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EFFECT OF ECCENTRICITY ON SURFACE TOPOGRAPHY OBTAINED IN BALL-END MILLING PROCESSES

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ABSTRACT

In the present work, in order to simulate surface topography in ball-end milling processes a numerical program was used. Input data of the program are cutting conditions such as feed or radial depth of cut, as well as geometric characteristics of the tool, like tool diameter, number of teeth and helix angle among other. The program allows calculating different 2D and 3D parameters, as well as volume of peaks and valleys at a certain height. This will influence the polishing operations that are usually applied after milling in the manufacturing process of injection molds.

In order to study how surface topography and areal roughness parameters Sa and St change as a function of eccentricity, three different eccentricity values were considered: 0.001 mm, 0.010 mm and 0.100 mm. Simulated results were validated by means of experimental tests.

Keywords: ball-end milling, roughness, surface topography

1. INTRODUCTION

In ball-end milling operations tool geometry influences surface roughness and surface topography to be obtained. Different aspects to be taken into account are: tool radius, tool radial runout, tool eccentricity, tool tilt, etc. Different authors studied effect of geometry on roughness in ball-end milling. For example, Kim and Chu studied the effect of cutting conditions on surface roughness in a general model for different tool geometries, taking into account cutter marks and geometric runout [1]. Bouzakis et al. considered feed, radial depth of cut and tool orientation for simulating surface topographies in ball-end milling [2]. Toh extended the work of Bouzakis to machining operation of inclined surfaces when using different cutter path orientations [3]. Gao predicted surface topography from equations of cutting edge trajectory as a function of tool path, tool geometry, and spindle runout [4]. Fontaine et al. studied the effect of tool eccentricity, which is produced by an offset between tool rotation axis and spindle rotation axis, on cutting forces. They qualitatively reported poor surface quality at high eccentricity values [5]. In a previous work, the authors of the present paper studied effect of feed and radial depth of cut on surface roughness and surface topography [6]. In this paper, results about effect of eccentricity on surface roughness and surface topography to be obtained in parallel passes on a flat surface are presented.

2. SIMULATION

A numerical model had been previously prepared for obtaining surface roughness and surface topography as a function of radial depth of cut and feed [6]. Tool geometric parameters such as tool diameter, tool runout, tool eccentricity, helix angle or phase angle of tool teeth can be varied in the numerical program. The program only takes into account the effect of tool geometry and cutting conditions on surface roughness. It does not consider other factors such as plasticity of the material, vibrations, etc. In the present paper, effect of geometry and cutting conditions on roughness is isolated from effect of other factors.

In order to assess effect of eccentricity on surface roughness and surface topography, three different values for eccentricity E were taken into account: E=0.001 mm, E=0.010 mm and E=0.100 mm. Four different cases were studied. Case 1: feed f=0.05 mm·tooth^{-1}·revolution^{-1} and radial depth of cut Rd= 0.4 mm. Case 2: f=0.2 mm·tooth^{-1}·revolution^{-1} and Rd= 0.2 mm. Case 3: f=0.4 mm·tooth^{-1}·revolution^{-1} and Rd= 0.05 mm. Case 4: f=0.4 mm·tooth^{-1}·revolution^{-1} and Rd= 0.4 mm.

Simulated values of areal average roughness Sa and areal maximum peak-to-valley roughness St were studied, as well as surface topographies obtained.

3. EXPERIMENTAL TESTS

Steel Wr. 12344 blocks were used for experimental validation with 6 mm tools having 2 cutting edges, in a Haas VM-2 3-axes machining centre. Face milling experiments with parallel passes were performed to validate the 4 simulated cases.

4. RESULTS

4.1. Simulated roughness

In Table 1 simulated results for Sa and St values are presented.

Table 1. Simulated areal average surface roughness Sa and areal peak-to-valley roughness St at different feed f and radial depth of cut Rd, for different eccentricity values

f	Rd	Sa (E = 0.001)	Sa (E = 0.010)	Sa (E = 0.100)	St (E = 0.001)	St (E = 0.010)	St (E = 0.100)
0.05	0.04	1.548	1.401	0.326	6.092	5.542	1.637
0.20	0.20	1.101	1.068	0.351	5.970	5.949	3.062
0.40	0.05	0.090	0.103	0.047	1.087	1.134	1.818
0.40	0.40	4.410	4.471	3.433	24.152	26.841	22.156

According to simulation, at high eccentricity value of 10 µm, as a general trend roughness is significantly reduced with respect to lower eccentricity values.

4.2. Experimental roughness

In Table 2 experimental for Sa and St values are presented.

Table 2. Experimental areal average surface roughness Sa and areal peak-to-valley roughness St at different feed f and radial depth of cut Rd, for different eccentricity values

f	Rd	Sa (E = 0.001)	Sa (E = 0.010)	Sa (E = 0.100)	St (E = 0.001)	St (E = 0.010)	St (E = 0.100)
0.05	0.04	4.734	3.997	2.210	19.609	16.841	19.180
0.20	0.20	3.032	2.914	3.644	17.973	16.308	19.345
0.40	0.05	0.679	0.773	0.707	5.627	7.511	9.643
0.40	0.40	7.571	7.660	7.372	40.241	43.505	39.590

As can be seen in Table 2, experimental roughness values are higher than simulated ones. The difference is attributed to the influence on roughness of other effects such as plastic deformation of the material instead of clean cutting. Since tool axis is perpendicular to feed direction, in the tool end cutting speed is equal to 0. Although experimental roughness values are higher than simulated ones, influence of eccentricity is reflected in the shape of surface topographies obtained (Section 4.3).

4.3. Surface topographies

Surface topographies for f=0.05 mm·tooth^{-1}·revolution^{-1} and Rd=0.40 mm, for E=0.001 mm and E=0.100 mm respectively are presented in Figure 1.

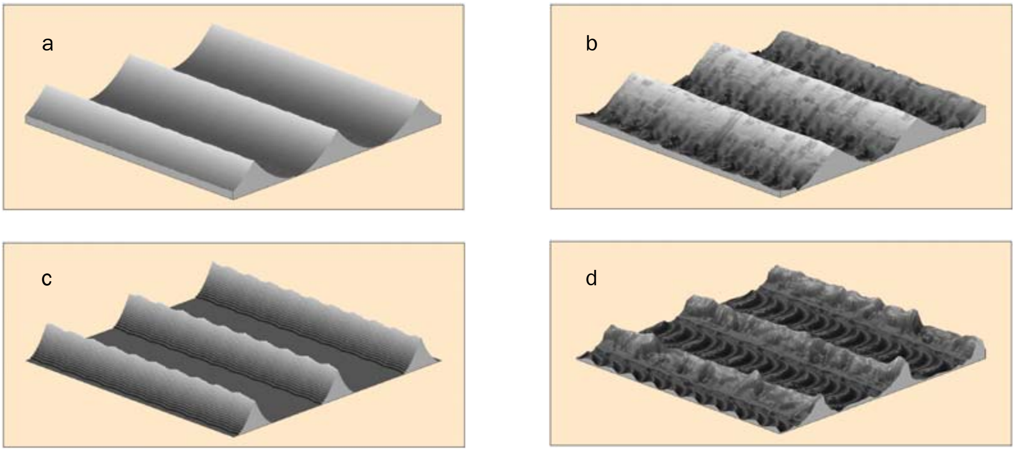

Figure 1. Surface topography for f=0.05 mm·tooth^{-1}·revolution^{-1} and Rd=0.40 mm, for E=0.001: a) simulated, b) experimental, and for E =0.100 mm: c) simulated, d) experimental

In this case, Rd is higher than f parallel cutting marks are obtained. As eccentricity increases higher roughness marks appear along the valleys while height of peaks is reduced.

Surface topographies for f=0.20 mm·tooth^{-1}·revolution^{-1} and Rd=0.20 mm, for E=0.001 mm and E=0.100 mm respectively are presented in Figure 2.

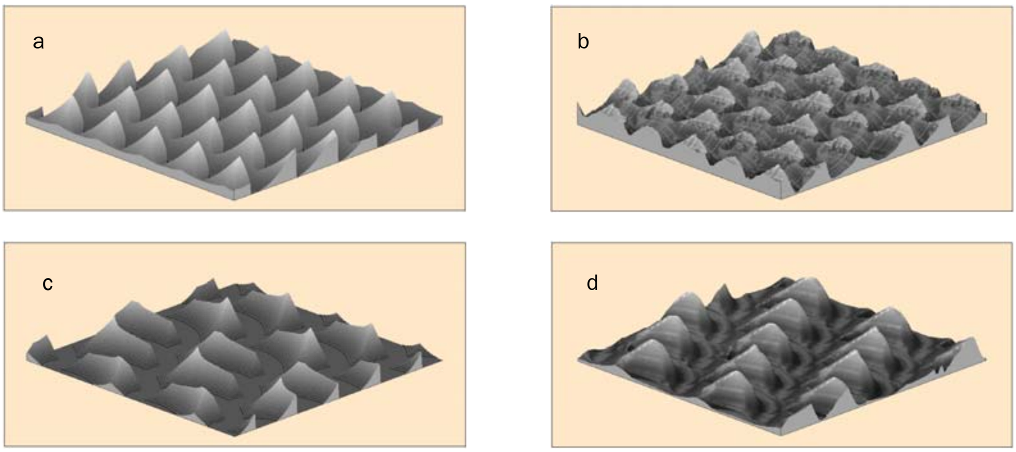

Figure 2. Surface topography for f=0.20 mm·tooth^{-1}·revolution^{-1} and Rd=0.20 mm, for E=0.001: a) simulated, b) experimental, and for E =0.100 mm: c) simulated, d) experimental

At similar Rd and f values parallel marks in the longitudinal direction are broken by marks in the transversal direction. This effect is more important as eccentricity increases.

Surface topographies for f=0.40 mm·tooth^{-1}·revolution^{-1} and Rd=0.05 mm, for E=0.001 mm and E=0.100 mm respectively are presented in Figure 3.

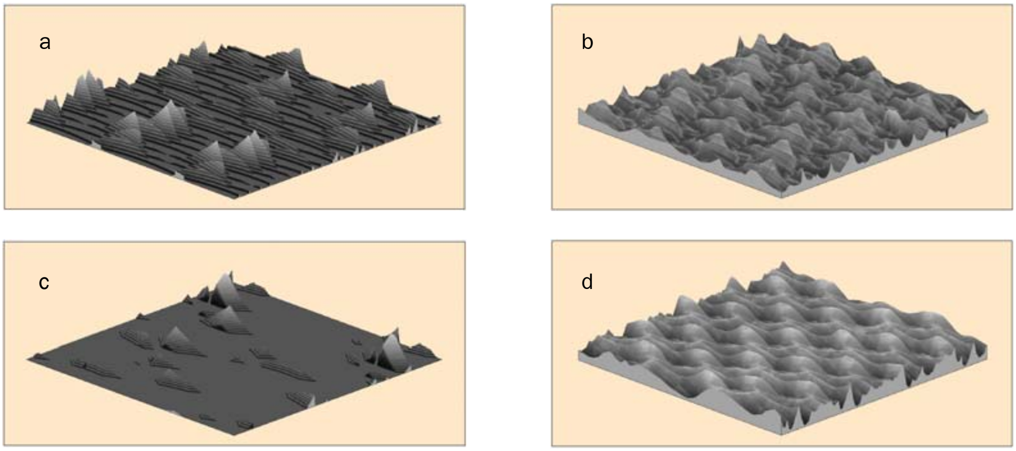

Figure 3. Surface topography for f=0.40 mm·tooth^{-1}·revolution^{-1} and Rd=0.05 mm, for E=0.001: a) simulated, b) experimental, and for E =0.100 mm: c) simulated, d) experimental

Since Rd is much lower than f, narrow channels are obtained in the longitudinal direction, which are cut by wider channels in the transversal direction, leading to narrow peaks. At high eccentricity many peaks are smoothed.

5. CONCLUSIONS

In ball end milling, when Rd is high with respect to f, longitudinal cutting marks are obtained. When Rd is similar to f, topography is composed of cusps. When Rd is lower than f, narrow cusps are obtained. The higher eccentricity, the wider channels in the longitudinal direction become, leading to more irregular profiles. As a general trend, roughness values decrease at high eccentricity.

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