THE INFLUENCE OF THE BASIC CONDITIONS OF THE FORCED FEED OF ABRASIVE COMPOUND ON THE SURFACES ROUGHNESS OF FLAT CERAMIC ELEMENTS AFTER LAPPING

Wpływ podstawowych warunków wymuszonego dawkowania zawiesiny ściernej na parametry chropowatości powierzchni płaskich elementów ceramicznych po docieraniu

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Abstract: In standard lapping, the abrasive compound is feed to the machining zone in a continuous manner – either by flooding or by droplets – which generates significant loss of the abrasive. The paper describes an innovative method of dosing and applying the abrasive compound onto the surface of a lapping disc, which eliminates this drawback. Additionally, the results of the examination of the influence of the compound feed on the selected parameters of the surface roughness of ceramic elements after lapping. In the conducted experiments the Authors examined the influence of the percentage content of grinding grains in the carrier, as well as the size of the compound dosage and viscosity of a liquid carrier on the values of particular surface roughness parameters of the lapped sealing elements.

Keywords: lapping of flat surfaces, abrasive compound, forced feed

Streszczenie: W docieraniu standardowym zawiesina ścierna dostarczana jest do strefy obróbki w sposób ciągły – zalewowo lub kroplowo, co powoduje duże straty ścierniwa. W artykule opisano innowacyjny system dozowania i nanoszenia zawiesiny ściernej na powierzchnię docieraka tarczowego, który eliminuje tą wadę. Przedstawiono wyniki badań wpływu warunków dawkowania zawiesiny na wybrane parametry chropowatości powierzchni elementów ceramicznych po docieraniu. W przeprowadzonych eksperymentach badano wpływ procentowej zawartość ziaren ściernych w nośniku oraz wielkości dawki zawiesiny i lepkości nośnika płynnego na wartości poszczególnych parametrów chropowatości powierzchni docieranych uszczelniań.

Słowa kluczowe: docieranie powierzchni płaskich, zawiesina ścierna, dawkowanie wymuszone

Introduction

Lapping process covers not only shaping of the surfaces of metal elements but also the surfaces of ceramic elements [3, 9, 11]. In practice, in case of flat surfaces, machine lapping on a single-disc machines with ring actuator system is prevailing [13, 16, 18]. Machined elements, placed in separators are being set in motion by guiding rings cooperating abrasively with the active surface of the lapping disc (Fig. 1) [4].

On the surface of the lap (1) guiding rings (5) rotate with the rate of rotation ns. Lapping disc rotates with the rate of rotation n_t driving the rings in which separators (4) are placed freely, enabling, usually negligible, additional rotary motion of the machined elements (3). Load is exerted onto the machined elements through a felt pad. The guiding ring rotates under the influence of the friction force torque and the rotations depend on the velocity of the lapping disc, friction conditions, load and location of the separator in relation to the lapping disc. Realization of the correct course of machining requires, among others, the appropriate value of unit pressure on the element and dosage of abrasive compound which is usually fed with certain excess. The outcome of lapping is influenced by a number of factors connected with the

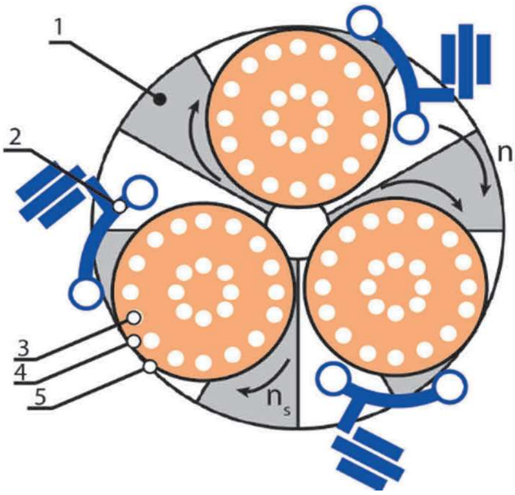

Fig. 1. Kinematic system of a single-disc lapping machine

lapping disc, components of the abrasive compound (type and size of abrasive micro-grains, concentration of the abrasive and size of the dosage), kinematic and technological conditions (mostly relative velocity and value of acceleration in the actuator system and unit pressure) [5,10]. Method and intensity of feeding the abrasive compound into the lapping zone is also of significant importance. In standard configuration the compound is fed continuously by means of flooding or droplets. This causes an excessive loss of abrasive, since some abrasive micro-grains become quickly removed from the working surface of the lapping disc by rotating guiding rings with separators and do not participate in the machining process. This significantly increases the machining costs and, indirectly, has a negative influence on the environment [7, 14]. Application of a system of forced feed of the abrasive compound on the working surface of the lapping disc eliminates these drawbacks to a large extent [1, 12].

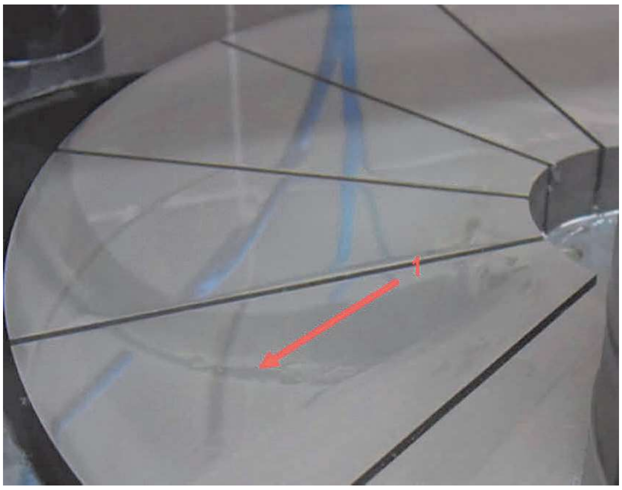

Fig. 3. Covering the surface of the lapping disc with abrasive compound after the application of the system of forced feed of the compound (1 – coruscant working surface of the lap)

Lapping station and methodology of the research

In order to conduct the research on the influence of the basic conditions of the forced feed of abrasive compound on the parameters of the geometric structure of the surface after lapping flat ceramic elements, a system of forced feed and dosage of abrasive compound was applied (Fig. 2) [6].

Application of a system of the forced feed of abrasive compound ensures an even distribution of the layer of abrasive compound, which can be seen in Fig. 3.

In experimental research a static, determined, selective, multi-factored quasi-rotable second rank plan developed by Box and Hunter with spherical distribution of information was applied. This ensures the stability of estimating the regressive function in certain surroundings of the central point of the plan *PS/DS-P*: λ [8, 15, 17]. Values of the output factors Y are variables of random character. Such an assumption allows to assume that occurring distortions U and constant conditions C constitute parameters that are seemingly constant with the assumed conditions of the research. In the paper the function of an object has been defined in multi-dimensional factor space as an equation of regression:

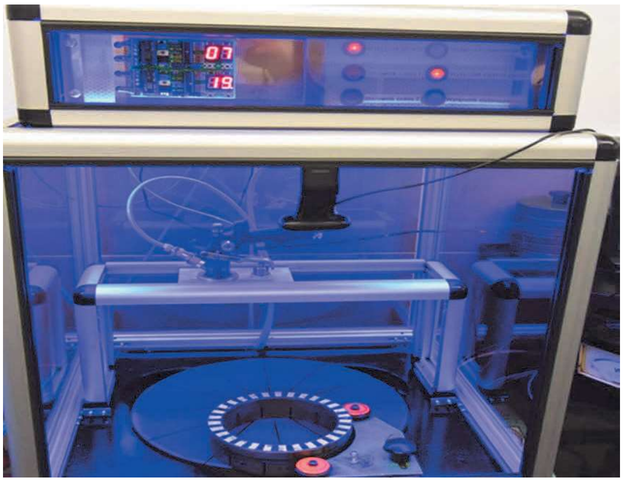

Fig. 2. System of the forced feed of abrasive compound

$$Y = f\,(x_1, x_2, x_3, \ldots\, ,x_k) \qquad (1)$$

where:

k – number of the analyses variables,

Determined coefficients $B = [b_1, b_2, \ldots, b_k]$ apply to the regression equation:

$$Y = b_0x_1 + b_1x_2 + b_2x_3 + b_3x_4 + b_4x_2^2 + b_5x_3^2 + b_6x_4^2 + b_7(x_1x_2) + b_7(x_2x_4) + b_7(x_3x_4) \qquad (2)$$

where:

$Y = Rz$ is the value of the input factor from the model (surface roughness parameter),

while independent variables are, respectively: $x_1 = 1$, $x_2 = K$, $x_3 = V_s$, $x_4 = L_e$;

whereby:

K – percentage content of the abrasive grains in a carrier,

V_s – dosage of the abrasive compound [ml/20min],

L_e – viscosity of the carrier of abrasive grains [mPa·s].

Experimental research has been conducted while lapping sealing elements made of Al_2O_3 ceramics. Correlations between the dosage parameters for the abrasive compound and other (selected) roughness parameters: *Ra*, *Rq*, *Rt*, *Rv*, *Rz*, *Rp*, *Rku*, *Rsm* and *Rsk* of the lapped surfaces have also been analysed.

Results of the research

Table 1 contains the results of the experiments. Surface charts (Fig. 4–6) has been built. Several characteristic points have been marked in these graphs.

Table 1. Conditions of the forced feed of abrasive compound and results of the measurement of roughness parameter *Rz* (mean values of 3 measurements have been listed)

	K [%]	V_s [ml/20min]	L_e [mPa·s]	Rz [µm]
1	15	10	23	5.4954
2	15	50	23	5.2069
3	15	50	23	5.2567
4	15	50	23	5.225
5	15	50	23	5.2269
6	15	50	23	5.2869
7	15	50	23	5.2673
8	15	90	23	6.0191
9	5	50	23	6.5775
10	25	50	23	6.064
11	21	74	29.5	6.1754
12	21	26	29.5	6.1458
13	9	74	29.5	6.7796
14	9	26	29.5	6.1509
15	15	50	34	5.8279
16	15	50	10.3	5.8783
17	21	74	16.5	6.0677
18	21	26	16.5	5.9464
19	9	74	16.5	6.3593
20	9	26	16.5	5.3033

Necessary calculations and spatial graphs showing the influence of the input factors (*K*, V_s and L_e), on surface roughness parameter *Rz* were conducted in Statistica software.

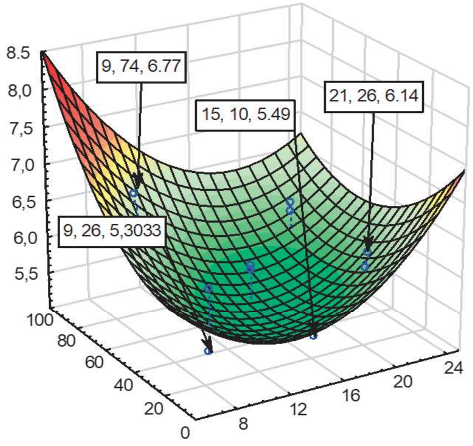

Fig. 4. Surface chart of the height of *Rz* surface roughness parameter in relation with the input factors *K* and V_s

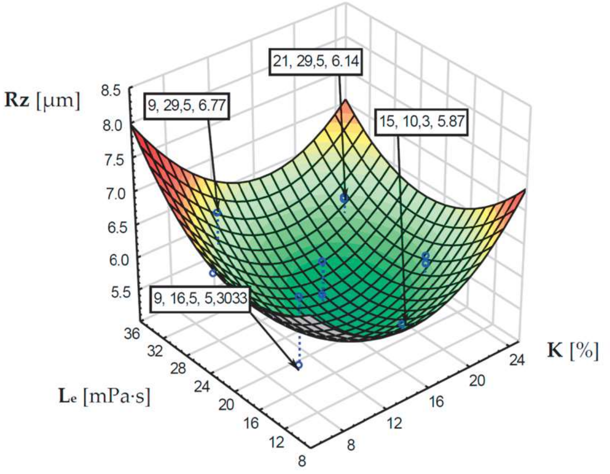

Fig. 5. Surface chart of the height of *Rz* surface roughness parameter in relation with the input factors *K* and L_e

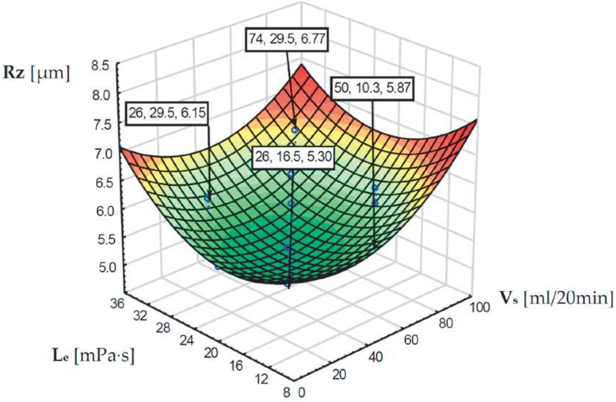

Fig. 6. Surface chart of the height of *Rz* surface roughness parameter in relation with the input factors V_s and L_e

Processing the results of research

The obtained results confirm the efficiency of the operation of a forced dosing system. Values of the roughness parameter *Rz* recorded in the research are close to the values of *Rz* parameter for elements lapped with the conventional method of dosing the abrasive compound [2].

Rz_{min} = 5.21 µm obtained for: *K*= 15%, V_s = 50 ml/20 min and L_e = 23 mPa·s

as well as Rz_{max} = 6.78 µm for: *K* = 9%, V_s =74 ml/20 min and L_e = 29.5 mPa·s

A statistical analysis of the obtained results has also been conducted. SS test for model (2) has been conducted on the basis of data contained in Tab. 1. Multiple correlation factor and determination factor (Tab. 2) have been determined.

Next, unidimensional formula significance tests were performed for $Rz = f(K, V_s, L_e)$ (Tab. 3).

For the analysed regression equation, the value of F coefficient was 20.40820. This value corresponds with the significance level p-value = 0.000059. Low value of

Table 2. Model analysis results

Dependent variable	SS Test for a complete model										
Rz	Multiple R	Multiple R^2	Corrected R^2	Model SS	Model df	Model MS	Rest SS	Rest df	Rest MS	F	P
	0.9763	0.9532	0.9065	4,3843	9	0.4871	9	0.0238	0.0233	20.4082	0.00005

Table 3. Unidimensional test of regression formula significance

Effect	Unidimensional significance tests for *Rz* Parametrization with sigma-limitations Decomposition of effective hypotheses; Standard error of the assessment: 0.1545				
	SS	Degrees of freedom	*MS*	*F*	*p*
Absolute term	1.8450	1	1.8450	77.2947	0.00001
K	0.4388	1	0.4388	18.3867	0.0020
K^2	2.2961	1	2.2961	96.1924	0.000004
V_s	0.0002	1	0.0002	0.0094	0.9246
V_s^2	0.5926	1	0.5922	24.8118	0.0007
L_e	0.2044	1	0.2044	8.5635	0.0168
L_e^2	0.8478	1	0.8478	35.5205	0.0002
$K \cdot V_s$	0.2257	1	0.2257	9.4581	0.01323
$K \cdot L_e$	0.0781	1	0.0781	3.2743	0.1038
$V_s \cdot L_e$	0.212	1	0.0212	0.8918	0.3696
Error	0.2148	9	0.2338		

Table 4. Values of the regression coefficients and their level of significance

Effect	Assessment of parameters Parametrization with sigma-limitations									
	Rz	*Rz* Stat. Error	*Rz* t	*Rz* p	-95.00% Confidence boundary	+95.00% Confidence boundary	*Rz* Beta (β)	*Rz* Stat. Error (β)	-95.00% Confidence boundary	+95.00% Confidence boundary
Absolute term	8.2241	0.9354	8.7917	0.00001	6.1080	10.3403				
K	-0.2213	0.0516	-4.2879	0.0020	-0.3381	-0.1045	-2.1899	0.5107	-3.3452	-0.0346
K^2	0.0114	0.0016	9.8077	0.00004	0.0088	0.0140	3.4561	0.3523	2.6559	4.2533
V_s	0.0012	0.0122	0.0973	0.9246	-0.0267	0.0291	0.0476	0.4894	-1.0595	1.1547
V_s^2	0.0003	0.00007	4.9811	0.0007	0.0001	0.0005	1.4752	0.2961	0.8052	2.1452
Le	-0.1467	0.0501	-2.9263	0.0168	-0.2601	-0.0333	-1.6432	0.5615	-0.9135	-0.3729
L_e^2	0.0050	0.0008	5.9599	0.0002	0.0031	0.0069	2.5617	0.4298	1.5894	3.5341
KV_s	-0.0013	0.0004	-3.0754	0.0132	-0.0023	-0.0003	-0.9975	0.3243	-1.7312	-0.2637
KL_e	-0.0029	0.0016	-1.8095	0.1038	-0.0066	0.0007	-0.8841	0.4886	-1.9894	0.2211
$V_s L_e$	-0.0003	0.0004	-0.9443	0.3696	-0.0013	0.0005	-0.,4365	0.4622	-1.4822	0.6091

the significance level indicates a high significance of the constructed regression equation. Standard error of the test assessment is 0.1545, which indicates that all the parameters of the model were estimated with sufficient precision. The model was assessed as positive. The analysis of the regression equation was extended with testing the significance of the equation's coefficients (Tab. 4).

On this basis, a mathematical mode was obtained, being a quadratic polynomial with three input variables (K, V_s, L_e):

$$Rz = 8.2241 - 0.2213K + 0.0114K^2 + 0.0012V_s + 0.0003V_s^2 - 0.1467L_e + 0.0050L_e^2 - 0.0013KV_s - 0.0029KL_e - 0.0003V_sL_e \tag{3}$$

Comparison of the real results of *Rz* parameter and predicted *Rzt* (from a model) parameter is presented in (Tab. 5).

Utility function parameter notion has also been introduced (Tab. 6). The maximum value of the parameter obtained as a result of optimization was *Rzt* = 6.81 µm, while $Rzu_{\text{żyt}} = 1$, in case when *Rzt* = 4.79, $Rzu_{\text{żyt}} = 0$.

List of the replies regarding the predicted value of the roughness parameter *Rz* is presented in Tab. 7.

Profiles of the approximated and theoretical values (in the function of input coefficients K_t, V_{st}, L_{et}) have been presented in Fig. 7. In this case, the dependent variable is $Rzt = Rz_{\text{użyt}}$, while predicators are K_t, V_{st} and L_{et}. Fig. 8–10 present the surface charts $Rz_{\text{użyt}} = f(K_t, Vst, L_{et})$.

Table 5. Comparison of *Rz* values (observed vs anticipated)

No.	**Observed, anticipated and rest values** **Parametrization with sigma-limitations**		
	Observed *Rz*	**Predicted *Rz***	**Rest *Rz***
1	5.4954	5.4892	0.0061
2	5.2069	5.2361	-0.0292
3	5.2567	5.2361	0.0205
4	5.2250	5.2361	-0.0111
5	5.2269	5.2361	-0.0092
6	5.2869	5.2361	0.0507
7	5.2673	5.2361	0.0311
8	6.019	6.1462	-0.1271
9	6.5775	6.5226	0.0548
10	6.0640	6.2397	-0.1757
11	6.1754	5.9397	0.2356
12	6.1458	6.0588	0.0870
13	6.7796	6.7331	0.0464
14	6.1509	6.0628	0.0839
15	5.8279	6.0628	-0.2349
16	5.8783	5.7900	0.0882
17	5.8783	5.7900	0.0882
18	5.9464	5.908	0.0375
19	6.3593	6.3623	-0.0030
20	5.3033	5.4549	-0.1516

Table 6. Parameters of the utility function of the roughness parameter *Rz*

Variable	**Utility function parameters** **Settings of the utility function for each dependent variable**							
	Low value	**Useful value**	**Intermediate value**	**Useful value**	**High value**	**Useful value**	**s Parameter**	**t Parameter**
Rz	4.7886	0.00	5.7996	0.5000	6.8105	1.0000	1.0000	1.0000

Table 7. List of the replies regarding the predicted value of the roughness parameter *Rz*

Coefficient	**Levels of the coefficient and predicted replies Predicted replies for all the levels of each coefficient with set values of all the other coefficients**				
	Level of the coefficient	**Predicted** *Rz*	**Useful value**	**-95% P** *Rz*	**+95% P** *Rz*
K	4.6830	6.5865	0.8891	6.1354	7.0376
K	9.6836	5.6255	0.4139	5.2460	6.0050
K	14.6842	5.2371	0.2218	4.8598	5.6144
K	19.6848	5.4214	0.3129	5.0422	5.8007
K	24.6853	6.1784	0.6873	5.7331	6.6237
V_s	8.7321	5.5137	0.3586	5.0626	5.9648
V_s	28.7345	5.2300	0.2183	4.8505	5.6095
V_s	48.7368	5.2371	0.2218	4.8598	5.6144
V_s	68.7391	5.5351	0.3692	5.1559	5.9143
V_s	88.7415	6.1239	0.6604	5.6786	6.5692
L_e	11.9308	5.6079	0.4052	5.1792	6.0366
L_e	17.5917	5.2619	0.2341	4.8825	5.6414
L_e	23.2526	5.2371	0.2218	4.8598	5.6144
L_e	28.9135	5.5335	0.3684	5.1528	5.9142
L_e	34.5744	6.1511	0.6738	5.6962	6.6059

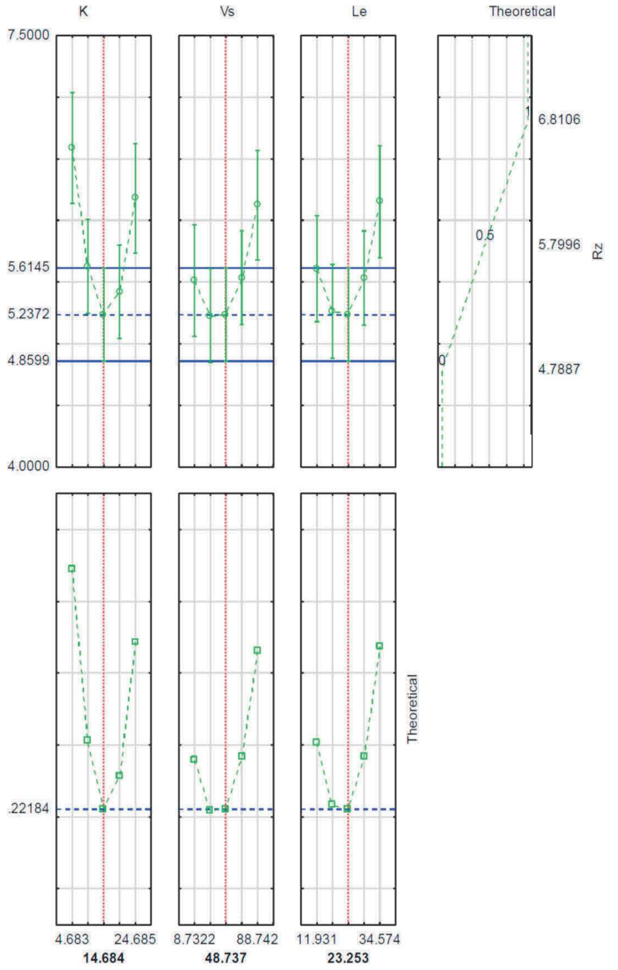

Fig. 7. Profiles of the approximated and useful values of the examined coefficients *K*, V_s and L_e, influencing the value of the surface roughness parameter *Rz*

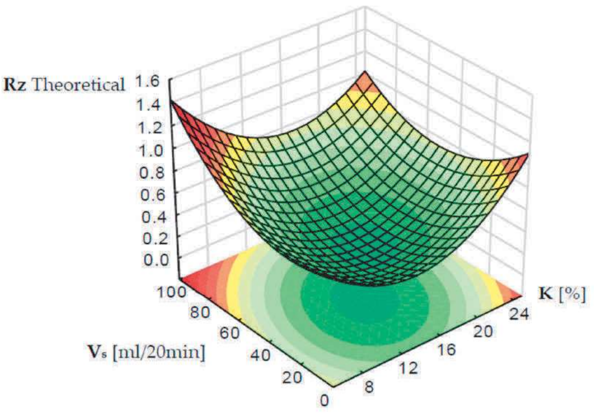

Fig. 8. Surface chart of the predicted value of roughness parameter *Rz* in relation to *K* and V_s coefficients

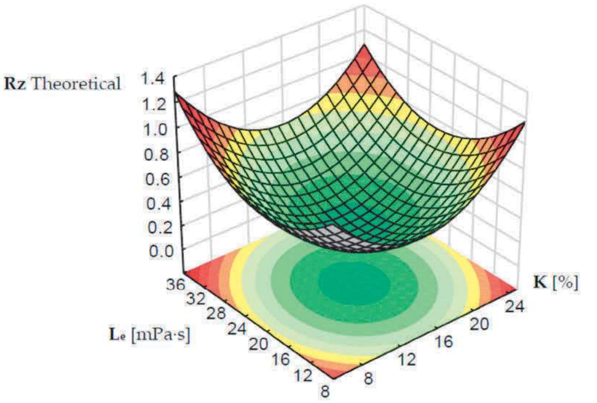

Fig. 9. Surface chart of the predicted value of roughness parameter *Rz* in relation to *K* and L_e coefficients

Analysing the graphs presented above, it is possible to see the influence exerted by predicators on the explicated variable. With this method it is possible to predict replies regarding the roughness parameter *Rz* in the function of input coefficients.

In the experimental research, roughness parameter *Rz* assumed the following values: i:

Rz_{min} = 5.225 μm for input parameters *K* = 15%, V_s = 50 ml/20 min and L_e = 23 mPa·s and

Rz_{max} = 6.777 μm for input parameters *K* = 9%, V_s = 74 ml/20 min, L_e = 29.5 mPa·s.

Conducting the optimization of the predicted replies, it was determined that the roughness parameter Rzt_{min} = 5.237 μm corresponds with input parameters: K = 14.6%, V_s = 48.7 ml/20 min i L_e= 23.2 mPa·s.

On this basis it can be stated, that after the optimization the following values were corrected: *Rz*- by 0%, *K* – conservation of the abrasive grains by 2,7%, V_s – conservation of the dosage by 2,6%.

It is also advised to slightly change the viscosity of the compound from 23 to 23.2 mPa·s.

He assessment of the influence of the parameters of forced dosing on the quality of the surface should be conducted in conjunction with the efficiency of machining. An optimum solution consists in obtaining high efficiency of machining while maintaining a high quality of the surface. This is a complex issue, since it is difficult to have a simultaneous influence on a number of roughness parameters. Concentration on a single parameter can cause the deterioration of other parameters, such as, for example, surface bearing capacity. The most important roughness parameters should result from the relationship between specific 2D parameters (such as location of the tips) in mutually perpendicular directions, due to the fact that the shape and location of the contact areas of contacting surfaces are of particular importance. To assess the influence of the conditions of forced dosing on selected 2D roughness parameters, their measurements were conducted. The results of the measurements have been presented in Tab. 8.

Next, analysis of the correlation of the influence of examined (variable) coefficients on selected roughness parameters (Tab. 9).

Table 8. List of the parameters determined for P2D(i) outline

No.	*K* [%]	V_s [ml/20min]	L_e [mPa·s]	*Ra*	*Rq*	*Rt*	*Rv*	*Rz*	*Rp*	*Rku*	*Rsm*	*Rsk*
1	15	10	23	0.9171	1.4636	6.5887	3.4616	5.4954	2.0363	4.0670	48.0559	-0.5857
2	15	50	23	0.6329	0.9371	7.0647	3.0876	5.2069	2.1886	4.3347	36.0138	-0.4355
3	15	50	23	0.6361	0.9372	7.0124	3.0851	5.2567	2.1841	4.3110	36.0850	-0.4386
4	15	50	23	0.6361	0.9333	7.0321	3.0967	5.2250	2.1833	4.3387	36.0429	-0.4366
5	15	50	23	0.6255	0.9353	7.0345	3.0303	5.2269	2.1815	4.3550	36.0934	-0.4375
6	15	50	23	0.6381	0.9329	7.0579	3.0716	5.2869	2.1852	4.3110	36.0811	-0.4357
7	15	50	23	0.6328	0.9381	7.0078	3.0786	5.2673	2.1887	4.3013	36.0246	-0.4350
8	15	90	23	0.8107	1.0716	8.8133	3.8043	6.0191	2.2154	9.5737	39.6956	-1.3440
9	5	50	23	0.6868	0.9582	10.0875	4.2833	6.5775	2.2943	9.7350	35.1398	-1.5710
10	25	50	23	0.7956	1.0345	7.3878	3.7032	6.0640	2.3608	4.1340	42.5203	-0.4247
11	21	74	29.5	0.7429	0.9713	7.7281	3.5886	6.1754	2.5869	3.9137	43.4665	-0.3703
12	21	26	29.5	0.7431	0.9649	7.8105	3.9819	6.1458	2.1639	4.5010	41.2469	-0.7273
13	9	74	29.5	0.7034	0.9077	8.8420	4.2404	6.7796	2.5391	5.4597	6.0630	-0.7630
14	9	26	29.5	0.7697	0.9941	7.7722	4.0603	6.1509	2.0906	4.5857	6.0630	-0.8240
15	15	50	34	0.7391	0.9583	7.4016	3.3392	5.8279	2.4887	3.6740	6.0630	-0.3223
16	15	50	10.3	0.6884	0.9023	7.1104	3.4198	5.8783	2.4585	3.6877	41.7411	-0.3997
17	21	74	16.5	0.6876	0.9030	8.0437	3.7786	6.0677	2.2891	5.3783	40.5722	-0.8247
18	21	26	16.5	0.7438	0.9833	7.3874	3.6503	5.9464	2.2960	4.4053	41.1710	-0.5543
19	9	74	16.5	0.7796	1.0073	8.1021	4.0598	6.3593	2.2995	4.3187	45.3597	-0.7023
20	9	26	16.5	0.6444	0.8546	6.2794	3.5118	5.3033	1.7916	4.8453	36.4907	-0.8787

Table 9. Levels of significance for the significance tests of correlation coefficients between the following variables: K, V_s, L_e, Ra, Rq, Rt, Rv, Rz, Rp, Rku, Rsm, Rsk (red is indicated for statistically significant dependencies)

Variable	**Marker correlation coefficients are significan with p < 0.05000 N = 20 (lack of data mitigated with specific cases)**											
	K	***Vs***	***Le***	***Ra***	***Rq***	***Rt***	***Rv***	***Rz***	***Rp***	***Rku***	***Rsm***	***Rsk***
K	1.0000 p= ...	.0000 p=1.00	.0000 p=1.00	.1624 p=.494	.0934 p=.169	-.3196 p=.196	-.2753 p=.240	-.1400 p=.556	.2478 p=.292	-.3831 p=.095	.4137 p=.070	.4936 p=.027
V_s	.0000 p=1.00	1.0000 p= ...	.0000 p=1.00	-.1327 p=.577	-.3321 p=.153	.5067 p=.023	.1548 p=.515	.3405 p=.142	.5705 p=.009	.3670 p=.111	-.1783 p=.452	-.1783 p=.452
L_e	.0000 p=1.00	.0000 p=1.00	1.0000 p= ...	.1516 p=.524	.0989 p=.678	.2006 p=.396	.1111 p=.641	.1779 p=.453	.2301 p=.329	-.0068 p=.977	-.6051 p=.005	.0624 p=.794
Ra	.1624 p=.494	-.1327 p=.577	.1516 p=.524	1.0000 p= ...	.8141 p=.000	.1694 p=.475	.4820 p=.031	.4467 p=.048	.0888 p=.710	.0974 p=.683	.1080 p=.650	-.1955 p=.409
Rq	.0934 p=.169	-.3321 p=.153	.0989 p=.678	.8141 p=.000	1.0000 p= ...	-.0955 p=.689	.0673 p=.778	-.0048 p=.984	-.1729 p=.466	.0187 p=.938	.2716 p=.247	-.0491 p=.837
Rt	-.3196 p=.196	.5067 p=.023	.2006 p=.396	.1694 p=.475	-.0955 p=.689	1.0000 p= ...	.7651 p=.000	.8085 p=.000	.4334 p=.056	.7807 p=.000	.2067 p=.382	-.7498 p=.000
Rv	-.2753 p=.240	.1548 p=.515	.1111 p=.641	.4820 p=.031	.0673 p=.778	.7651 p=.000	1.0000 p= ...	.9318 p=.000	.2194 p=.353	.4897 p=.028	-.2072 p=.381	-.6820 p=.001
Rz	-.1400 p=.556	.3405 p=.142	.1779 p=.453	.4467 p=.048	-.0048 p=.984	.8085 p=.000	.9318 p=.000	1.0000 p= ...	.5563 p=.011	.3976 p=.083	-.2514 p=.285	-.5023 p=.024
Rp	.2478 p=.292	.5705 p=.009	.2301 p=.329	.0888 p=.710	-.1729 p=.466	.4334 p=.056	.2194 p=.353	.5563 p=.011	1.0000 p= ...	-.0464 p=.846	-.2060 p=.383	.2086 p=.378
Rku	-.3831 p=.095	.3670 p=.111	-.0068 p=.977	.0974 p=.683	.0187 p=.938	.7807 p=.000	.4897 p=.028	.3976 p=.083	-.0464 p=.846	1.0000 p= ...	.0130 p=.956	-.9242 p=.000
Rsm	.4137 p=.070	-.0168 p=.944	-.6051 p=.005	.1080 p=.650	.2716 p=.247	.2067 p=.382	-.2072 p=.381	-.2514 p=.285	-.2060 p=.383	.0130 p=.956	1.0000 p= ...	.0210 p=.930
Rsk	.4936 p=.027	-.1783 p=.452	.0624 p=.794	-.1955 p=.409	-.0491 p=.837	-.7498 p=.000	-.6820 p=.001	-.5023 p=.024	.2086 p=.378	-.9242 p=.000	.0210 p=.930	1.0000 p= ...

Analysing the influence of the conditions of forced dosing (K, V_s and L_e) on correlation with surface roughness parameters (Ra, Rq, Rt, Rv, Rz, Rp, Rku, Rsm and Rsk) it was determined that dosing conditions influence only certain parameters of roughness. Statistically significant correlations of the examined coefficients occur for the following pairs: K - Rsk (Fig. 11), V_s - Rt (Fig. 12), V_s - Rp (Fig. 13) and L_e - Rsm (Fig. 14).

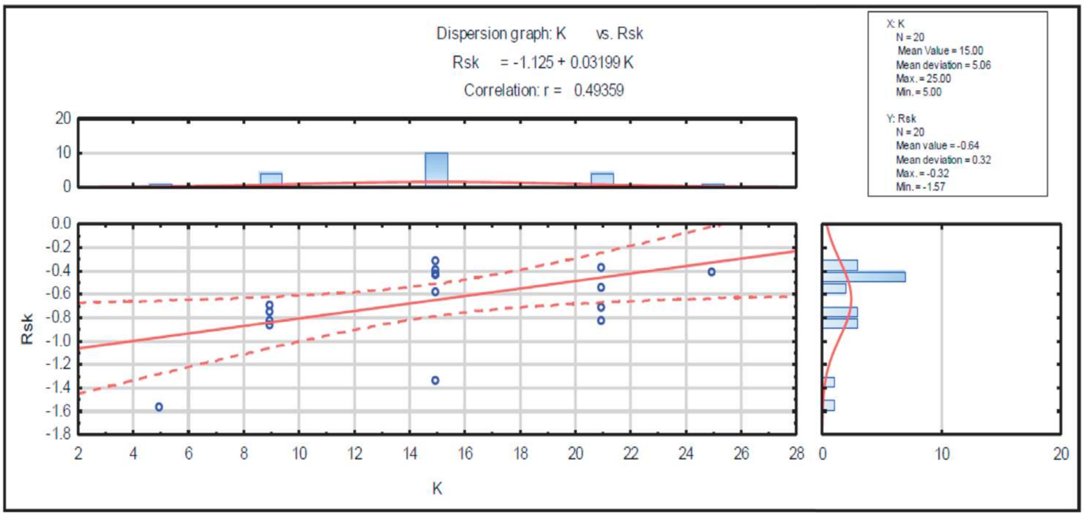

Fig. 11. Correlation of the input coefficient K and roughness parameter Rsk

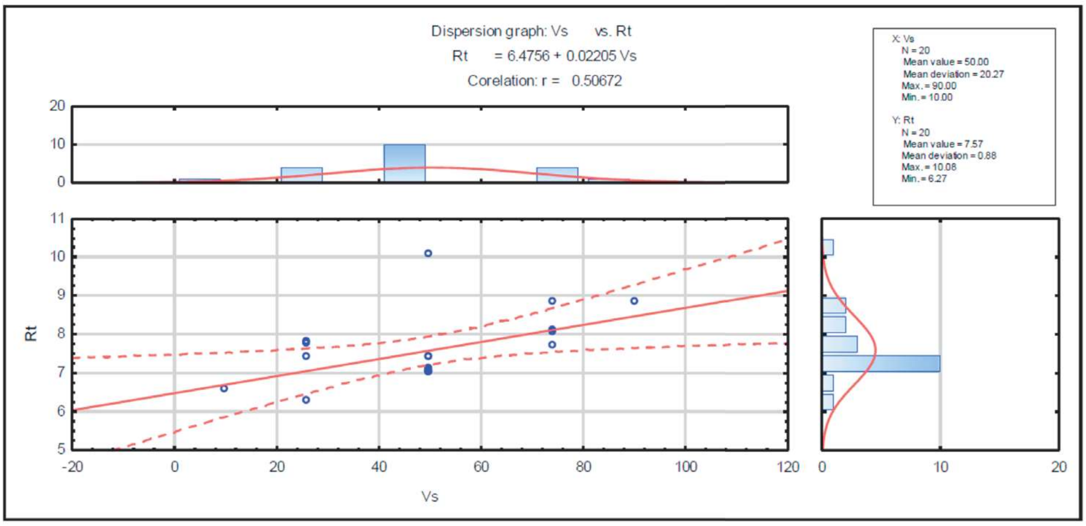

Fig.12. Correlation between input coefficient *K* and roughness parameter *Rt*

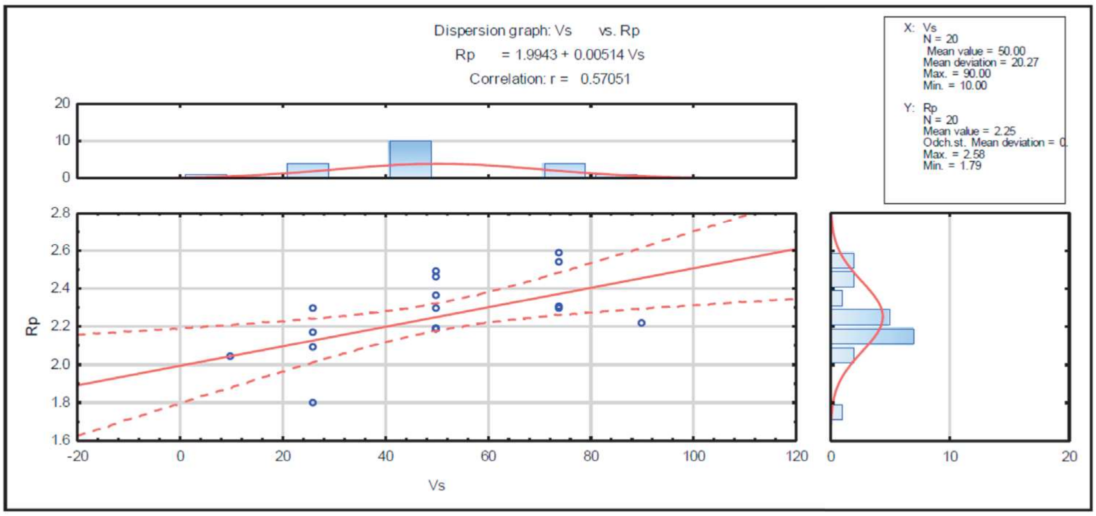

Fig. 13. Correlation of the input coefficient *K* and roughness parameter *Rp*

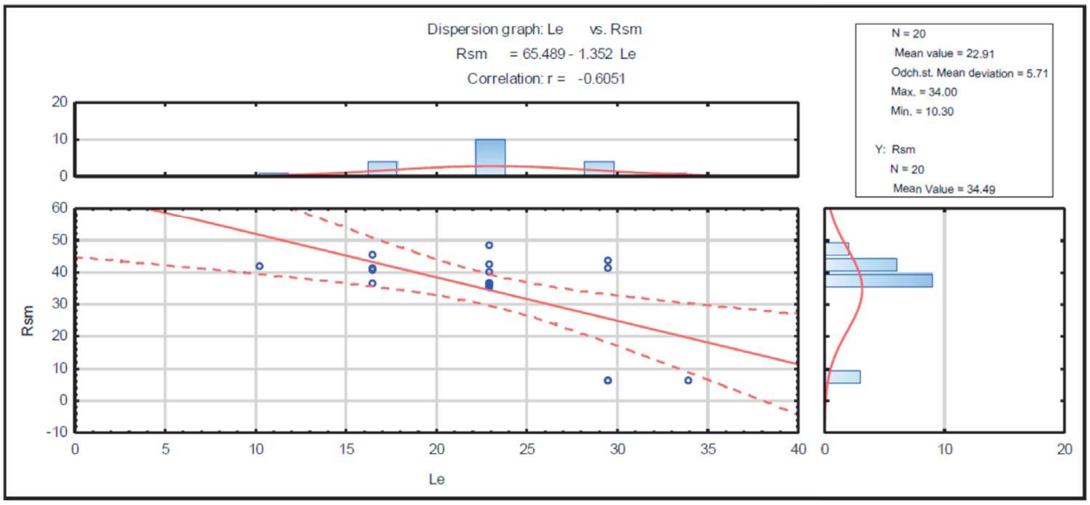

Fig. 14. Correlation of the input coefficient *K* and roughness parameter *Rsm*

Final conclusions

On the basis of the conducted research and analyses, the following general conclusions can be formulated:

- Developed and constructed innovative system of dosing the abrasive compound onto a disc lap brings significant savings in terms of the level of wear of micro-grains, thereby reducing the tool costs of this process of highly-precise machining,
- Analysed conditions of forced dosing, such as percentage content of the abrasive grains in the compound K, dosage of the compound V_s and viscosity of the liquid components of the compound have a significant influence on the basic parameters of the surface roughness of the machined technical ceramics,
- Regression equation developed in the result of the conducted research allows predicting the surface roughness parameter Rz for lapped sealing elements made of Al_2O_3 ceramics.

References

[1] Bakoń A., Barylski A. 2017. Ziarna i mikroziarna diamentowe. Rodzaje ścierniw i przykłady zastosowania. Gdańsk: Wydawnictwo Politechniki Gdańskiej,.

[2] Barylski A. 2015. „Badania wpływu koncentracji ścierniwa i intensywności dawkowania zawiesiny na efekty docierania jednotarczowego". Mechanik 8-9: 20-24.

[3] Barylski A., Deja M. 2010. "Wear of a tool in double-disk lapping of silicon wafers". [In] ASME 2010 International Manufacturing Science and Engineering Conference, American Society of Mechanical Engineers Digital Collection 1: 301-307.

[4] Barylski A. 2013. Docieranie powierzchni płaskich na docierarkach. Gdańsk: Wydawnictwo Politechniki Gdańskiej.

[5] Barylski A. 2013. "Technological problems in lapping on flat surfaces of ceramics parts". Solid State Phenomena 199: 627-632.

[6] Barylski A., Gniot M. 2018. „Wpływ zawiesiny ściernej dawkowanej w sposób wymuszony na wydajność docierania jednotarczowego elementów ceramicznych". Mechanik 8-9: 734-736.

[7] Belkhir N., Bouzid D., Herold V. 2009. "Surface behaviour during abrasive grain action in the glass lapping process". Applied Surface 255(18):7951-7958.

[8] Box G., Hunter J. 1957. "Multifactor experimental designs for exploring response surfaces". Ann Math. Statist. 1.

[9] Deja M., List, M., Lichtschlag L., Uhlmann E. 2019. "Thermal and technological aspects of double face grinding of Al2O3 ceramic materials". Ceramics International 45(15): 19489-19495.

[10] Deja M. 2010. "Simulation Model for the Shape Error Estimation During Machining With Flat Lapping Kinematics". [In] ASME 2010 International Manufacturing Science and Engineering Conference, American Society of Mechanical Engineers Digital Collection 1: 291-299.

[11] Deshpande L.S., Raman S., Sunanta O., Agbaraji C. 2008. "Observations in the flat lapping of stainless, steel and bronze". Wear 265(1-2): 105-116.

[12] Gniot M., Barylski A., Migawa K. 2017. „System dawkowania zawiesiny ściernej w docieraniu powierzchni płaskich". Mechanik 10: 894-896.

[13] Klocke F. 2009. Manufacturing Processes 2 – Grinding, Honing, Lapping. Springer – Verlag,.

[14] Liu H.K., Chen C.C., Chen W.C. 2017. "Diamond lapping of sapphire wafer with addition of Graphene in slurry". Procedia Engineering 184: 156-162.

[15] Mańczak K. 1976. Technika planowania eksperymentu. Warszawa: WNT,.

[16] Marinescu I.D., Uhlmann E., Doi T.K. 2007. Handbook of Lapping and Polishing. Manufacturing Engineering and Materials Processing. CRC Press, Taylor & Francis Group.

[17] Polański Z. 1977. Metody optymalizacji w technologii maszyn. Warszawa: PWN.

[18] Zong W.J., Cheng K., Sun T., Wang H.X., Liang Y.C. 2005. "The material removal mechanism in mechanical lapping of diamond cutting tools". International Journal of Machine Tools and Manufacture 45(7-8): 783-788.

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