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Diamond burnishing for mould and die industry

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Abstract

Special ultra-precision processes are necessary to machine surfaces for optical applications with required surface roughness Ra < 30 nm. The use of ultra-precision cutting results in low feed f and significantly reduced cost-efficiency. Diamond burnishing can be a cost-effective alternative. The process reduces the surfaces roughness and generates residual stress, which is advantageous for the workpiece's fatigue strength. However, diamond burnishing is mostly used for post-processing of rotating parts. Applications of diamond burnishing by linear motion, e. g. in mould and die making, are not common. The article shows first investigations to manufacture surfaces with optical quality on milled parts made of steel X37CrMoV5-1, copper CW008A, brass CW612N and aluminium 5083. The experiments were carried out on a 5-axis milling machine tool PFM 4024-5D, Primacon GmbH, Peißenberg, Germany. The feed velocity, the penetration depth, and the stepover were varied as input parameters. Vickers hardness and the surfaces roughness were measured as reference criteria. Thus, the ability for the surface improvement by diamond burnishing of complex shaped surfaces could be shown.

Keywords: burnishing, milling, surface roughness, workpiece hardening

1. Introduction

The surface refinement which can be achieved by cutting processes is decisively limited by process parameters feed f, cutting width a_e, cutting depth a_p, and the corner radius r_ε of the tool, as well as the machine tool and material properties. To manufacture surfaces with low surfaces roughness values low feeds f are needed. This results in decreasing economic efficiency. Moreover, the production of optical-functional components on conventional high-precision milling machine tools is not possible yet. Therefore, various techniques were used for post-processing technical surfaces [1]. For example diamond burnishing is able to reduce the surface roughness by plastic deformation. Moreover, diamond burnishing generates residual stress σ_r in a workpiece. Due to this, higher fatigue strength σ_f of the workpiece can be achieved. Advantages of diamond as material for burnishing tools are especially the high hardness H, the high resistance against abrasive wear as well as the low friction coefficient µ [2].

In diamond burnishing processes the burnishing force F_{BN} has to generate strains σ in the contact zone between workpiece and tooltip which are higher than the yield point.

According to DIN 8583 diamond burnishing has to be distinguished in rotating and linear movements because the used machine tools, the manufactured workpieces and the used tools are various. However, diamond burnishing is commonly used for post-processing of turned workpieces. One reason is the different configuration of turning and milling machine tools. For example, the maximum generated burnishing force F_{BN} is nearly independent of the spindle using diamond burnishing processes on turning machine tools but limitated in milling machine tools.

At least, diamond burnishing has the potential to decrease the surface roughness of milled workpieces by using conventional high-precision milling machine tools, to increase the hardness H of the workpiece surface, and to generate internal compressive stress σ_C [3].

2. Experimental Setup

The first investigations serve to identify the strain for the milling spindle of the 5-axis-milling machine tool PFM4024-5D, Primacon GmbH, Peissenberg, Germany. Therefore, an apparatus with high mechanical stiffness S_{Mech} was developed and integrated into the PFM4024-5D. The used burnishing tools, Mössner GmbH, Pforzheim, Germany, have a sphere of monocrystalline diamond with a radius r_{Sp} = 2 mm.

After that, the workpieces were prepared by milling. For heat dissipation and reduction of friction between workpiece and burnishing tool the high-performance cutting oil Swisscut 6122S, Motorex, Langenthal, Switzerland, was used. The burnishing tool was orientated perpendicular to the workpiece surface. The process parameters feed velocity v_f, penetration depth d_p, and stepover a_{St} were varied to get results for the Vickers hardness HV and the surfaces roughness Ra and Rz. The setup is illustrated in figure 1.

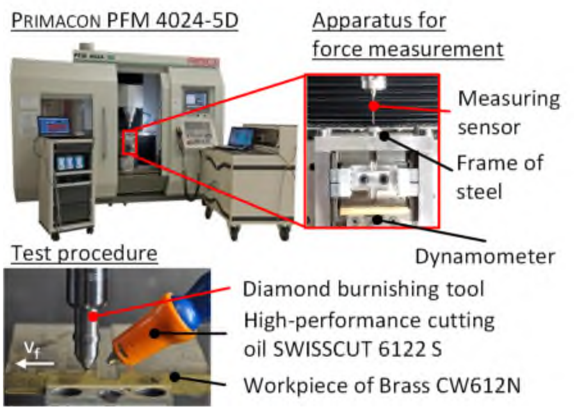

Figure 1. Used machine tool for the experiments and test procedure

3. Results

The surface roughness was measured with the white light interferometer ZYGOLOT NEWVIEW™5010, AMETEK GERMANY GMBH, Weiterstadt, Germany. Areal surface parameters were not investigated yet, because the die and mould industry don´t use that for evaluation the processes. It was proven that an increase of the stepover from $a_{ST} = 4.0$ µm to $a_{ST} = 35.8$ µm results in lower surfaces roughness for non-ferrous metals. The surface roughness could be reduced by 82 % to Ra = 14 nm and by 85 % to Rz = 37 nm using diamond burnishing for pre-milled aluminium parts. For X37CrMoV5-1 the surfaces roughness could be reduced by 85.4 % to Ra = 29 nm and by 86 % to Rz = 142 nm using diamond burnishing. Nevertheless, an increase of the stepover a_{St} leads to higher surface roughness for steel as workpiece material. The results of the measured surface roughness are shown in figure 2. The number of repetition per measurement was $n_i = 3$. The standard deviation for every condition was $s < 0.1$ nm, which is within the measurement resolution. However, the degree of forming ϕ depends on the workpiece material structure and composition. Therefore, the degree of forming ϕ has a high influence of the surface condition. Hence, the achieved surface roughness depends on the workpiece material. For more accurate statements about the correlations between material and degree of forming ϕ additional investigations are in process. Furthermore, the influence of the penetration depth d_p and the feed velocity v_f on the surfaces roughness can be neglected.

The hardness HV was measured with the FISCHERSCOPE H100C, HELMUT FISCHER GMBH INSTITUT FÜR ELEKTROTECHNIK UND MESSTECHNIK, Sindelfingen, Germany. Strain hardening increase only with higher process force F_{BN}. That means, the process forces F_{BN} depends on the penetration depth d_p and the workpiece material but not on the feed velocity v_f and the stepover a_{ST}. Thus, micro hardness HV only rise with increasing penetration depth d_p. Like for surface roughness measurements, the number of repetition per measurement was $n_i = 3$.

The maximum measured micro hardness values are shown in table 1 and the used method is conforming to DIN EN ISO 14577-1.

Table 1. Mean values for the Hardness HV of the investigated workpiece materials

Workpiece material	Composition [%]				Micro hardness HV values Start	Maximum
X37CrMoV5-1	Fe:	91.63	Mo:	1.3	680 HV 1/20	820 HV 1/20
	C:	0.37	V:	0.4		
	Cr:	5.3				
Cu-OFE	Cu:	≥ 99.95	Pb:	≤ 0.005	135 HV 0.3/20	171 HV 0.3/20
	Bi:	≤ 0.0005	Sg:	≤ 0.030		
CuZn39Pb2	Cu:	59	Pb:	1.6	200 HV 0.35/20	248 HV 0.35/20
	Zn:	39				
AlMg4,5Mn	Al:	≥ 93	Mg:	≤ 4.5	122 HV 0.2/20	168 HV 0.2/20
	Si:	≤ 0.4	Cr:	≤ 0.25		
	Fe:	≤ 0.4	Zn:	≤ 0.25		
	Cu:	≤ 0.1	Ti:	≤ 0.15		
	Mn:	≤ 1				

Process:
Diamond burnishing
Tool:
Diamond burnishing tool
MÖSSNER GMBH
$r_{Sp} = 2$ mm
Workpieces:
Steel X37CrMoV5-1
Copper CW008A
Brass CW612N
Aluminium alloy 5083

Investigated parameter:
feed velocity v_f;
stepover a_{St}
Measurement system:
White light interferometer
ZYGOLOT NEWVIEW™5010
Initial values:
Ra = 199 nm; Rz = 1.026 nm
Ra = 328 nm; Rz = 1.119 nm
Ra = 438 nm; Rz = 1.987 nm
Ra = 77 nm; Rz = 253 nm

Measurement Setting:
Lateral solution:
$s_L = 1.18$ µm
Vertical solution:
$s_V = 0.10$ nm
Filter cut-off:
$\lambda_c = 0.06$ mm
Measurement length:
$l_m = 0.30$ mm
Measuring field: Objective 10x
$m_f = 0.35 \times 0.26$ mm

Process Forces:
Steel X37CrMoV5-1 (I): $F_{BN} = 95$ N
Steel X37CrMoV5-1 (II): $F_{BN} = 60$ N
Copper CW008A: $F_{BN} = 45$ N
Brass CW612N: $F_{BN} = 41$ N
Aluminium alloy 5083: $F_{BN} = 53$ N
Legend:
▲ Steel X37CrMoV5-1 (I)
● Copper CW008A
▲ Aluminium alloy 5083
◆ Brass CW612N
□ Steel X37CrMoV5-1 (II)

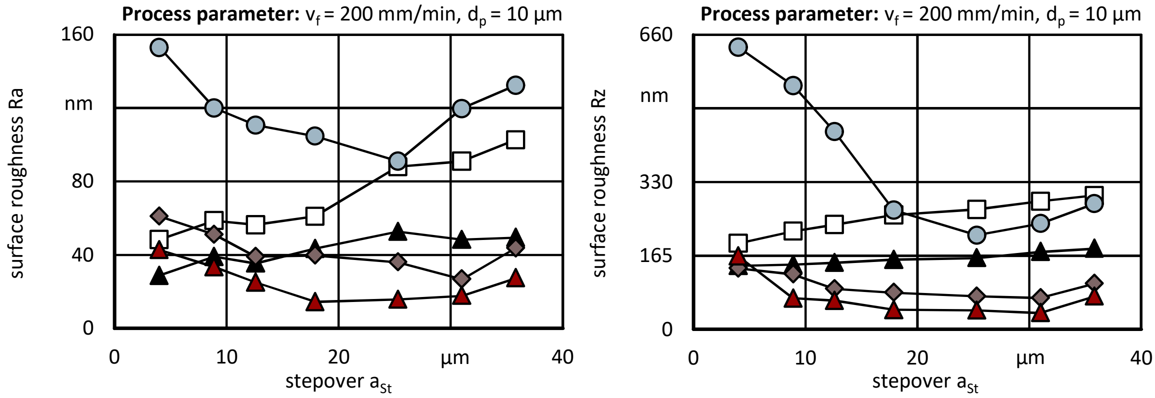

Figure 2. Results of surface roughness Ra and Rz for diamond burnish steel, copper, brass and aluminium alloy

The Vickers hardness HV increased by 20.5 % using diamond burnishing for the pre-milled steel parts, by 26.6 % for the pre-milled cooper parts, by 24 % for the pre-milled brass parts and by 37.7 % for the pre-milled aluminium alloy parts.

4. Conclusions

The results shown that surface roughness and the hardness of the workpiece can be improved using diamond burnishing on pre-milled parts.

In addition, the process can be used for the machining of various workpiece materials, especially in mould and die industry. In the future, comprehensive investigations on the influence of the workpiece and the machine tool will be carried out.

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