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MACHINING OF HARDENED BEARING STEELS

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Abstract: *The paper deals with the issues of machining by finishing turning of hardened materials in the production of bearing rings. In this area, grinding is mainly used as standard technology. It is a demanding production process requiring precision machinery and optimally set technology. Under these conditions, the mass-production can offer components with prescribed degrees of accuracy in the tolerance level from IT 4 to IT 5 and with the arithmetical mean deviation of the profile in the range between Ra = 0.4 and Ra = 0.8. For these conditions, there has been a long search for alternative technology that would ensure the same required values with simpler demands on manufacturing process. One of the developmental paths was focused on turning with the use of advanced cutting materials for machine tools. It is primarily the use of cubic boron nitride (CBN). A cheaper and more affordable option is also the application of cemented carbide of group H. This carbide is intended primarily for finishing machining of the materials difficult to machine. Regarding the tool geometry, either the classic variant with radius edge or the Wiper variant can be used. On the world market, reputable companies offer these materials in the form of replaceable inserts; nevertheless their application for machining of e.g. hardened materials also depends on other decisive factors. As shown in performed and evaluated practical experiments, it is not easy to determine the initial conditions. The experience gained from this area is the subject of this article.*

Keywords: *hardened material, bearing ring, machining, turning, replaceable insert, cutting speed, feed.*

1. INTRODUCTION

Replacement of grinding operations by another machining method has been employing technologists and developers of many companies for a long time. The so-far results have shown the applicability of new kinds of cutting materials. However, these results require a number of tests and their evaluation [6, 7]. A described experiment of our research team aims to contribute to findings in this area.

2. IDENTIFICATION OF PROBLEM

2.1. Material for machined parts

The machined part is a bearing ring from steel 14209 according to the CSN 414209 standard [3]. According to EN ISO 683-17:2002 is marking material 100CrMnSi6-4. The material composition is referred to in Table 1.

Table 1

Chemical composition of steel 14209

C	*Mn*	*Si*	*P*	*S*	*Cr*	*Ni*	*Cu*	*Ni +Cu*
0.9 ÷ 1.1	0.9 ÷ 1.2	0.35 ÷ 0.65	0.027	0.03	1.3 ÷ 1.65	0.3	0.25	0.5

The material is used in hardened state and tempered state 63÷59 HRC. Prior to machining, the state of thermal processing of our samples was 59 HRC.

2.2. Machine tool used

The machining experiment was performed on a universal centre lathe SV18 RD with fixed revolutions. This is a typical machine with a rigid structure and a range of parameters suitable for our tests. Machine tool SV18RD is shown in Fig.1. Machine specifications are as follows:

- circular dimension above the bed 380 mm,
- circular dimension above the saddle 215 mm,
- length of turning 1.250 mm,
- range of spindle revolutions min^{-1} 30 – 2.800,
- range of longitudinal feeds $mm{\cdot}rev^{-1}$ 0.02 – 2.8,
- range of transverse feeds $mm{\cdot}rev^{-1}$ 0.01 – 1.4,
- output of principal motor 10 kW,
- dimensions $w \times l \times h$ 950 × 2.720 × 1.210 mm,
- mass 1.950 kg.

2.3. Tools used for experiment

For turning of hardened material we used replaceable inserts of cubic boron nitride CBN10, CBN060K and CBN160C made by company Seco Tools AB and also cemented carbide inserts TH1000 from the same company [4, 10]. The insert geometry was in the variant of radius edge with *R* 0.4 mm or *R* 0.8 mm and in some variants of CBN material and also of Wiper design.

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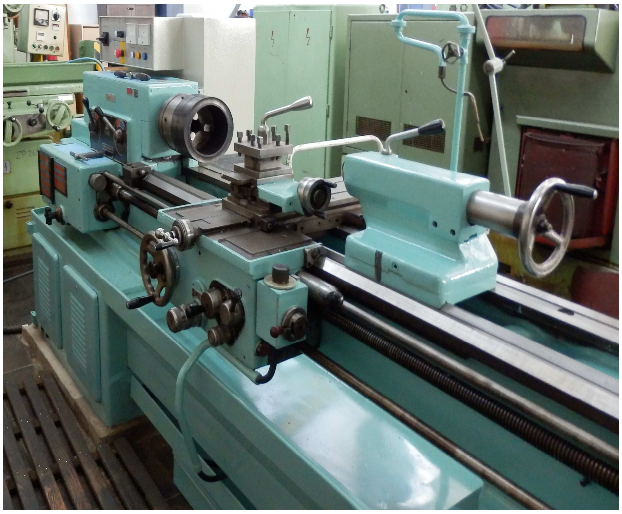

Fig. 1. Machine tool SV18RD.

Fig. 2. Roughness measuring device Taylor Hobson.

2.4. Recommended cutting conditions

Selected cutting conditions were primarily based on the recommendations and restrictions generally given by the manufacturer. For cubic boron nitride the cutting speed v_c is in the range 100 ÷ 200 m·min^{-1} with the used mean value of 150 m·min^{-1}. For cemented carbide, specific recommendations for individual inserts were used, which also means a mean cutting speed of each range. For all materials the depth of cut a_p was determined 0.2 mm and in one case 0.25 mm and in another case 0.4 mm. Feed was selected from the range of recommended values in the middle and upper regions [8, 10].

2.5. Conditions of measurement

Evaluation was performed of measuring the average arithmetic deviation of profile *Ra*, and then the maximum height of the profile *Rz* and magnetoelastic parameter Mp. Roughness was measured by the Taylor Hobson device as shown in Fig. 2. Measurement of each sample was performed 5 times across the length of 12.4 mm in various random locations of the workpiece. Magnetoelastic parameter measurements were carried out using Barkhausen analyser Rollscan 300. An analysis of the so-called Barkhausen noise is a method of assessing the surface integrity after the operations such as grinding because of occurrence of surface loading with residual stress [9]. The difference between grinding and finishing turning may be very important in this region. Thus, it is possible to test the exposed surface of the component in a non-destructive way, especially to quantitatively assess a degree of damage to the surface and then subsequently to optimize the machining process. However, primary results are *Ra*.

2.6. Methodology for assessment of measured values

The measured values are assumed to be of continuous random nature and normal distribution. Out of the five values obtained for each measurement, the estimate is carried out of the mean value of *x*, the estimate of the standard deviation *s*, the confidence limit *mh*1 and statistical limit *Ls*1. For selected results, tables are further complemented with graphs of selected measurements. The default quantile *q* of Student distribution is determined by $t_{1-\alpha/2,n-1}$ = 2.776 for one-sided confidence interval and coefficient $k_{1(n,p,1-\alpha)}$ = 4.21 for one-sided statistical interval [1, 2, 5].

3. EXPERIMENT

3.1. Cutting conditions used

Cutting conditions used for each cutting material for 20 turnings on 10 samples of bearing rings are shown in Table 2. The revolutions are calculated from the recommended cutting speed and a diameter of machined component in the value of 215 mm. Figure 3 shows the working space of the machine during the experiment, where the accuracy of cutting conditions is documented by a characteristic fine friable chip.

Used cutting conditions are referred to in Table 2.

Figure 4 shows measurements on the Taylor Hobson device in detail.

Table 3 refers to the individual measured values.

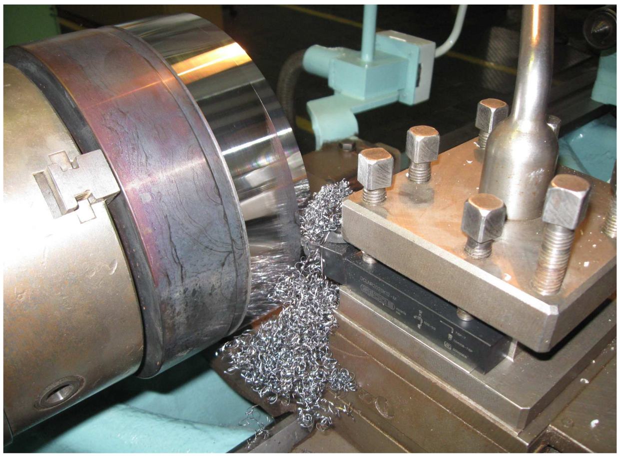

Fig. 3. Working space of machine SV18RD.

Table 2

Used cutting conditions

Turn. No.	*insert*	*a_p (mm)*	*f (mm)*	*v_c ($m \cdot min^{-1}$)*	*n (min^{-1})*
1	CNGA 120404 S 01020 L1B CBN10	0.2	0.05	150	222
2		0.2	0.147	150	222
3	CNGA 120408 S 01020 L1B CBN10	0.2	0,1	150	222
4		0.2	0.147	150	222
5	CNGA 120408 S 01020 L1 WZB CBN10	0.2	0.1	150	222
6		0.2	0,1	150	222
7	CNGA 120408 S 01525 L1 WZB CBN060K	0.2	0.1	150	222
8		0.2	0.2	150	222
9	CNGA 120408 S 01525 L1 WZP-B CBN060K	0.2	0.1	150	222
10		0.2	0.2	150	222
11	CNGA 120412 S 01525 L1 WZB CBN160C	0.2	0.1	150	222
12		0.4	0.2	150	222
13		0.2	0.2	150	222
14	CNMG120404-MF1. TH1000	0.2	0.1	170	252
15		0.2	0.2	170	252
16	CNMG120408-MF1. TH1000	0.2	0.2	155	229
17		0.25	0.2	155	229
18		0.2	0.3	155	229
19	CNMG120408-MF2. TH1000	0.2	0.2	125	185
20		0.2	0.4	125	185

Fig. 4. Measurements on the Taylor Hobson device.

Table 3

Measured values

turn. No.	*µm µm mV*	*meas. No.1*	*meas. No.2*	*meas. No.3*	*meas. No.4*	*meas. No.5*
1	Ra	1.1053	1.0942	0.8078	0.4179	0.4363
	Rz	5.2088	5.5651	4.8808	2.4534	2.4326
	Mp	14.0000	14.9000	13.9000	13.7000	14.4000
2	Ra	1.0819	1.0433	1.0367	1.0214	1.0074
	Rz	4.9274	4.4700	4.5655	4.5809	4.5010
	Mp	14.6000	14.8000	14.8000	15.2000	15.2000
3	Ra	0.3461	0.6011	1.0287	1.1563	0.6309
	Rz	2.1219	3.3234	4.8627	5.9268	3.5722
	Mp	14.6000	13.3000	13.5000	14.0000	14.2000
4	Ra	1.0093	0.9737	0.9704	0.9444	0.9480
	Rz	4.3676	4.1935	4.3046	4.0904	4.2953
	Mp	14.3000	15.7000	14.4000	16.4000	15.6000
5	Ra	1.0950	1.1247	1.2442	2.4555	2.4148
	Rz	4.9141	4.8230	6.4230	12.5533	13.8321
	Mp	14.2000	14.5000	14.9000	15.2000	14.8000
6	Ra	1.7276	1.8129	2.0800	1.8016	1.7589
	Rz	8.5455	8.5656	11.6935	8.2499	8.3208
	Mp	14.7000	14.5000	14.6000	14.7000	14.6000
7	Ra	1.1716	1.2382	0.9934	1.1161	0.9371
	Rz	5.5298	6.7683	5.4367	5.1734	4.6375
	Mp	14.8000	14.7000	14.4000	14.8000	14.5000
8	Ra	2.1169	2.1952	2.5041	2.0622	1.9972
	Rz	9.4528	10.1546	11.2085	9.9090	10.1240
	Mp	15.7000	15.9000	15.7000	15.3000	15.5000
9	Ra	1.0980	1.0890	1.1107	1.1098	1.0560
	Rz	4.8247	4.6190	4.9115	4.8201	4.8147
	Mp	15.4000	15.0000	15.3000	14.8000	14.9000
10	Ra	1.3706	1.6708	1.7388	1.7940	1.7554
	Rz	6.2923	7.2256	7.6738	7.9622	7.9885
	Mp	15.3000	15.1000	15.0000	15.7000	15.2000
11	Ra	1.1257	1.2643	1.4502	1.5111	1.5616
	Rz	5.1192	5.0594	6.0252	6.4835	6.6523
	Mp	14.6000	15.2000	15.8000	15.1000	15.3000
12	Ra	2.8296	2.5448	2.6697	2.5146	2.1579
	Rz	12.1353	11.3026	12.5189	12.4040	9.8840
	Mp	15.7000	14.5000	15.1000	14.7000	14.9000
13	Ra	3.8324	4.0131	3.8927	3.9723	3.3974
	Rz	16.0756	17.0677	16.0392	18.0473	16.7554
	Mp	17.7000	16.0000	16.0000	16.2000	16.5000
14	Ra	0.7871	0.7867	0.7999	0.8000	0.7927
	Rz	3.4221	3.5380	3.6632	3.6947	3.4487
	Mp	14.8000	15.0000	14.8000	15.7000	15.2000
15	Ra	2.2009	2.1958	2.2189	2.2064	2.2200
	Rz	9.6422	9.8213	9.6036	9.8336	10.0505
	Mp	18.8000	20.8000	19.0000	18.3000	18.5000
16	Ra	1.1901	1.1891	1.1971	1.1785	1.1912
	Rz	4.7790	4.7006	7.7595	4.5912	4.8479
	Mp	15.8000	15.7000	16.3000	16.1000	16.2000
17	Ra	1.3682	1.3723	1.3958	1.3999	1.3795
	Rz	5.6944	5.0190	5.2494	5.2128	5.1230
	Mp	18.4000	19.1000	19.3000	19.0000	19.1000
18	Ra	1.2450	1.6626	1.5611	2.7432	3.6669
	Rz	6.2717	8.5028	10.6493	13.0296	17.3898
	Mp	15.1000	15.6000	15.2000	15.4000	15.3000
19	Ra	1.1887	1.1841	1.2021	1.1962	1.3044
	Rz	5.2458	5.2297	5.3410	5.4178	6.5459
	Mp	16.6000	16.3000	16.9000	17.4000	17.1000
20	Ra	3.7871	3.8206	3.8484	3.8507	3.8849
	Rz	14.5755	14.5818	14.6857	14.8769	14.7838
	Mp	25.0000	25.8000	24.5000	24.3000	24.2000

3.2. Statistic evaluation

Table 4

Statistic evaluation of measured values

Turning No.	*μm μm mV*	*x*	*s*	*mh1*	*Ls1*
1	Ra	0.7723	0.3370	1.191	2.191
	Rz	4.1081	1.53922	6.019	10.588
	Mp	14.1800	0.47645	14.771	16.186
2	Ra	1.0381	0.02815	1.073	1.157
	Rz	4.6090	0.18374	4.837	5.383
	Mp	14.9200	0.26833	15.253	16.050
3	Ra	0.7526	0.33249	1.165	2.152
	Rz	3.9614	1.46777	5.784	10.141
	Mp	13.9200	0.52631	14.573	16.136
4	Ra	0.9692	0.02595	1.001	1.078
	Rz	4.2503	0.109	4.386	4.709
	Mp	15.2800	0.90388	16.402	19.085
5	Ra	1.6668	0.70373	2.541	4.630
	Rz	8.5091	4.34606	13.905	26.806
	Mp	14.7200	0.38341	15.196	16.334
6	Ra	1.8362	0.14049	2.011	2.428
	Rz	9.0751	1.4702	10.900	15.265
	Mp	14.6200	0.08367	14.724	14.972
7	Ra	1.0913	0.1245	1.246	1.615
	Rz	5.5091	0.7848	6.483	8.813
	Mp	14.6400	0.18166	14.866	15.405
8	Ra	2.1751	0.19775	2.421	3.008
	Rz	10.1698	0.64485	10.970	12.885
	Mp	15.6200	0.22804	15.903	16.580
9	Ra	1.0927	0.02239	1.120	1.187
	Rz	4.7980	0.10771	4.932	5.251
	Mp	15.0800	0.25884	15.401	16.170
10	Ra	1.6659	0.171	1.878	2.386
	Rz	7.4285	0.70547	8.304	10.398
	Mp	15.2600	0.27019	15.595	16.397
11	Ra	1.3826	0.18242	1.609	2.151
	Rz	5.8679	0.7472	6.796	9.014
	Mp	15.2000	0.43012	15.734	17.011
12	Ra	2.5433	0.24865	2.852	3.590
	Rz	11.6490	1.09527	13.009	16.260
	Mp	14.9800	0.46043	15.552	16.918
13	Ra	3.8216	0.24723	4.129	4.862
	Rz	16.7970	0.82658	17.823	20.277
	Mp	16.4800	0.71204	17.364	19.478
14	Ra	0.7933	0.00653	0.801	0.821
	Rz	3.5533	0.12294	3.706	4.071
	Mp	15.1000	0.37417	15.565	16.675
15	Ra	2.2084	0.0108	2.222	2.254
	Rz	9.7902	0.1784	10.012	10.541
	Mp	19.0800	0.9985	20.320	23.284
16	Ra	1.1892	0.0067	1.198	1.218
	Rz	5.3356	1.3583	7.022	11.054
	Mp	16.0200	0.25884	16.341	17.110
17	Ra	1.3831	0.0141	1.401	1.442
	Rz	5.2597	0.2588	5.581	6.349
	Mp	18.9800	0.34205	19.405	20.420
18	Ra	2.1758	1.0066	3.425	6.414
	Rz	11.1686	4.2873	16.491	29.218
	Mp	15.3200	0.19235	15.559	16.130
19	Ra	1.2151	0.0504	1.278	1.427
	Rz	5.5560	0.5586	6.249	7.908
	Mp	16.8600	0.42778	17.391	18.661
20	Ra	3.8383	0.0366	3.884	3.992
	Rz	14.7007	0.1304	14.863	15.250
	Mp	24.7600	0.65803	25.577	27.530

The best results were achieved by machining No. 1, No. 3 and No. 14. Surprisingly, this never occurred with Wiper geometry inserts; apparently there were problems with vibrations. These can be affected by changing the revolutions and hence the cutting speed. Statistical values for machining were also processed graphically and are shown in Figs. 5 and 6 for machining No. 1.

The individual values of *Ra* in Fig. 4 range slightly above 0. 4, however the confidence interval is nearly 1.2, which is not an optimum.

Statistic values for machining No. 3 were processed graphically and are referred to in Figs. 7 and 8.

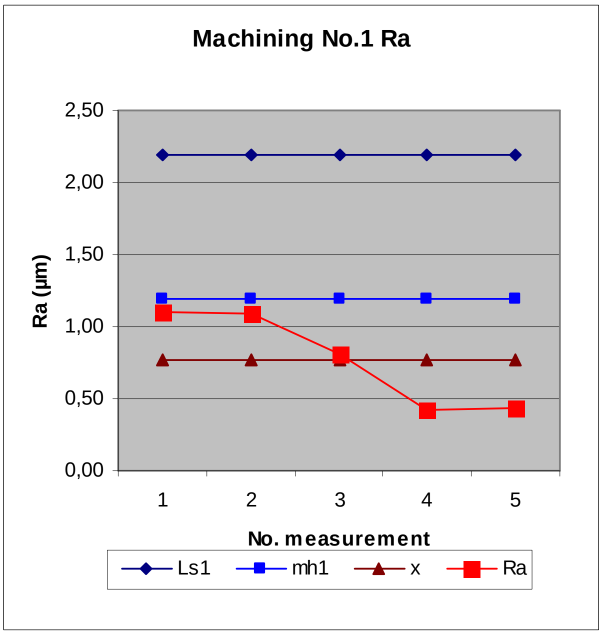

Fig. 5. Graph of machining No. 1 (parameter *Ra*).

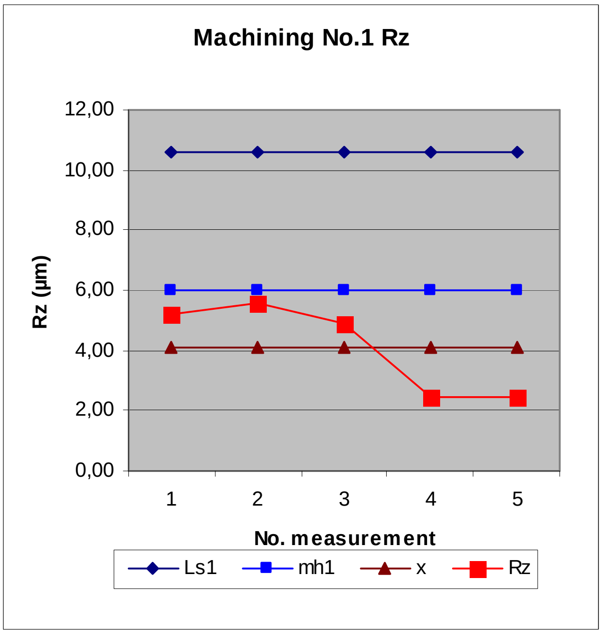

Fig. 6. Graph of machining No. 1 (parameter *Rz*).

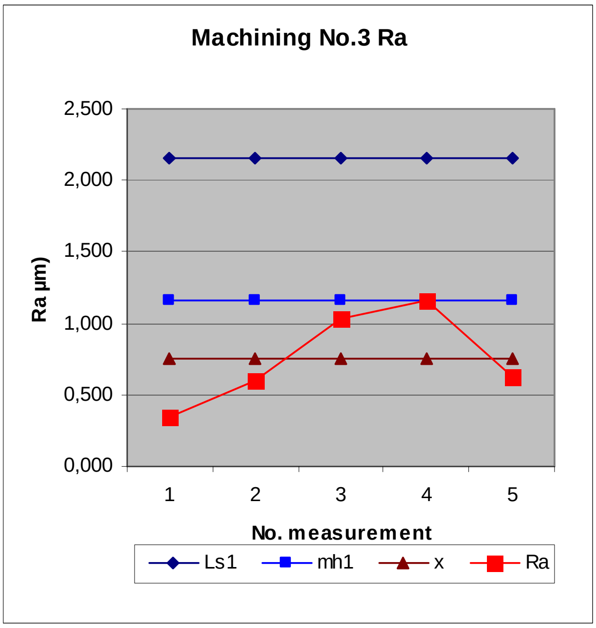

Fig. 7. Graph of machining No. 3 (parameter *Ra*).

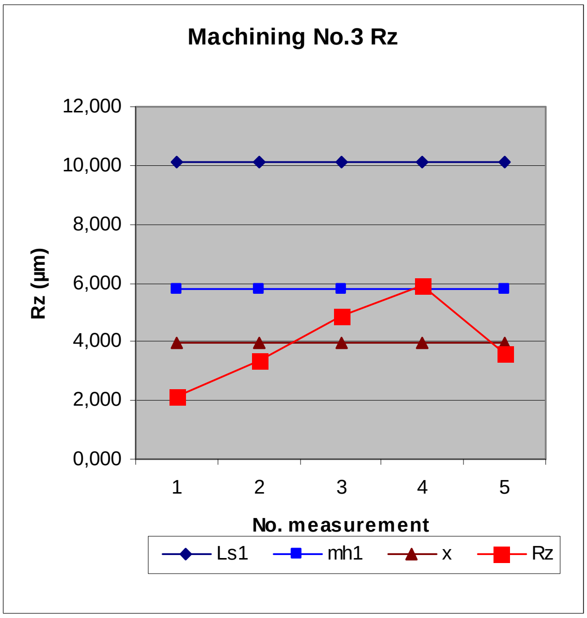

Fig. 8. Graph of machining No.3 (parameter Rz).

In Fig. 7, one of the *Ra* values reaches 0.34; however the confidence interval is 1.165, which is not acceptable for repeated production.

The best results in terms of variance and repeatability were paradoxically achieved with cemented carbide where the confidence interval reached the Ra value of 0.801 and the estimate of standard deviation was 0.00653, as shown in Fig. 9.

Moreover, the value of *Rz* shows a similar course and a very small size of standard deviation estimate of 0.12294. The situation is shown in Fig. 10.

Figure 11 shows the assessment of the course of Barkhausen noise of surface integrity after turning of hardened material.

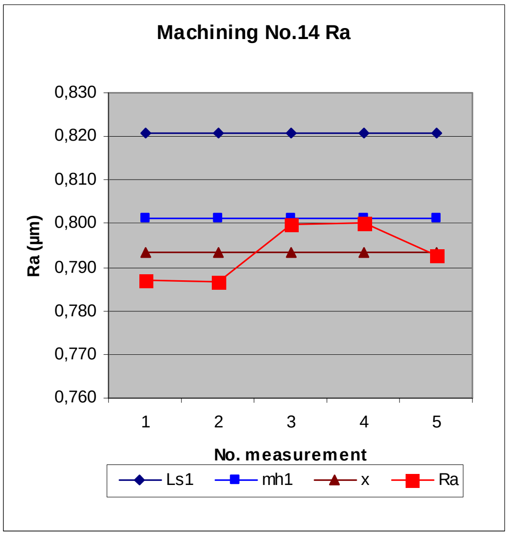

Fig. 9. Graph of machining No. 14 (parameter *Ra*).

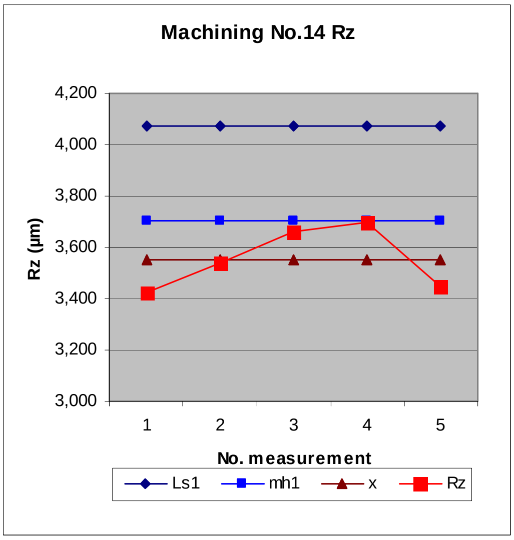

Fig. 10. Graph of machining No.14 (parameter Rz).

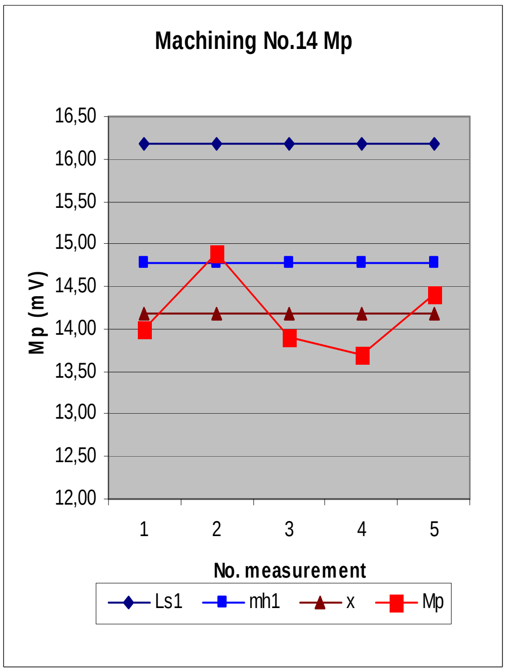

Fig. 11. Graph of machining No.14 (parameter Mp).

4. CONCLUSIONS

This experiment verified the characteristics and suitability of advanced tools indicated by renowned producers in their catalogue databases. Verification was carried out under specific conditions in laboratories of the Institute of Manufacturing Technology, Faculty of Mechanical Engineering; these conditions may not be fully identical in ordinary industrial environment. Tools were fitted with replaceable inserts made of CBN and cemented carbide of type H. The geometry of insert edge was in a version of standard radius tip, and also the tip of Wiper version.

Primary results of experimental machining are included in Tables 1 to 3. From these values it is apparent that the expected compliance of catalogue data and inserts was only with inserts labelled 1, 3, and 14. Other inserts failed to meet the values, mainly their variance was high. However, in items 5-13 with Wiper geometry, vibration problems are noticeable; these were clearly manifested during the machining process. According to the authors' experience and opinion, this phenomenon can be suppressed by changing the operating parameters, i.e. primarily the cutting speed v_c, in small extent also feed f, and depth of cut a_p. This fine-tuning has not been included in the present experiment. However, continuation of the experiment is planned in the near future.

Another important finding results from the analysis of Barkhausen noise during this experimental machining. However, for serious evaluation, it is first necessary to know the noise manifestation in a standard grinding operation that has not yet been performed; therefore the data are not available. From the existing partial evaluation it is evident that Barkhausen noise is dependent on the values of feed f and depth of cut a_p.

At present it can be stated that according to the existing values of Barkhausen noise the residual internal stress in the surface layer of the material is relatively low, as shown by measurements performed. Thus the experiment has served its purpose. Under fine-tuned conditions, within certain limits, a grinding operation of hardened material can be replaced by finishing turning.

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