity deviation of the cylindrical part of the neck coating at the same distances from the face of the crown were measured with the use of a Taylrond 365 circularity tester. Next, based on the contours of circularity obtained, a contour of cylindrical shape of the spindle-neck coating, both burnished and burnished and anodic oxidized, brand-new and after an operational time was prepared. An assessment of the topography and microphotography of the oxide layer of the spindle-neck coating was performed, both in brand-new condition and after an operational time. Analysis of the wear and tear process, as well as the thickness of the oxide layer, in brand-new condition and after an operational time, confirmed that the oxide layer assures a wear-resistance several times higher. As a result of the hard anodic oxidation implemented, equalisation of the durability of the spindle-neck coating occurres with the durability of the bearing system.

Key words: *collapse balloon spindle, surface treatment, operational wear.*

Introduction

The results presented in this paper are a continuation of research on the wear of a metal - yarn tribological pair. In the previous work [1], observations and measurements of the wear of spindle-neck coating with a collapse balloon crown produced from EN AW-2024 (AlCu4Mg1) alloy, subjected to grinding first with abrasive cloth of 80 and next with cloth of 150 grain size, and finally polishing with de-sludged abrasive paper. Evaluation of the spindle-neck coating's wear was performed in industrial conditions for two yarn mixture types: 20 - 30% polyester + 70 - 80% wool and 10% wool + 90% polyamide. Due to the fact that the durability of the spindle-neck coating after grinding was approximately 2.5 times lower than that of SKF's (Germany) bearing insert, new surface processing was developed consisting in the following operations: burnishing, hard anodic oxidation and next grinding with corundum grinding sandpaper - PS20, having a grain size of 600.

The aim of the research presented in this paper was determining the influence of the type of surface finish on the wear of spindle-neck coating produced from EN AW-2024 (AlCu4Mg1) alloy, and subjected to, in the first variant, the operation of burnishing, and in the second variant – the burnishing operation followed by hard anodic oxidation and grinding with abrasive paper having a grain size of 600.

Method of evaluating the wear of spindle-neck coating with a collapse balloon crown

We produced and installed, on a PG-7A ring spinning frame, two series of spindles, 160 pieces each, with a neck coating manufactured according to the following finishing technologies [2]:

- burnishing with the use of a roller of 40 mm diameter and radius in the axial cross-section of 9 mm, with a pressure load of 0.30 kN, feed rate of 0.10 mm/rotation, neck coating tangential velocity of 2.07 m/s, and lubrication with grade 10 machine oil. The surface roughness after burnishing, described by parameter $R_{a,}$, amounted to 0.18 ÷ 0.23 µm.
- burnishing followed by hard anodic oxidation and grinding with PS20 corundum abrasive paper with a grain size of 600. The surface roughness, described by parameter $3R_a$, amounted to 1.05 ÷ 1.35 µm.

Hard anodic oxidation [3] was performed in a solution of electrolyte composed (gravimetrically) of: sulfuric acid – 6%, sulfosalicylic acid – 3%, lactic acid – 2%, glycerol – 2%, aluminum sulfate – 0.1%, and distilled water as the remainder. Mixing of the electrolyte bath was performed with the use of compressed air. The conditions of anodic oxidation were as follows: 25 ÷ 60 V direct current, current density - 3 A/dm^2, temperature of electrolyte solution - about 6 °C, duration of the anodic oxidation - about 60 min. Before hard anodic oxidation, the following preparations of the surface were performed: degreasing in organic solvent and etching in 5% solution of sodium hydrate for two minutes [2].

Wear tests of the spindle-neck coating with a collapse balloon crown (***Figure 1***), due to contact with yarn, were carried out with the use of the metric method [4] on ring spinning frames within industrial conditions. Measurements of the wear during the spinning of blends, described in ***Table 1***, were carried out at three month intervals using a micrometer with a range from 0 to 25 mm and scale interval of 0.002 mm, especially adapted to such purposes. The value of wear, Δz, was determined as the maximal difference between five measurements of the neck coating's diameter, performed every 60º at a distance of 5 mm from the crown.

Moreover, to assess the wear of the spindle-neck coating, measurements of the circularity deviation (scanning of the neck coating diameter) were made with the use of a Taylrond 365 circularity tester, made by Taylor Hobson, equipped with a ball-type gauging point having a radius of R = 0.5 mm. Measurements of circularity deviations were performed at a distance of 1 ÷ 16 mm from the crown in cross-sections spaced at a distance of

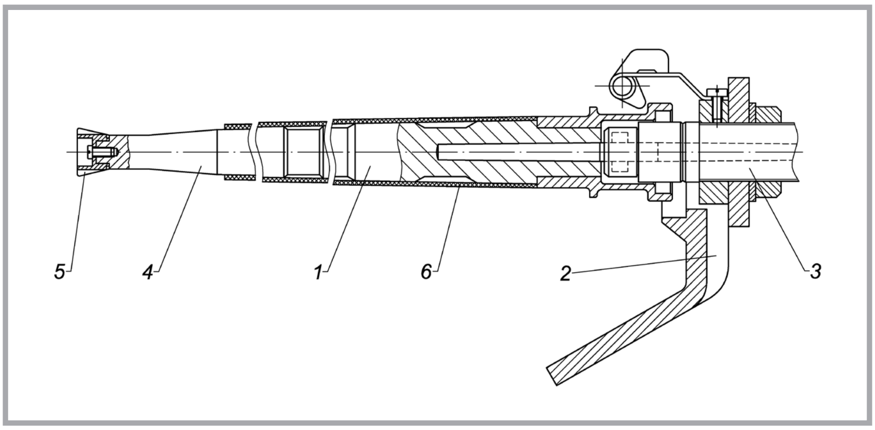

***Figure 1**. Complete spindle with a collapse balloon crown of the PG-7A ring spinning frame: 1 – spindle coating, 2 – brake, 3 – spindle bearing unit, 4 –spindle neck made of aluminum alloy AlCu4Mg1, 5 – spindle crown, 6 – bobbin [1].*

***Table 1.** Types of yarn processed on the ring spinning frame, their characteristics and percentage of duration of their processing.*

Type of processed raw material	Linear mass of the yarn, tex	Number of yarn twists per 1 meter, 1/m	Spindle rotation speed, rpm	Percentage duration of their processing, %
Polyester 30% + wool 70%	100; 125	390; 360	10000	38.8
Polyester 20% + wool 80%	150	280	8000	2.6
Polyester 30% + viscose 40% + wool 30%	100	390	9000	20.6
Wool 100%	110	360	7500	2.0
Polyamide 20% + wool 80%	125	310	8000	36.0

every 0.5 mm (the neck after burnishing) and 1 mm (the neck after anodic oxidation), for brand-new and after an operational time spindles. Next, as a result of the strategy of circularity contour measurement implemented, the contour of the cylindrical shape of the spindle-neck coating was plotted after burnishing, and after burnishing followed by anodic oxidation, brand-new and after an operational time [5, 6].

To assess the effect of displacement of yarn on the surface of the spindle-neck coating, measurements of the surface topography at a distance of about 5 mm below the crown were also performed. The following parameters of 3D geometric structure of the surface were measured [7 - 9] (brand-new and after-an-operational-time spindles): amplitude-type parameters – arithmetic mean of the surface ordinates S_a, mean square deviation of the surface S_q, maximum height of the surface peaks S_p, maximum height of the surface S_t; parameters of the surface curve of the materials part: depth of the surface core S_k, reduced height of the surface peaks S_{pk}, reduced depth of the surface cavities S_{vk}, load capacity part of the surface peaks S_{mr1}, load capacity part of the surface cavities S_{mr2}. Measurements of selected SGP 3D parameters were performed with the use of a Pethometer Concept profile gauge made by the Mahr company. Measurements of the topography were carried out on surfaces with dimensions of 2.0 mm × 2.0 mm, at intervals of 5 μm.

Micro-hardness measurements were performed on skew micro-sections, cut at an angle of 1º 30’ (0.026 rad), using a Leitz Wetzlar micro-hardness tester, under an intender’s load of 0.245 N. Microstructure photos of the oxide layer and microphotographs of the neck coating’s surface after burnishing treatment were made with the use of a Neophot 32 microscope, while microphotographs of the neck coating’s surface after burnishing operations and followed by anodic oxidation were taken with the use of a Jeol JSM-5500LV scanning electron microscope.

Wear of the spindle-neck coating with a collapse balloon crown during the spinning process

During the spindle’s operation, the yarn moves at a velocity of 25 ÷ 35 m/min as a result of local friction due to an insufficiently smooth passage (‘jumping’) from one notch of the crown to the adjacent one (***Figure 2.a***), and occasionally as a result of the ‘outstaying’ of one of the crown’s teeth, producing excessive wear of the spindle-neck coating. After an operational time from a few to several thousand working hours, the wear manifests itself in carved helical grooves with a width reaching 2 mm and depth of about 1 mm (***Figure 2.b***). The grooves disable the smooth displacement of the yarn on the neck coating, and in result lead to increased number of yarn breakages.

The effect of spindle-neck coating wear is intensified by dead particles present in the stream of fibres (particles of grass,

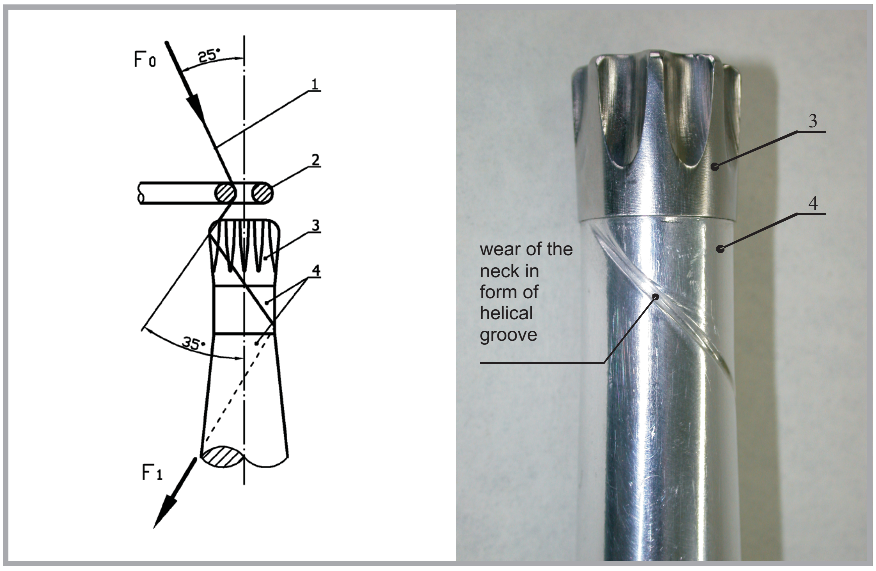

***Figure 2.** Spindle-neck coating made of aluminum alloy AlCu4Mg1 with a spindle crown for collapsed balloon spinning: a) run of the yarn from output rollers on the guide, and next to the crown and neck coating, b) wear of burnished spindle-neck coating in the form of helical groove, after an operational time of about 21600 hours. 1 – yarn, 2 – guide, 3 – crown, 4 – spindle-neck coating from EN AW-2024 alloy* [1].

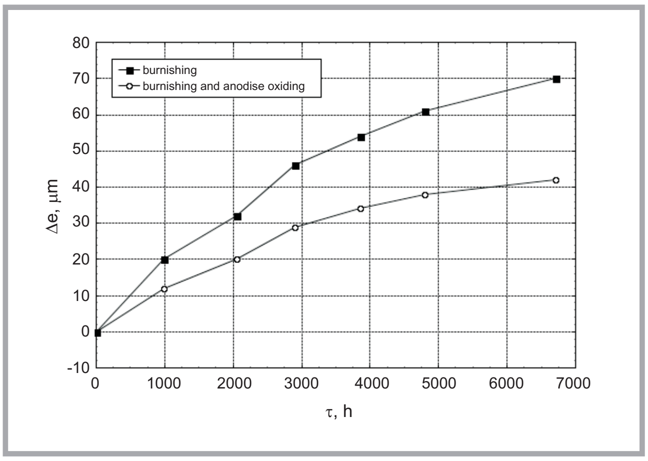

Figure 3. *Effect of surface and finishing treatments of the spindle-neck coating with a collapse balloon crown, made of aluminum alloy AlCu4Mg1, on the wear: 1 – burnishing, 2 – burnishing, hard anodic oxidation and grinding with abrasive paper.*

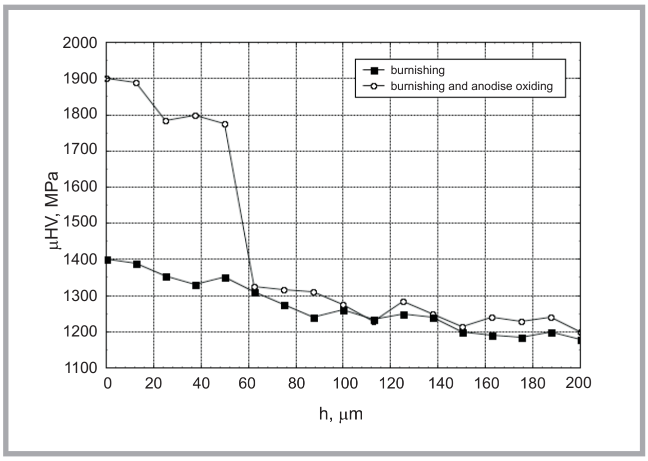

Figure 4. *Distribution of micro-hardness in the surface layer of the spindle-neck coating, made of the aluminum alloy AlCu4Mg1, in the function of the distance from the surface for various types of surface and finishing treatments.*

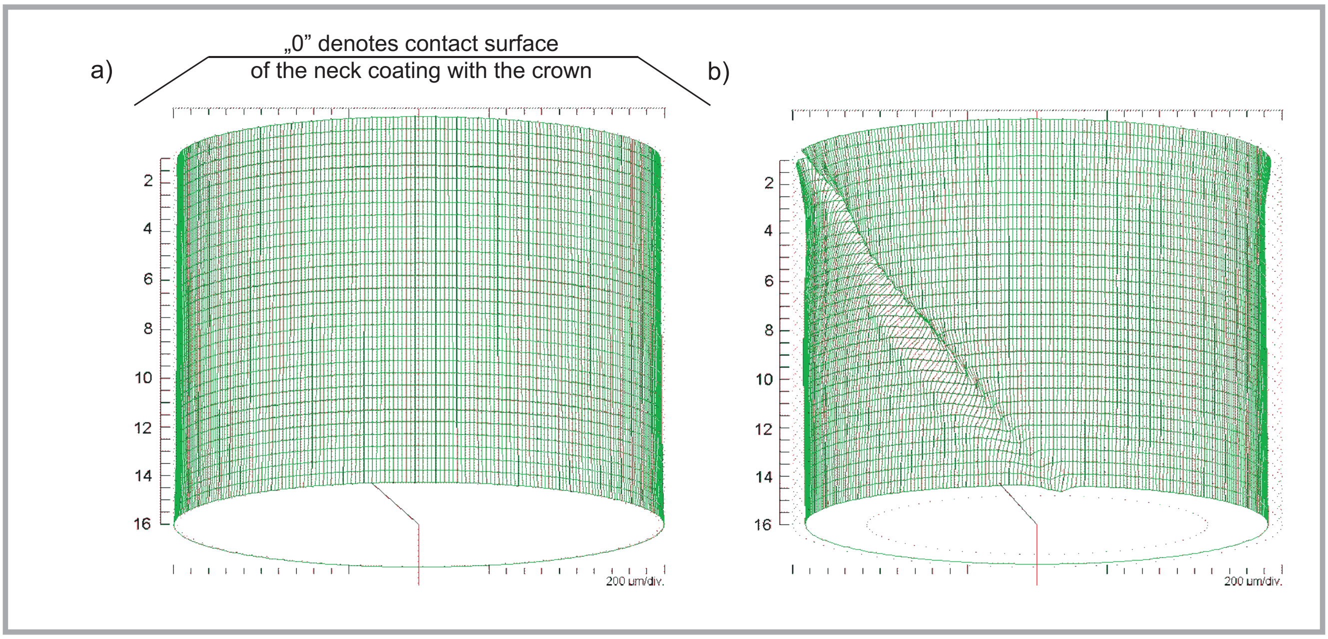

Figure 5. *Shape of cylindrical part of the spindle-neck coating with a collapse balloon crown, made of the aluminum alloy AlCu4Mg1, after burnishing: a) brand-new (0 hours in contact with yarn), b) after operational time (21600 hours of contact with yarn).*

bark of trees, straw) and occasional granules of dust stuck to fibres of wool [10].

Effect of surface and finishing treatments of the spindle-neck coating on the wear is presented in ***Figure 3***. The spindle-neck coating after the burnishing operation only features more intense wear because the maximal micro-hardness of the surface layer was considerably lower and did not exceed 600 MPa (***Figure 4***). The spindle-neck coating after the burnishing treatments, followed by subsequent hard anodic oxidation and grinding operations featured a wear-resistance a few times higher. This can be explained by a more than 1.6 fold higher maximal micro-hardness of the oxide layer, which amounted to 2600 MPa, comparing to the micro-hardness of the burnished spindle-neck coating, and by the considerable thickness of this layer, equal to about 56 µm.

The shape of the burnished cylindrical surface of the spindle-neck coating, located directly under the crown, both brand-new and after an operational time, is presented in ***Figure 5***. Exemplary diagrams of the circularity deviation of the spinning neck coating after burnishing treatment, both brand-new and after an operational time of about 21600 working hours, at the same distance from the face of the crown, are presented in ***Figure 6***. Before usage, the cylindrical part of the neck coating was characterized by, in particular the cross-sections, a circularity deviation in the range of 3.37 ÷ 9.88 µm, whereas the cylindrical shape deviation amounted to 17.21 µm. After an operational time of about 21600 working hours, the circularity deviation had grown from 26.5 to about 162.0 times and was in the range of 261.69 ÷ 769.30 µm, while the cylindrical shape deviation amounted to 849.71 µm.

Measurement results of selected SGP 3D parameters of the burnished spindle-neck coatings, both brand-new and after an operational time, are presented in ***Table 2***. Movement of the stream of fibres (yarn) on the spindle-neck coating after the burnishing operation resulted in a brighten-

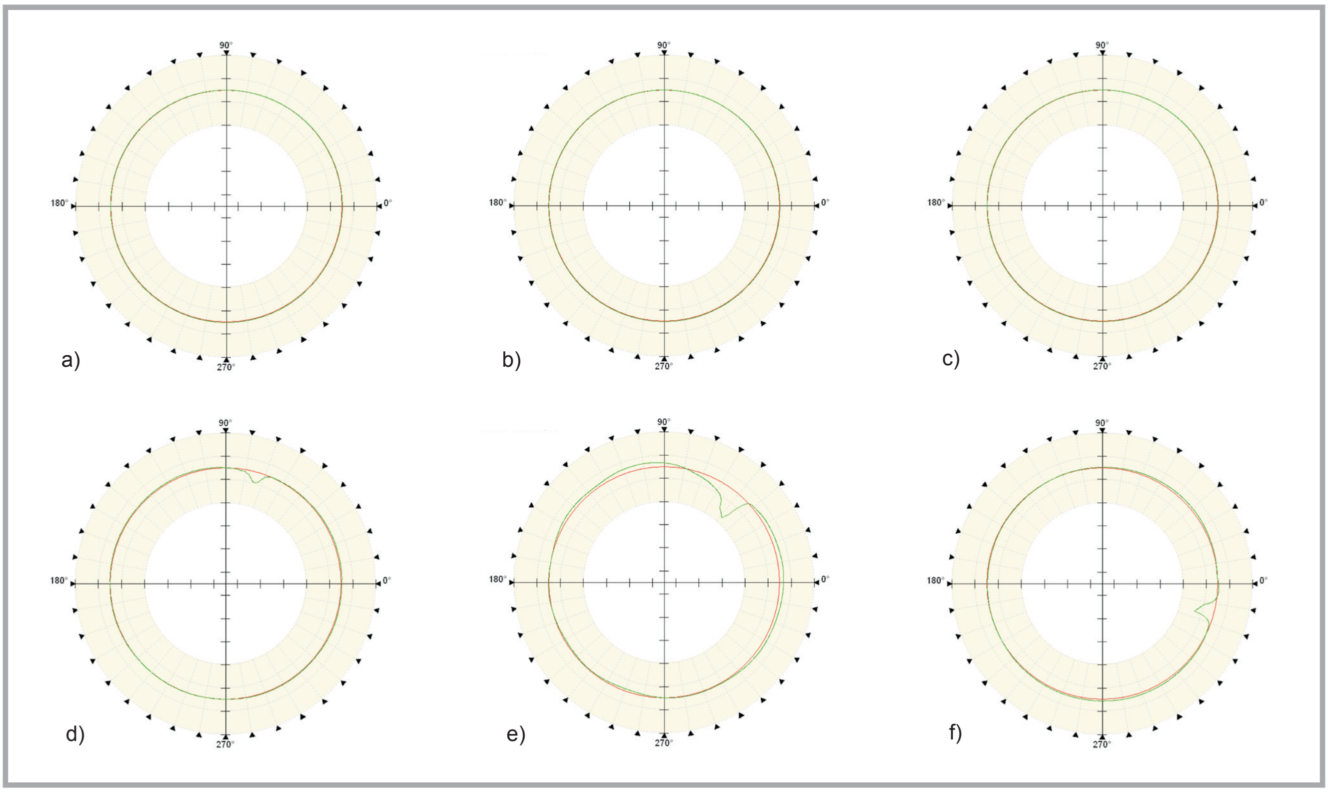

***Figure 6.** Circularity deviation of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, after burnishing, at the following distances from the face of the crown: a) 1 mm, b) 5 mm, c) 16 mm (in brand-new condition); d) 1 mm, e) 5 mm, f) 16 mm (after an operational time of about 21600 working hour).*

ing of the coating's surface after a very short time of contact with yarn; but in general, values of the main parameters of the roughness did not change. When the yarn is positioned inside cavities of the crown and closely girds the neck coating, its contact with the surface of the neck is distinctly longer, as a result of which, all SGP 3D parameters of the neck coating measured, after an operational time of about 21600 working hours, underwent a distinctive growth. For instance, the mean square deviation of the surface S_q of the burnished brand-new spindle-neck coating, amounted to from 0.38 to 0.40 µm, whereas after working contact with yarn for about 21600 working hours – S_q it equalled 0.41 ÷ 0.56 µm. While the maximal height of surface peaks in the case of brand-new coatings amounted to S_p = 1.37 ÷ 1.57 µm, after working contact with yarn for about 21600 working hours it was S_p = 1.50 ÷ 6.77 µm.

Figures 7, 8** and **9 present complex characteristics of the SGP 3D surface of burnished neck coating, both brand-new and after an operational time. The characteristics comprise the surface topography, a microphotograph of the surface and the curve of the surface material. Before use, the surface topography of the neck coating after burnishing shows rounded peaks, while after grinding and polishing with de-sludged abrasive paper the peaks are sharp [1]. The maximum height of the surface peaks *Sp* after burnishing is 42 - 50% smaller compared to the maximum surface peaks after grinding. The material ratio curve for a burnished surface has a significantly smaller slope compared to the grinded surface. However, the stereometric structure of the grinded surface after an exploitation time of ca. 14000 hours and the burnished surface after an exploitation time of ca. 21600 hours is very similar.

The wear of the cylindrical burnished surface of the neck coating is uneven, both on the perimeter and along the axis of the spindle (***Figure 5.b, 6.d, 6.e*** and ***6.f***). Displacement of the fibre stream (yarn) on the spindle-neck coating (after burnishing operation) results in, after a very short time of contact with yarn, negligible wear of the neck in terms of surface irregularities, most often manifesting itself in surface brightening. Such a situation occurs when the yarn is positioned in one of the neck's teeth, hence

***Table 2.** Values of selected SGP 3D parameters of the spindle-neck coating with a collapse balloon crown, made of aluminum alloy AlCu4Mg1, after burnishing, brand-new and after an operational time.*

Roughness parameters 3D	Surface of the neck after burnishing, brand-new neck			Surface of the neck after burnishing, the neck after about 21600 hours of working contact with yarn		
	measurement			measurement		
	1	2	3	1	2	3
S_a, µm	0.31	0.33	0.34	0.40	0.34	0.39
S_q, µm	0.38	0.38	0.40	0.56	0.41	0.53
S_p, µm	1.37	1.40	1.57	6.77	1.50	5.64
S_t, µm	3.25	3.43	3.74	11.73	4.14	8.67
S_k, µm	1.45	1.62	1.87	2.06	0.96	1.92
S_{pk}, µm	0.03	0.03	0.04	0.16	0.03	0.05
S_{vk}, µm	0.39	0.56	0.56	1.44	0.94	0.58
S_{mr1}, %	4.21	4.46	4.94	10.83	8.89	4.15
S_{mr2}, %	94.58	83.51	85.74	92.79	80.37	93.35

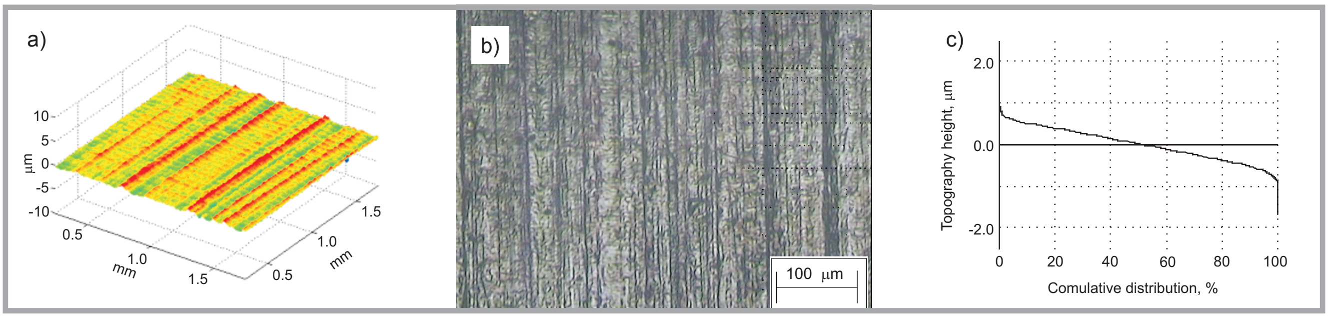

Figure 7. Stereometric structure of burnished surface of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, in brand-new condition: a) surface topography: S_a = 0.31 µm, S_q = 0.38 µm, S_p = 1.37 µm, S_t = 3.25 µm S_k = 1.45 µm, S_{pk} = 0.03 µm, S_{vk} = 0.39 µm, b) microphotograph of the surface, c) curve of the surface material part.

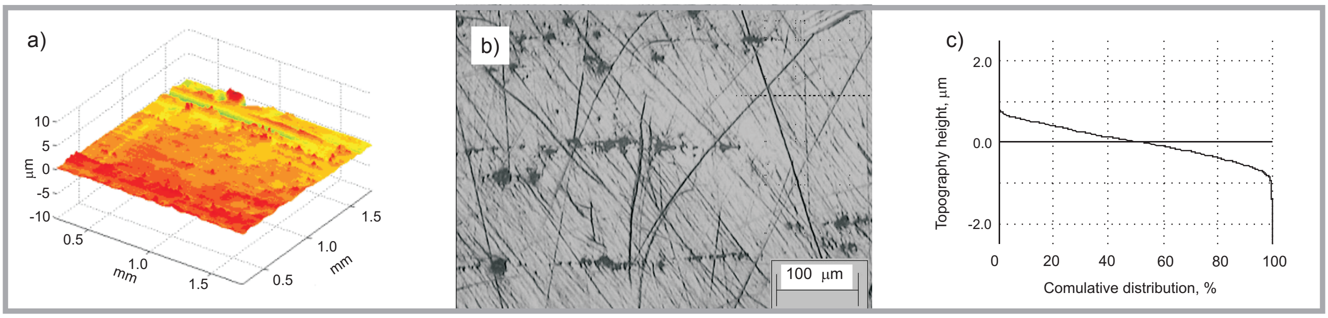

Figure 8. Stereometric structure of the burnished surface of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, after about 21600 hours of working contact with yarn (in an area of brightening of the surface): a) surface topography: S_a = 0.34 µm, S_q = 0.41 µm, S_p = 1,50 µm, S_t = 4.14 µm, S_k = 0.96 µm, S_{pk} = 0.03 µm, S_{vk} = 0.94 µm, b) microphotograph of the surface, c) curves of the surface material part.

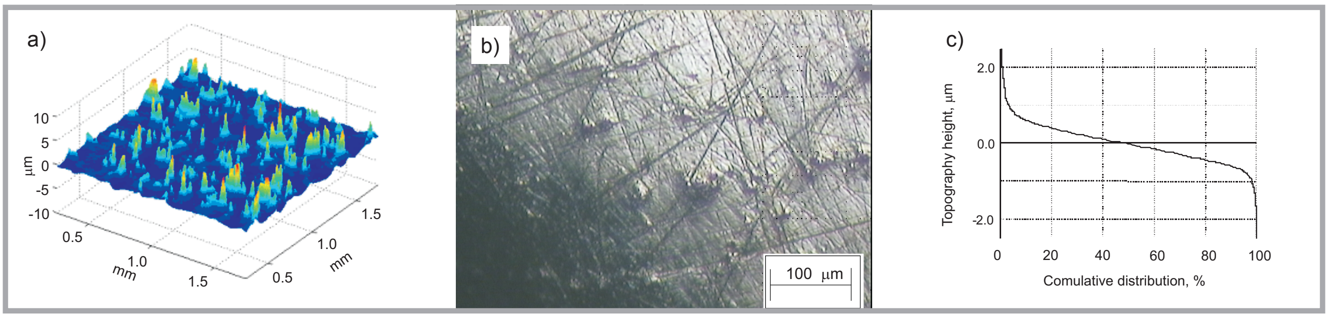

Figure 9. Stereometric structure of the burnished surface of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, after about 21600 hours of working contact with yarn (on the border of the helical groove): a) surface topography: S_a = 0.40 µm, S_q = 0.53 µm, S_p = 6.77 µm, S_t = 11.73 µm, S_k = 2.06 µm, S_{pk} = 0.16 µm, S_{vk} = 0.54 µm; b) microphotograph of the surface, c) curves of the surface material part.

at the biggest distance from the spindle axis. In this case the thrust of the yarn against the neck coating is the smallest and shortest. In the case when the yarn is located in cavities of the crown, it more closely girds and adheres to the surface of the spindle-neck coating. The thrust of yarn against the surface of the neck becomes many times bigger, and the duration of its contact with the surface of the neck distinctly lengthens, leading to the increased intensity of wear of the neck coating and to the carving of cavities; the quantity of cavities in the case of burnished necks is one less than that of teeth in the crown (***Figure 10***). In general, in 5 to 8% of cases, due to the imperfection of the manufacturing process, one tooth of the crown holds down the yarn considerably longer than the other teeth, which leads to the sculpturing of a groove of considerably bigger width and depth, sometimes reaching a value of 1 mm (***Figure 10***). The biggest wear among the series of the spindles investigated took place at a distance of about 5 mm from the face of the crown, amounting to about 0.95 mm.

The shape of a burnished cylindrical surface of the spindle-neck crown, next anodic oxidized and ground with abrasive paper, located directly under the crown, in brand-new condition and after

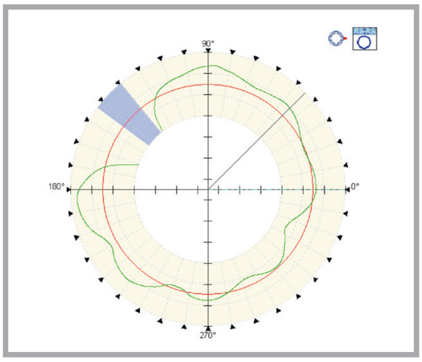

Figure 10. Shape of burnished spindle-neck coating of a spinning frame, made of aluminum alloy AlCu4Mg1, after an operational time of about 21600 working hours (at a distance of about 5 mm from the face of the crown).

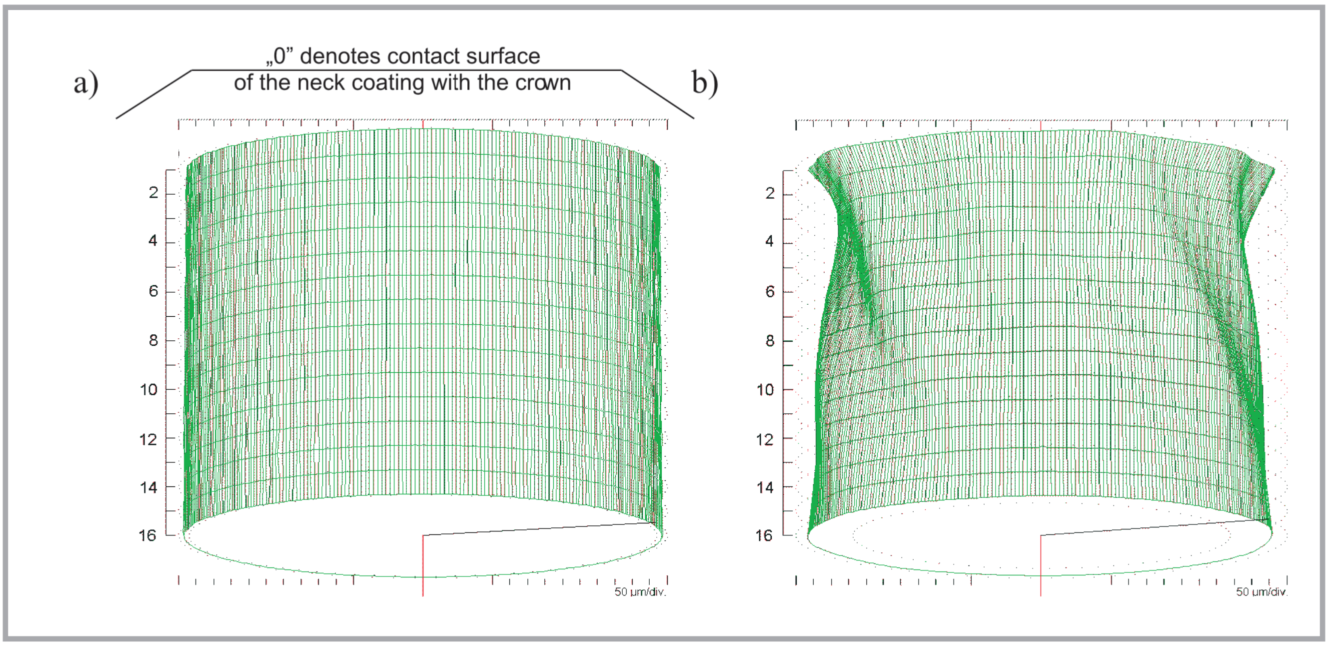

Figure 11. *Shape of cylindrical part of the spindle-neck coating with a collapse balloon crown, made of aluminum alloy AlCu4Mg1, after burnishing and hard anodic oxidation: a) in brand-new condition (0 hours of contact with yarn), b) after an operational time of about 84 000 working hours*

an operational time is presented in the ***Figure 11***. Exemplary diagrams of the circularity deviation of the spindle-neck coating after burnishing, anodic oxidation and grinding, in brand-new condition and after an operational time of about 84000 working hours, at the same distance from the face of the crown, are shown in ***Figure 12***. In brand-new condition, the cylindrical part of the neck coating was characterised by, in particular the cross-sections, circularity deviation within the interval of 9.35 ÷ 20.77 µm, while the cylindrical shape deviation amounted to 45.21 µm. After an operational time of about 84000 working hours, the circularity deviation had grown from about 2.5 to about 4.7 times, being within the interval of 23.37 ÷ 96.90 µm, whereas the cylindrical shape deviation amounted to 164.37 µm.

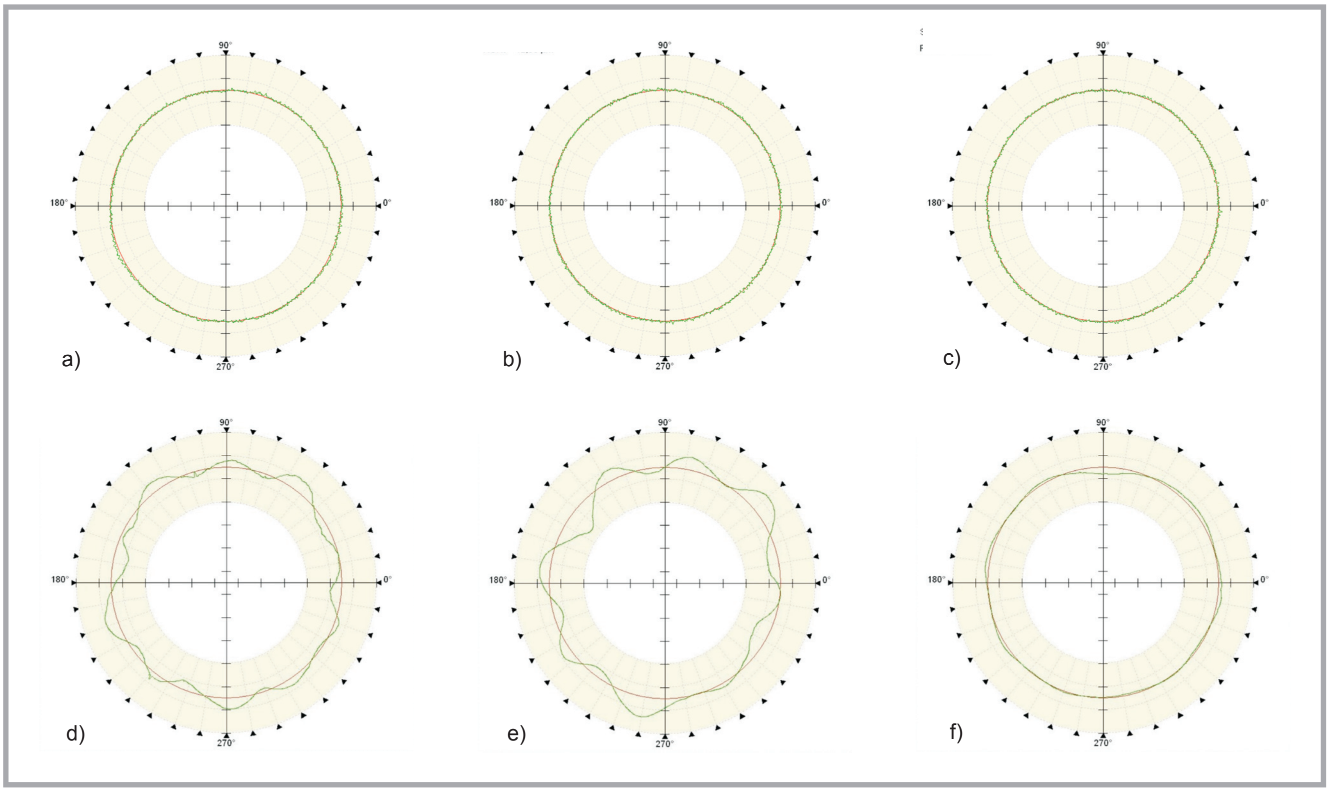

Figure 12. *Circularity deviation of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, after burnishing and hard anodic oxidation, at the following distance from the face of the crown: a) 1 mm, b) 5 mm, c) 16 mm (in brand-new condition); d) 1 mm, e) 5 mm, f) 16 mm (after operational time of about 84 000 working hours).*

Measurement results of selected SGP 3D parameters of burnished, anodic oxidized and ground spindle-neck coatings, both brand-new and after an operational time, are presented in ***Table 3***. Movement of the stream of fibres (yarn) on the spindle-neck coating after hard anodic oxidation resulted in the smoothening of its surface (***Table 3***). All SGP 3D parameters of the oxide layer measured after an operational time of about 84000 working hours underwent a distinct reduction. For instance, the mean square deviation of the surface S_q of anodic oxidized spindle-neck coating in brand-new condition was within the range of 1.44 to 2.02 µm, whereas after working contact with yarn for about 84000 working hours - S_q = 0.34 ÷ 0.41 µm. While the maximal height of surface peaks in the case of brand-new coatings amounted to 0.34 ÷ 0.41 µm, after 84000 hours of working contact with yarn it was S_p = 0.68 ÷ 0.96 µm. The SGP 3D parameters, which characterise the peaks of surface irregularities, underwent the biggest reduction. The S_{pk} parameter was reduced from 6.0 to 16.0 times, the S_p parameter – from 5.1 to 8.6 times, and the S_t parameter – from 1.37 to 3.26 times.

Figures 13 and ***14*** present complex characteristics of the SGP 3D surface of the burnished neck coating, in both brand-new condition and after an operational time. The characteristics comprise the surface topography, a microphotograph of surface and the curve of surface material. In turn, microstructure of oxide layer of the spindle-neck coating made of the aluminum alloy AlCu4Mg1, brand-new and after an operational time of about 84000 working hours, is presented in the ***Figure 15***.

Table 3. *Values of selected SGP 3D parameters of the spindle-neck coating with a collapse balloon crown, made of aluminum alloy AlCu4Mg1, after burnishing and hard anodic oxidation, in brand-new condition and after an operational time.*

Surface roughness 3D	Surface of the neck, anodic oxidized, brand-new			Surface of the neck, anodic oxidized, after about 84 000 hours of working contact with yarn		
	measurement			measurement		
	1	2	3	1	2	3
S_a, µm	1.64	1.16	1.50	0.33	0.28	0.29
S_q, µm	2.02	1.44	1.84	0.41	0.33	0.37
S_p, µm	6.54	4.91	5.58	0.96	0.68	0.85
S_t, µm	14.56	10.9	12.4	7.93	4.38	6.43
S_k, µm	5.70	5.30	5.24	1.22	1.89	1.07
S_{pk}, µm	0.16	0.12	0.13	0.02	0.01	0.01
S_{vk}, µm	2.21	2.40	2.06	0.66	0.34	0.54
S_{mr1}, %	8.34	7.38	6.79	4.79	3.55	6.01
S_{mr2}, %	89.55	88.14	88.98	87.28	92.89	82.3

The wear of the oxide layer on the cylindrical surface of the spindle-neck coating is non-uniform, both on the circumference and along the axis of the spindle (***Figures 11.b, 12.d, 12.e*** and ***12.f***). The biggest wear occurred at a distance of 5 mm from the crown and amounted to about 0.156 mm. For this study one assumed such a shape of cavities whose number on the circumference of the spindle-neck coating corresponds to that of its teeth. The cavities have the shape of a helix with a direction consistent with the movement of the yarn (with the direction of girding of the neck by the yarn). In spite of significant and uneven wear of the oxide layer, at no point of the investigation of the spindle-neck coating did the complete removal of this layer take place.

Observations of the surface of the spindle-neck coating with a collapse balloon crown, hard anodic oxidized, after an

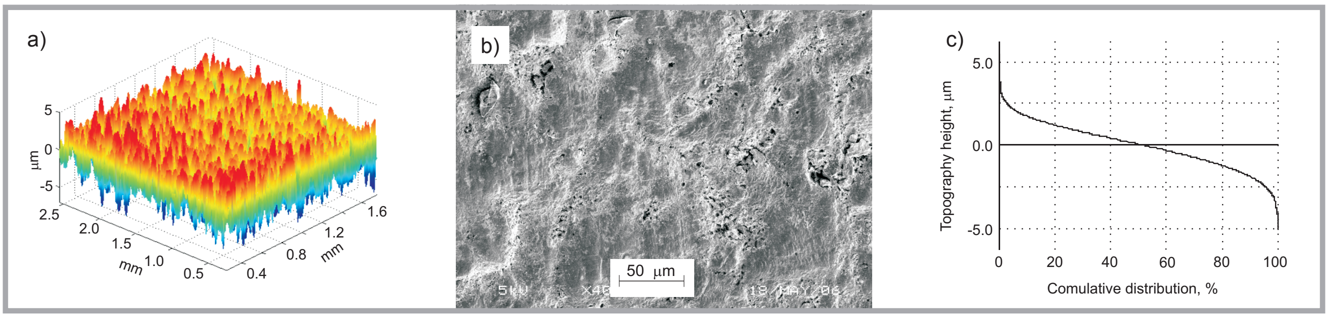

Figure 13. *Stereometric structure of surface of oxide layer of the spindle-neck coating, made of the aluminum alloy AlCu4Mg1, brand-new: a) surface topography: S_a = 1.50 µm; S_q = 1.84 µm; S_p = 5.58 µm; S_t = 12.40 µm; S_k = 5.24 µm; S_{pk} = 0.13 µm; S_{vk} = 2.06 µm; b) microphotograph of the surface, c) curve of the surface material.*

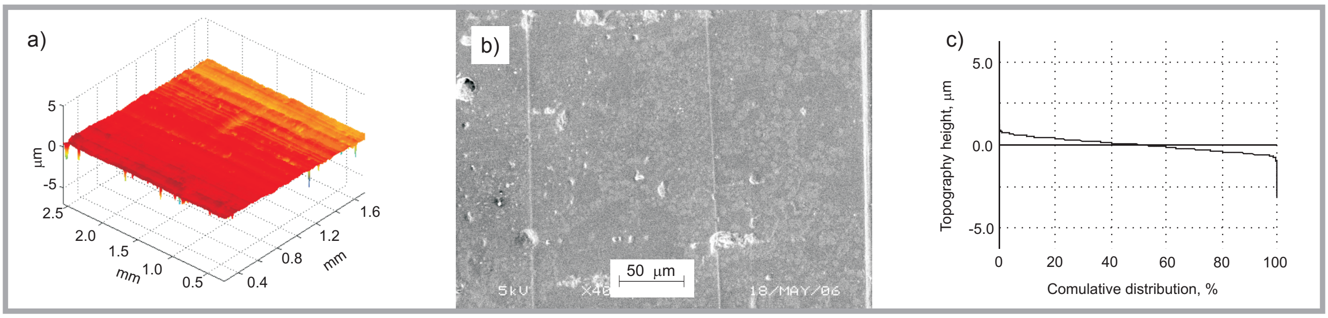

Figure 14. *Stereometric structure of the surface of the oxide layer of the spindle-neck coating, made of aluminum alloy AlCu4Mg1, after about 84000 hours of working contact with yarn: a) surface topography: S_a = 0.29 µm, S_q = 0.37 µm, S_p = 0.85 µm, S_t = 6.43 µm, S_k = 1.07 µm, S_{pk} = 0.01 µm; S_{vk} = 0.54 µm, b) microphotograph of the surface, c) curve of the surface material.*

operational time of about 84000 working hours, in the area of contact with yarn, at 5× magnification, confirmed that the surface is smooth and shiny, with visible and negligible cavities on the circumference, distributed along the helix lines according to the direction of yarn movement. However, in photos of this surface, taken at a magnification of 400×, traces are seen after surface treatments preceding the operation of hard anodic oxidation, as well as slight white stains, proving the lack of an oxide layer (damage of the oxide layer - ***Figure 14.b***). The surface of the oxide layer of the brand-new spindle-neck coating is rough, with visible micro-pores (***Figure 13.b***). From an assessment of microphotographs of the microstructure of the oxide layer of the spindle-neck coating, bran-new and after an operational time, we can state that the thickness of the oxide layer was reduced from about 58 μm (***Figure 15.a***) to about 16 μm (***Figure 15.b***).

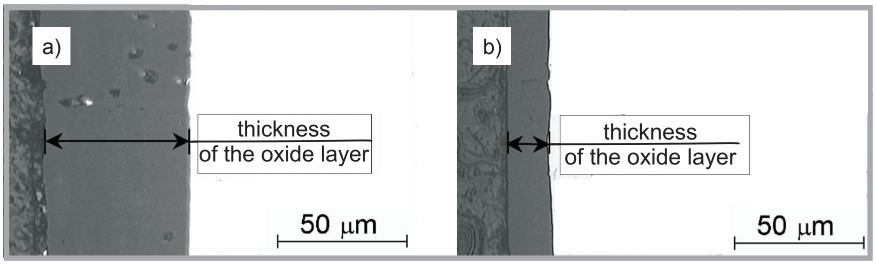

Figure 15. *Microphotographs of the microstructure of the surface layer of the spindle-neck coating of spinning frames, made of aluminum alloy AlCu4Mg1, (magn. 1000×): a) brand-new, b) after an operational time of about 84 000 hours.*

The most likely seems to be the thesis that the loss of material on the circumference of the spindle-neck coating with a collapse balloon crown, having the form of helix line cavities, and simultaneous reduction in its diameter is caused by the separation of micro-volumes of material due to mirco-cutting by solid particles formed from grass, the bark of trees, straw, and occasionally granules of dust nesting in the stream of fibres and moving together with the stream. The particles are pressed down with the changing force against the surface of the neck coating due to the tension of the yarn, which results from cyclic coming in and coming out from notches of the crown and changes during the rotational movement position of the spindle's axle ending in the crown. In comparison with the operation of grinding with abrasive paper unwound from a roll, it can be assumed that constant particles play the role of locating micro-cutting edges, which during a long period of time affect the carving of cavities of variable depth. In the case of a burnished neck the number of cavities at a distance of about 5 mm from the face of the crown is one less than the number of teeth of the crown, whereas in the case of burnished and anodic oxidised necks it is equal to the number of teeth of the neck. According to the opinion of the author, abrasive wear plays a decisive role during the friction of yarn against the surface of the spindle-neck coating with a collapse balloon crown.

Two groups of the following factors have a decisive effect on the intensity of wear: the first group – connected with physical properties of the surface layer of the spindle-neck coating, primarily its hardness, and the second one – connected with characteristics of the spinning process, i.e. type of processed blend, tension and speed of yarn movement. A growth in the hardness of the surface layer of the spindle-neck coating from 1600 MPa to 2600 MPa results in a more than quintuple growth in the hardness of the spindle-neck coating.

Final remarks and conclusions

Implementation of the burnishing operation as a surface treatment of spindle-neck coating with a collapse balloon crown, made of aluminum alloy AlCu4Mg1, brought about a nearly 30% growth in wear-resistance during working contact with yarn, as compared with ground necks. This occurred due to the fact that the micro-hardness of the surface layer after burnishing was higher than after grinding at about 240 MPa, amounting to 1600 MPa. This wear manifested itself after working contact with yarn lasting about 21600 hours in a carved helical groove with a width of about 2 mm and depth of about 1 mm. Such a groove disables the smooth movement of yarn on the neck coating, leading to an increased number of yarn breakages.

Assessment of the burnished layer wear proves that after a working time of about 21600 hours nearly all roughness parameters had worsened, e.g. the reduced height of surface peaks S_{pk} and maximal height of surface peaks S_p during some measurements increased by up to a few times. Implementation of hard anodic oxidation after the burnishing operation as a surface treatment of spindle-neck coating with a collapse balloon crown resulted in a more than quintuple growth in wear-resistance in contact with yarn. Assessment of oxide layer wear proves that this occurred through smoothening of irregularities in the peaks of the oxide layer due to the separation of micro-volumes of material as a result of micro-cutting by solid particles in the form of grass, bark of trees, straw, and, most of all, by granules of dust nesting in the stream of yarn. As a result, the reduced height of surface peaks S_{pk} decreased by a few to several times, while the maximal height of the peaks S_p dropped by a few times.

On the basis of the tests performed and analysis of their results, it has been ascertained that abrasive wear has critical importance for the wear of the oxide layer of spindle-neck coating made of aluminum alloy AlCu4Mg1 during the friction of yarn against the surface of the neck.

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