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RELEVANT ROUGHNESS PARAMETERS IN POLISHING OPERATIONS OF PREVIOUSLY MILLED SURFACES

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ABSTRACT
For time and cost saving reasons, the lowest surface roughness possible is sought in milling operations. High speed milling is recommended in order to minimise the amount of material to be removed in subsequent finishing operations, e.g. grinding, electrical discharge machining or manual polishing. Several roughness parameters are usually employed for the characterization of polished surfaces. In this paper relevant roughness parameters are determined for polishing operations after side milling with cylindrical milling tool or after ball-end milling. It was observed that, in polishing operations after side milling, most relevant parameters are average roughness parameters such as R_k *and* R_a*. On the contrary, in polishing operations after ball-end milling most relevant roughness parameters are those related to peaks, such as* R_{pk} *and* M_{r1}*.*
Keywords: polishing time, roughness parameters, finish milling.

1. INTRODUCTION
In moulds and dies manufacturing, a manual polishing operation is usually employed after milling, since machine polishing is usually applied to flat, cylindrical or spherical surfaces [1]. Several roughness parameters are usually employed for the characterization of machined surfaces, such as arithmetic average roughness *Ra*; maximum peak-to valley roughness *Rt*; roughness parameters related to the Abbott-Firestone curve like reduced peak height *Rpk*, reduced valley height *Rvk* and average core roughness depth *Rk* [2], etc. However, not all roughness parameters vary to the same extent when a polishing operation is applied to the previously milled surface. The aim of the present work is to determine relevant profile roughness parameters to be used in the characterization of polished surfaces. For doing that, a polishing test was applied to previously milled samples, which was explained in a previous work [3]. Roughness was measured before polishing test and during subsequent polishing operations. Relevance of each parameter was quantitatively determined by means of Analysis of Variance (ANOVA). According to the method by Bigerelle et al., parameters having higher treatment index *F* with regards to a certain factor in the ANOVA test are considered to be more statistically significant [4, 5].

2. MATERIALS AND METHODS

2.1. Materials
WNr. 1.2344 hardened steel blocks of hardness HRC 52, of 66 x 50 x 40 mm were machined. Machined area was 66 x 6 mm.

2.2. Methods

Milling operations

Cylindrical tools of diameter 6 mm having 6 cutting edges, and ball-end milling tools of diameter 6 mm having 2 cutting edges were used. Tool overhang was 22 mm in all cases. A Mori-Seiki vertical machining centre was employed. Cutting conditions were:

- Cylindrical milling tool: Cutting speed v_c = 180 m·min^{-1}; axial depth of cut *Ad* = 6 mm; radial depth of cut *Rd* = 0.15 mm; air cooling. Feed per tooth *f* = 0.02 and 0.06 mm·tooth^{-1}·revolution^{-1}.
- Ball-end milling tool: Cutting speed v_c = 180 m·min^{-1}; axial depth of cut *Ad* = 0.15 mm; air cooling. Feed per tooth *f* = 0.05 and 0.4 mm·tooth^{-1}·revolution^{-1}; radial depth of cut *Rd* = 0.25 and 0.4 mm.

Polishing operations

An automatic polishing machine Mecapol P230 was employed. Corundum polishing pads were used with grain size 400, according to the recommendations of a mould and die manufacturer. Figure 1 shows the polishing machine.

Figure 1. Mecapol P230 polishing machine

Polishing cutting conditions were:

- Surface previously milled with cylindrical milling tool: Force = 1.5 daN; speed = 50 min^{-1}; time *t* = 0, 20, 40 and 60 s.
- Surface previously milled with ball-end milling tool: Force = 1.5 daN; speed = 50 min^{-1}; time *t* = 0, 10, 20, 30, 40, 50 and 60 s.

Two replicates were performed of each experiment.

Roughness measurements

A Taylor Hobson Taylsurf Series 2 roughness stylus profilometer with Taylor Hobson µltra software (v. 4.6.8) was used for measuring roughness (Figure 2). Thirteen different roughness parameters were measured: *Ra, Rt, Rq, Rk, Rpk, Rvk, Mr1, Mr2, Rku, Rsk, Rmq, Rpq, Rvq*. Only profile parameters were determined, which are easy to be obtained with conventional roughness meters and are common in industry. Each measuring process consisted of first measuring roughness of the milled surface and then measuring roughness after different polishing times, in order to study the evolution of roughness parameters with polishing time. Ten measurements were performed in the longitudinal or feed direction at two different heights, since some differences had been previously detected. Five measurements were performed in the transversal direction. An average value of longitudinal and transversal roughness was calculated for each roughness parameter.

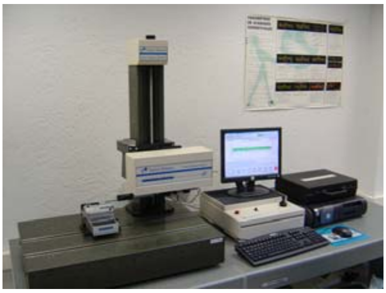

Figure 2. Taylor Hobson Talysurf Series 2 roughness stylus profilometer

ANOVA test

A linear general model was used for performing ANOVA test to all roughness parameters studied. The Fischer-Snedecor test used in ANOVA assumes that roughness measurements correspond to a normal law (normality) and standard deviations are similar (homoscedasticity of variance). In the present paper, it was proved in all cases that the roughness distribution followed a normal law and that variance of residues had an average zero value.

3. RESULTS

3.1. Cylindrical milling tool

Results for cylindrical milling tool are presented in Table 1.

Table 1. Treatment index F for different roughness parameters of previously cylindrical tool milled surfaces

	f	*t*	*f*t*
Ra	58.17	72.51	31.68
Rt	6.24	ns	ns
Rq	40.76	44.53	18.08
Rk	70.94	123.4	43.99
Rpk	17.77	34.01	16.31
Rvk	18.14	15.99	ns
Mr1	13.9	60.44	49.67
Mr2	5.38	ns	5.88
Rku	ns	20.07	14.72
Rsk	ns	5.55	ns
Rmq	16.11	ns	ns
Rpq	10.26	6.41	5.1
Rvq	17.39	5.49	ns

ns: not significant

Most significant parameters with respect to polishing time *t* are: *Rk* > *Ra* > *Mr1* > *Rq* > *Rpk* > *Rku* > *Rvk* > *Rpq* > *Rsk* > *Rvq*. Therefore, the recommended profile roughness parameters are average parameters *Rk*, *Ra*, followed by parameters such as *Mr1*, *Rpk*. Kurtosis *Rku* and parameters related to probability curve like *Rpq* and *Rvq* are less significant. On the other hand, R_k is the most relevant parameter for describing the effect of *f* in the milling operation, while *Mr1* is the most relevant parameter with regards to interaction $f{\cdot}t$, although *F* value is lower than for *f* or *t* alone.

3.2. Ball-end milling tool

Results for ball-end milling tool are presented in Table 2.

Table 2. Treatment index F for different roughness parameters of previously ball-end milled surfaces

	Rd	*f*	*t*	*Rd*f*	*Rd*t*	*f*t*	*Rd*f*t*
Ra	24.53	33.05	50.89	ns	3.75	8.13	ns
Rt	24.02	20.1	37.13	4.63	3.06	7.38	ns
Rq	25.3	31.28	48.34	ns	3.44	7.5	ns
Rk	14.83	42.16	43.29	11.53	2.63	16.02	ns
Rpk	41.33	ns	245.16	4.62	21.36	ns	8.18
Rvk	21.49	13.89	5.62	5.93	ns	ns	ns
Mr1	ns	16.18	85.07	8.86	2.56	ns	3.38
Mr2	25.7	17.88	33.85	ns	3.72	4.47	ns
Rku	ns	6.11	42.17	11.53	3.05	4.97	3.96
Rsk	5.57	ns	31.22	ns	ns	ns	ns
Rmq	4.19	ns	8.11	ns	ns	2.6	ns
Rpq	17.28	27.82	46.88	4.38	3.26	11.22	ns
Rvq	25.8	13	7.44	5.23	ns	ns	ns

ns: not *significant*

Most significant parameters regarding polishing time *t* are: *Rpk* > *Mr1* > *Ra* > *Rq* > *Rpq* > *Rk* > *Rku* > *Rt* > *Mr2* > *Rsk*. In ball-end milling processes, recommended roughness parameters for *t* are those related to peaks, *Rpk* and *Mr1*, followed by average roughness parameters such as *Ra* and *Rq*. With regards to *Rd*, most significant parameter is *Rpk*, while for feed *f* most significant parameter is *Rk*.

4. CONCLUSIONS

Roughness parameters that most influence polishing time of previously cylindrical tool milled parts are average roughness parameters followed by roughness parameters related to peaks. For previously ball-end milled parts, most significant parameters regarding polishing time are those related to peaks, while average roughness parameters are important too.

5. ACKNOWLEDGEMENTS

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