The changes of the workpiece surfaces by hard machining by milling and burnishing

Zmiany powierzchni przedmiotów obrabianych na twardo przez frezowanie i nagniatanie

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Today's machines have to be characterized by increasingly better functional and operational properties. The devices should work faster, more efficiently with higher accelerations and at the same time use less energy than it was a few years ago. These requirements apply to the products from the automotive industry, aviation machine tools or machines serving people in everyday life to play or learn. At the same time, a guarantee of long and trouble-free operation is required. In connection with the above, it is increasingly difficult for the technologist to prepare parts that meet the very strict requirements of dimensional and shape accuracy and the state of the geometric structure of the surface (SGP). Also, more and more emphasis is placed on meeting the additional functional requirements of the part surface (hydrophobic or hydrophilic properties, the degree of isotropy or the ability to maintain coatings and lubricants). The paper presents the results of the work aimed at determining the effect of technological parameters of milling and burnishing when treating the surface of parts in the state improved by heat to high hardness. The work focused in particular on the determination of the impact of the strategy of the implemented treatment on changes in the value of SGP indices describing the load-bearing capacity of the surface.
KEYWORDS: hybrid technologies, technological parameters of machining, geometric surface structure, surface bearing capacity

The required functional properties of the surface are given by the technologist on the path of increasingly complicated manufacturing processes. One of the technologies that are willingly used, which allows for the reduction of the surface heights [1–14], is the combination of a volumetric machining with finishing surface plastic finishing. In addition to the advantageous state of SGP (due to a significant reduction in roughness parameters after milling [1–9] or turning [10–13]) and improvement of reflexivity and surface isotropy, a state of stress in the surface layer, favorable from the point of view of fatigue strength, is obtained. parts [1, 11–13].

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The final state after a machining operation integrating two treatments (waste treatment with plastic working) depends mainly on the state of SGP obtained as a result of the first treatment, i.e. the chip treatment [14].

The work carried out so far in ITM ZUT in Szczecin confirmed that the state of SGP after chip machining (milling [1, 2]) can be easily modified by burnishing with two passes – provided a special machining strategy (appropriate trajectory of the burnishing tool in relation to direction of traces left by the cutter).

Advantageous effects can also be obtained with heat-treated materials for significant hardness. Then, burnishing with two passes gives just as good results as using high-value burnishing F_b. Such burnishing also ensures longer durability of the ceramic burnishing elements (made of ZrO_2 or Al_2O_3) and is safer in terms of the state of stress generated in the surface layer of the part.

In the literature related to the subject of the work, the application for improving the shape of the bearing curve (Abbott-Firestone) is often requested. Most of the work devoted to this issue, however, focuses on optimizing the set of technological processing parameters (in particular the burnishing force F_b), while the results of studies on the impact of burnishing strategies on the values describing the shape of the load curve are missing.

The aforementioned lack of publication and the interest of the Szczecin team of researchers in the subject of improving the tribological properties of spatial surfaces of such products as injection molds and dies induced scientists to perform appropriate experimental tests.

Experimental research

The selected high-quality SGP parameters were also included in the tests for improving the properties of the surface bearing curve. Work was carried out on samples made of X160CrMoV121 material, which were then heat-treated to a hardness of 52 ± 2 HRC. The shaping milling was carried out on the milling center DMG DMU-60 MONOBLOK. A folded toroid mill with six carbon plates was used for machining (for machining hard-to-cut materials RD.X1003 MOT – WTN1205) with a diameter of d_p = 10 mm. The crushing with a single-ball hydrostatic burner was carried out on the milling center MIKRON VCE 500; a ceramic burnt ball made of ZrO_2 material, diameter d_k = 10 mm, was mounted in the tool. Other technological processing parameters are listed in the table.

TABLE. Set of technological processing parameters adopted in the experimental design plan

Strategy	Cutting speed v_c, m/min	Depth of the cutting layer a_p, mm	Feed per revolution f_r, mm/rev	Transversal milling feed (drilling) f_{wf}, mm		Cross feed at burnishing f_{wn}, mm	Burnishing speed v_b, mm/min	Burnishing power F_b, N	The diameter of the burnishing ball d_k, mm
PO	110	0.5	0.6	A = 0.3	B = 0.5	0.02	8000	800	10
PP	110	0.5	0.6	A = 0.3	B = 0.5	0.02	8000	800	10
SK	110	0.5	0.6	A = 0.3	B = 0.5	0.02	8000	800	10

Three burnishing strategies were selected for the research. The first one was burnishing in a single pass straight to the traces left by the milling cutter (orthogonal strategy – PO). The second strategy was burnishing in two perpendicular transitions, where the first was orthogonal to milling marks (double-perpendicular strategy – PP). The last of the adopted strategies included two mutually perpendicular crossings, both being carried out at an angle of 45° relative to the milling tracks (skew strategy – SK).

The impact of the strategy was checked for two cases of burnishing during burnishing: f_{wf} = 0.3 and f_{wf} = 0.5 mm. A total of 16 samples were prepared during the tests, including 14 milled and burnished (two samples after milling were left as reference samples).

Surface measurements and preparation of test results

SGP measurements were carried out in the Surface Topography Laboratory (LTP) of ZUT in Szczecin. For this purpose, a multisensory AltiSurf A520 machine, armed with a CL1 chromatic confocal sensor [15] with an operating range of up to 130 μm and a resolution in the optical axis of the 8 nm instrument was used. The measurements were made on fields with dimensions of 3.0 × 3.0 mm. The scan resolution was experimentally determined: along the X axis – 0.47 μm, along the Y axis – 5 μm; it gave almost 3.8 million mapping points for each surface.

The digital treatment of the collected point cloud and the determination of the stereometric values of the SGP parameters (according to [16, 17]) were made in the AltiMap PREMIUM 6.2 software.

For each surface scan the collected point cloud was leveled (with the mean plane, approximated by the least squares method), and then the incorrectly collected surface points were removed (threshold values were taken from 0.05÷99.95%, while the removed points were set as un-measured values).

Finally, the values of the most popular parameters of constructors and technologists describing the height of the surface – Sa and Sq (fig. 1) – and the values of parameters used in describing the surface bearing capacity [16, 17] (fig. 2) were determined.
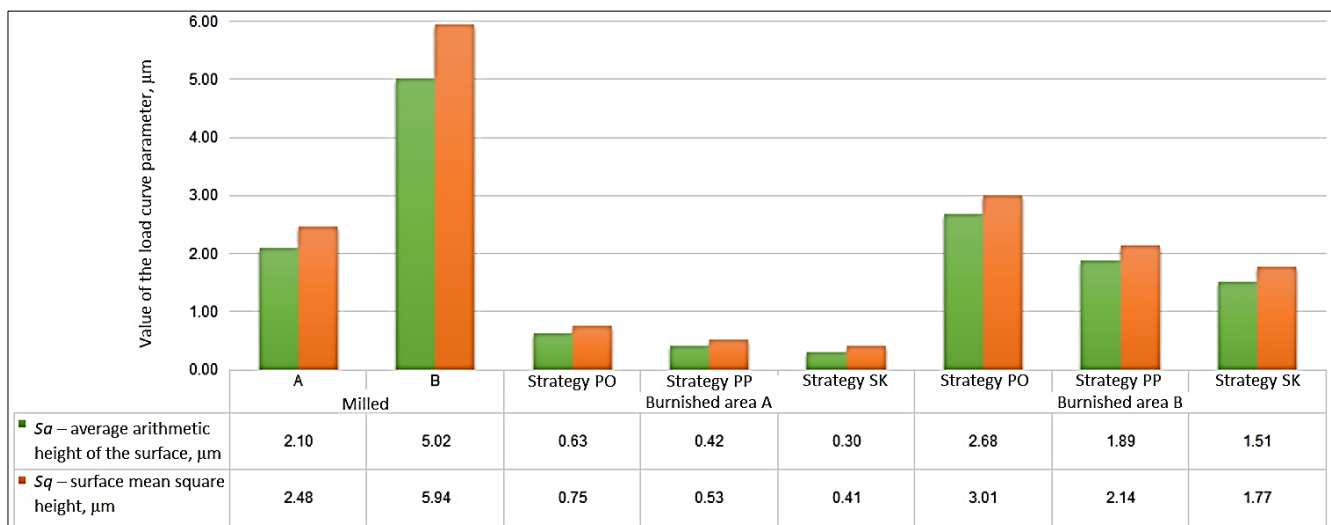

	A	B	Strategy PO	Strategy PP	Strategy SK	Strategy PO	Strategy PP	Strategy SK
	Milled		Burnished area A			Burnished area B		
Sa – average arithmetic height of the surface, μm	2.10	5.02	0.63	0.42	0.30	2.68	1.89	1.51
Sq – surface mean square height, μm	2.48	5.94	0.75	0.53	0.41	3.01	2.14	1.77

Fig. 1. Values of elevation surface parameters, registered during tests in accordance with ISO 25178

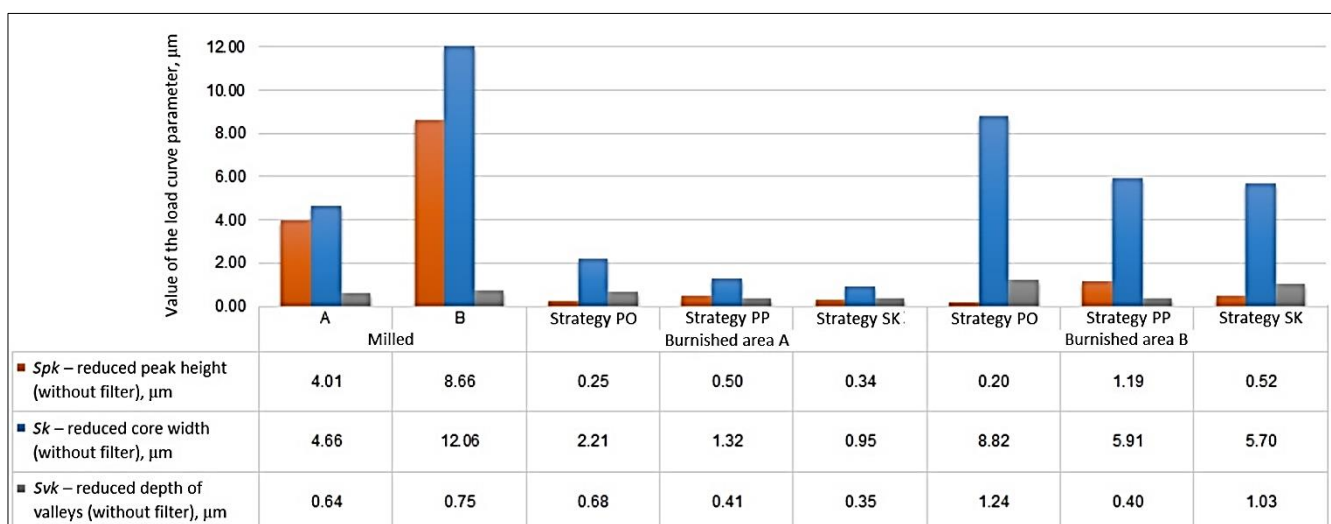|	A	B	Strategy PO	Strategy PP	Strategy SK	Strategy PO	Strategy PP	Strategy SK
	Milled		Burnished area A			Burnished area B		
Spk – reduced peak height (without filter), μm	4.01	8.66	0.25	0.50	0.34	0.20	1.19	0.52
Sk – reduced core width (without filter), μm	4.66	12.06	2.21	1.32	0.95	8.82	5.91	5.70
Svk – reduced depth of valleys (without filter), μm	0.64	0.75	0.68	0.41	0.35	1.24	0.40	1.03

Fig. 2. Values of functional surface parameters, registered during tests in accordance with ISO 25178

Conclusions

Based on the experimental tests carried out, it can be concluded that the use of already low burnishing force allows to significantly reduce the height values of the SGP parameters. The efficiency of neutralizing surface unevenness is all the greater, the smaller the inequalities the cutter has left. There is also a visible impact on the strategy of burial. In all cases, strategies with two penetrating transitions were found to be about 40÷100% better than burnishing in one orthogonal transition. The best strategy among those selected for the study was the skew strategy SK – in special cases it allows to reduce the height parameters of surface irregularities even by over 70%. This is very beneficial considering the advantages of integrating milling and burnishing technology on CNC machining centers.

Very interesting conclusions arise from the analysis of the SGP parameters describing the shape of the surface bearing curve. It turns out that burnishing first reduces the high surface peaks, making it more resistant to abrasion. This is clearly evident especially in the case of burnishing of "high" surface irregularities – the resulting plate-au plateau gives a large surface contact area, and at the same time does not change the volume of the core and valleys, thus leaving places where lubricants can be maintained.

In the future, the developed research material will be subjected to tribological tests aimed at practical verification of tribological properties described in the surface load curve.

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