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INVESTIGATION OF MICROGEOMETRY ON DIAMOND BURNISHED SURFACES

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SUMMARY
Paper deals with environment-friendly machining technologies, specifically with hard turning and diamond burnishing. Burnishing is a less known method, when we machine the surface of workpiece with a harder tool, without chip. At this technology we use minimal quantity lubrication (MQL) equipment. MQL technology and dry machining belongs to popular methods due to decreased coolant and lubricant fluid using. Experiments focus on the microgeometrical properties (surface roughness) of workpiece, at variation of feed and burnishing force.

Keywords: Diamond burnishing, diamond tool, feed, forming force, surface roughness.

1. INTRODUCTION

Diamond burnishing tools are very economical tools for producing mirror-like surfaces finished on machined surfaces. They are especially suited for shafts and can burnish flat face surfaces [1].

The diamond burnishing belongs to finish-machining. It is environment-friendly technology, because for cooling and lubricating we use MQL technology. It means large reduction of coolant and lubricant fluid (2-50 l/h), in comparison with standard machining methods (120-600 l/h). The surface roughness (Ra=0,03…0,2 μm) and the surface strength can be preparable by this method. So, it not only replaces the traditional surface finishing technologies (e.g. grinding, polishing), but those in many case proves more effective [2, 3].

2. BURNISHING OF EXTERNAL CYLINDRICAL SURFACES

This method is suitable for machining of internal and external cylindrical surfaces. Burnishing of external cylindrical surfaces can be performed on high precisely turning machine. The burnishing insert with diamond edge presses the spring to machined surface. The diamond is particularly good burnishing tool, because it slides on metals, has a low frictional factor with high hardness. The burnishing force has an optimum, during which the process is ineffective, above it due to destruction, the surface coarsen. Too high forming speed and high feed can cause the degradation of the effectiveness of process.

Similar surface roughness can be provided by fine turning or grinding [2, 3].

As we mentioned, diamond burnishing is finishing technology, therefore before burnishing we applied hard turning. So the experimental process is composed from the next parts:

- hard turning process - preparing of surface for the diamond burnishing (process without cooling – called as dry machining),
- diamond burnishing process (process with minimal quantity lubrication - MQL cooling).

3. CHARACTERISTICS OF HARD TURNING, EXPERIMENTAL RESULTS

Hard turning *(Hard Cutting, HC)* means machining of hardened steels and materials with hard coat by tools with regular tool geometry. The lower limit of hardness is 47 HRC. This process also belongs to environment-friendly methods, because here we apply dry machining. It means, that at machining process we don't use any coolant or lubricant fluid. In the past, workpieces with this hardness machined only by grinding [2, 3].

By hard turning, in addition to cost decreasing and productivity growth, frequently observed surface micro cracks and burns are avoidable.

The aim of hard turning experiments is to explore, what effect has a hard turning technology for machined surface roughness, before burnishing. We measured also the size of forces during machining process. Images represent the compiled measuring layout.

Figure 1. The measuring system and work area used for force measurements

Experimental conditions at hard turning were the following:

Applied machine: SU50/1500 turning machine.

Workpiece clamping: chuck with three jaws, with precision arbor.

Workpiece: material 100Cr6 hardened bearing steel (HRC64), with geometry Ø90x Ø74x23 mm.

Machined diameter: D_w = Ø 90 mm.

Machining tool: tool holder DCLNR 2020K12, material CBN plat, ABC 25/F (product ATORN) for solid surfaces, plat shape symbol CNGA 120508F-R. Material of plat is cubic nitride boron, what means, that isn't possible to use any coolant and lubricant fluid at machining process. Cutting materials CBN set new standards in continuous and intermittent cutting with their excellent wear characteristics.

Technological parameters were the following: cutting speed v_c = 100 m/min; depth of cut a = 0,3 mm; feed: f = 0,05… 0,3 mm/rev. We don’t used cooling or lubrication.
During experiments we used feed f = 0,05 mm/rev.; 0,1 mm/rev.; 0,2 mm/rev.; 0,3 mm/rev. Force components were measured with KISTLER 9257B three-component, piezoelectric force measuring machine and data recording system.
We found, that in range of small feed prevails the literature establishment, that $F_f < F_c < F_p$, but for f > 0,2 mm /rev is not valid. Furthermore it is appeared, that with increasing of feed, the force component F_c began to strong increasing. The results of force measurement are presented on Fig 2.

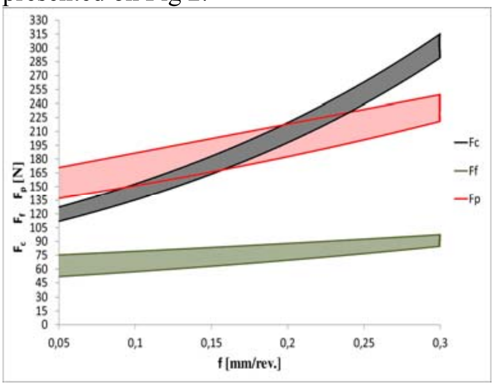

Figure 2. Diagram f-F_c, f-F_f, f-F_p

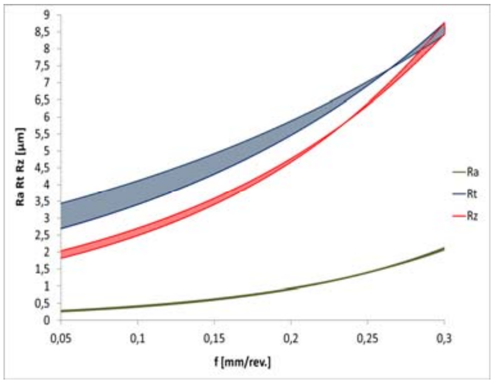

Figure 3. Diagram f-R_a, f-R_t, f-R_z

Literature data and later experiences shows, that surface roughness after burnishing depend on hard turning surface roughness. The surface roughness was measured on the MITUTOYO Formtracer SV-C3100 contour and roughness measuring machine.
The f–R_a, f–R_t diagrams, based on R-profile measurements are presented on Fig 3.

4. EXPERIMENTAL CONDITIONS AND RESULTS AT DIAMOND BURNISHING

Fig 4. presents the compiled measuring layout. Here we can see the MQL equipment, used at machining.

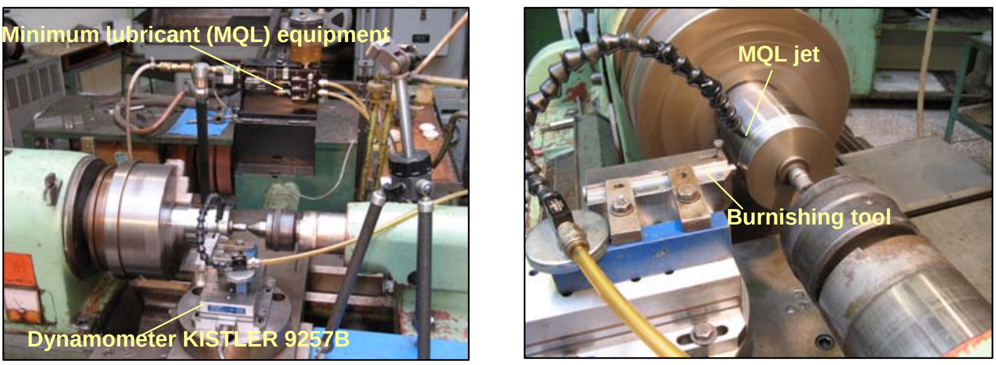

Figure 4. Experimental measuring layout for diamond burnishing

Experimental conditions at diamond burnishing were the following:
Applied machine: SU50/1500 turning machine.
Workpiece clamping: chuck with three jaws, with precision arbor.

Wokpiece: material: 100Cr6 hardened bearing steel (HRC64), with geometry: Ø89,4x Ø74x23 mm,.
Burnished diameter: D_w = 89,4 mm (after hard turning).
Burnishing tool: spring burnishing tool with PCD tip, r_v = 1,5 mm radius insert (Fig 5.).
Technological parameters were: forming speed v_b = 80 m/min; burnishing force in direction of grip: $F_b \approx$ 100 N; feed f_b = 0,03… 0,08 mm/rev.
We used minimal quantity lubrication (MQL) equipment UNIST 9570-4-5-12. The oil quality was DASCOLUB E9, with viscosity 20 °E.

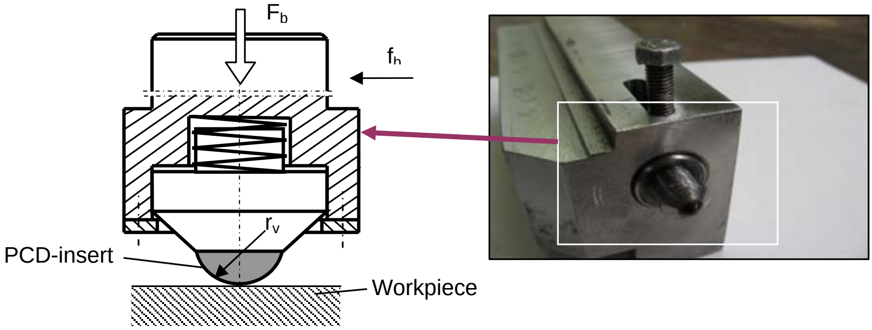

Figure 5.Schematic and photo of burnishing tool with PCD-insert

During the experiments, we measured force components (F_b) by dynamometer KISTLER 9257B and by data recording system. Results conclude, that between the tool (PCD) and the workpiece (100Cr6 hardened steel) is a very small friction. We burnished each previously, hard turned ring with feed f_b = 0,03 mm/rev; 0,05 mm/rev and 0,08 mm/rev. We measured the surface roughness on the MITUTOYO Formtracer SV-C3100 shape and roughness measuring machine.

We planned burnishing experiments on the base of full-factorial experiment. We can see roughness metrics (R_a, R_z, R_t) in Tables 1-3., at different technological settings. In tables values with index o presents the average of roughness data after hard turning. Values with mark * are calculated values, according to Eq. 1.

$$\log Rx=\log C_{Rx}+x_{1Rx}\cdot \log f_b+x_{2Rx}\cdot \log F_b, \quad (1)$$

where Rx is surface roughness (Rao; Rzo; Rto), C_{Rx} is constant and x_1 and x_2 are exponents.

Table 1. Measured roughness metrics (R_a, μm) at different technological settings

F_b [N]	**Hard turning, f [mm/rev]**											
	0,05 (Rao=0,291μm)			**0,1** (Rao=0,390μm)			**0,2** (Rao=0,885μm)			**0,3** (Rao=2,168μm)		
	Diamond burnishing f_b [mm/rev]											
	0,03	**0,05**	**0,08**	**0,03**	**0,05**	**0,08**	**0,03**	**0,05**	**0,08**	**0,03**	**0,05**	**0,08**
100	**0,1913**	**0,207***	**0,216**	**0,231**	**0,255***	**0,275**	**0,153**	**0,565***	**0,65**	**1,718**	**1,787***	**1,928**
150	**0,148***	**0,176**	**0,133***	**0,193***	**0,219**	**0,184***	**0,445***	**0,452**	**0,445***	**1,389***	**1,444**	**1,276***
200	**0,118**	**0,172***	**0,140**	**0,167**	**0,227***	**0,196**	**0,424**	**0,538***	**0,492**	**1,239**	**1,544***	**1,368**

Table 2. Measured roughness metrics (R_z, μm) at different technological settings

F_b [N]	Hard turning, f [mm/rev]											
	0,05 (Rzo=1,994μm)			**0,1** (Rzo=2,533μm)			**0,2** (Rzo=4,517μm)			**0,3** (Rzo=8,883μm)		
	Diamond burnishing f_b [mm/rev]											
	0,03	0,05	0,08	0,03	0,05	0,08	0,03	0,05	0,08	0,03	0,05	0,08
100	**1,196**	**1,266***	**1,32**	**1,488**	**1,523***	**1,554**	**2,347**	**2,56***	**2,809**	**5,946**	**6,199***	**6,479**
150	**0,855***	**1,031**	**0,783***	**1,108***	**1,193**	**0,966***	**2,116***	**2,139**	**2,143***	**5,012***	**5,175**	**4,671***
200	**0,669**	**1,048***	**0,915**	**0,885**	**1,225***	**1,039**	**1,659**	**2,5***	**2,368**	**4,448**	**5,519***	**4,948**

Table 3. Measured roughness metrics (R_t, μm) at different technological settings

F_b [N]	Hard turning, f [mm/rev]											
	0,05 (Rto=3,562 μm)			**0,1** (Rto=3,31 μm)			**0,2** (Rto=5,05μm)			**0,3** (Rto=9,467μm)		
	Diamond burnishing f_b [mm/rev]											
	0,03	0,05	0,08	0,03	0,05	0,08	0,03	0,05	0,08	0,03	0,05	0,08
100	**1,462**	**1,575***	**1,628**	**1,578**	**1,74***	**1,886**	**2,75**	**2,943***	**3,319**	**6,47**	**6,674***	**6,967**
150	**1,152***	**1,322**	**1,042***	**1,309***	**1,413**	**1,179***	**2,528***	**2,355**	**2,56***	**5,517***	**5,581**	**5,166***
200	**0,934**	**1,32***	**1,101**	**1,101**	**1,496***	**1,214**	**2,54**	**2,894***	**2,780**	**4,999**	**5,933***	**5,381**

Constants and exponents of statistical evaluation can see in Table 4.

Table 4. Constants and exponents of statistical evaluation

	Hard turning, f [mm/rev]											
	0,05			**0,1**			**0,2**			**0,3**		
	Diamond burnishing											
	Ra	Rz	Rt	Ra	Rz	Rt	Ra	Rz	Rt	Ra	Rz	Rt
C_{Rx}	**6,489**	**54,121**	**37,305**	**3,770**	**44,260**	**37,391**	**5,090**	**14,117**	**11,329**	**23,638**	**53,832**	**47,198**
$x_{1\ Rx}$	**0,152**	**0,212**	**0,140**	**0,171**	**0,104**	**0,141**	**0,195**	**0,172**	**0,138**	**0,108**	**0,097**	**0,075**
$x_{2\ Rx}$	**-0,648**	**-0,676**	**-0,597**	**-0,473**	**-0,663**	**-0,574**	**-0,349**	**-0,259**	**-0,202**	**-0,487**	**-0,406**	**-0,376**

Results of statistical evaluation were represented in 3D diagrams (Fig 7-9.).

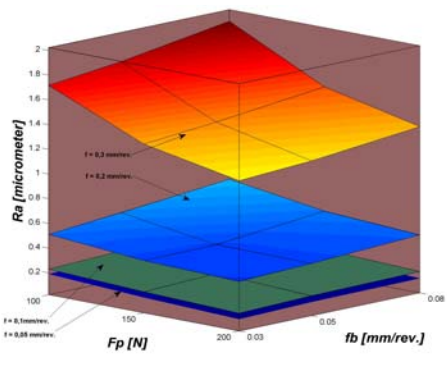

Figure 7. 3D diagram f-F_p-R_a

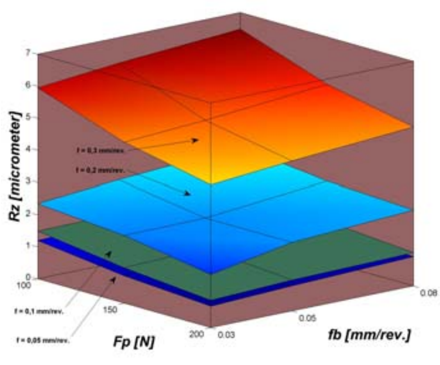

Figure 8. 3D diagram f-F_p-R_z

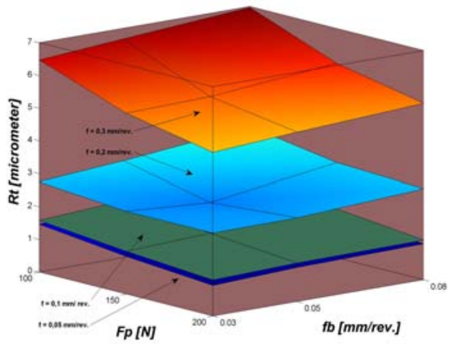

Figure 9. 3D diagram f-F_p-R_t

5. CONCLUSION

Paper deals with ecological machining technologies. At hard-turning process we did not use any cooling or lubrication.
At diamond burnishing process we use so called MQL – minimum quantity lubrication equipment UNIST 9570-4-5-12. The oil quality was DASCOLUB E9, with viscosity 20 °E.

On the base of achieved results we can conclude the next statements:

- We machined the raw workpiece by hard turning, while we investigated the force relations, before diamond burnishing. We determined that the passive force (F_p) is the dominant at machining with low feed, but at machining with high feed, the main cutting force (F_c) becomes more significant.
- The surface roughness (R_a, R_z, R_t) continuously (parabolic) increases with feed, in studied range, at hard turning.
- At diamond burnishing, we concluded by statistical evaluation, that by increasing of feed (f_b), the surface roughness (R_a, R_z, R_t) increases on each surface. In contrast, by increasing of burnishing force, the surface roughness decreases.
- Surface roughness by diamond burnishing can be reduced with third, compared to hard turning. The reduction slightly depends on feed and greatly depends on burnishing force.

Acknowledgements

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6. REFERENCES

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