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THE INFLUENCE OF TOOL WEAR ON THE SURFACE ROUGHNESS OBTAINED THROUGH HIGH SPEED MILLING OF HARDENED MOULD STEELS

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ABSTRACT
In this paper we study the influence of tool wear on the surface roughness of a same work material, depending on the cutting method (upward or downward), with down milling strategy and air lubrication, for a particular cutting condition and for high speed copy milling with a solid carbide ball nose end mill with a new nanocoating (Al, Ti) N. The tool life is measured in terms of the machined meters under the same cutting conditions (revolutions, feed per tooth and cutting depth).
Keywords: high speed milling, surface roughness, hardened mould steels.

1. INTRODUCTION
Knowing the tool life of cutting tools reduces manufacturing times and costs. Nowadays, in order to increase the performance of moulds, manufacturers offer new kinds of mould steels with improved mechanical properties, a higher balance between machinability and a good polish surface for the automobile industry.
The results of an internal survey on the technologies involved in High Speed Milling, carried out by our group of researchers among 25 manufacturers of moulds and dies in Catalonia (Spain), revealed a lack of knowledge regarding the tool life of the cutting tools used in different machining operations. To determine when a tool should be changed, many variables must be taken into account, making the wear analysis and the subsequent decision to change a tool an important issue to solve. The cost of high speed machining tools is high and, provided that there is no breakage of the cutting edges, they can be re-sharpened up to 3 times, thereby saving about 40% on tool costs.
Toh [1] considers a tool to be new as long as the flank wear is less than 0.05 mm. Like that, different machining tests can be carried out without having to change the tool and without the wear affecting the results of the experiments. The correct cutting strategy, down or up machining, upward or downward milling, greatly influences the tool life and quality of the surface finish. Certain authors have managed to improve the tool life and the stability of the surface finish through down machining and upward cutting for different materials and machining operations [2,3].
In this paper we study the influence of the tool flank wear (*VB1*) on the surface roughness, when applying different machining strategies.

2. MANUFACTURING CONDITIONS
The parts were manufactured using the following material: W-Nr. 1.2344, hardened steel at 51 HRC. The parts were machined in a HSM centre with vertical-spindle (Deckel Maho DMU 50 Evolution), with the pre-balanced tool holder ref. DN40AD-CTH20-75, manufacturer: MST. We used cutting tools of the new IMPACT MIRACLE series with nanocoating (Al,Ti) N, solid micrograin carbide, two flutes, ball nose end mill, ref. VF2SBR0300, manufacturer: MMC KOBE [4]. Two tools (T1 and T2) were used under the same test conditions in order to obtain information about the repeatability of the process. The eccentricity of both tools was checked with a millesimal comparator in order to guarantee a runout between the two cutting edges of less than 5 μm.

The cutting conditions were established according to the following relationship: cutting speed v_c = 250 m/min, revolutions S = 13270 min^{-1}; feed per tooth fz = 0.04 mm/tooth, feed rate F = 1060 mm/min; axial cutting depth Ad = 0.2 mm and radial cutting depth Rd = 0.05 mm; cutting method: down milling. Air blowing was used as a refrigerant. Because of the geometrical characteristics of the workpiece, the semi-cylindrical surface and the machining strategy used, the effective cutting diameter (D_e) and the effective cutting speed (v_{ce}) are variables. For example, for the final diameter of the 19.6 mm workpiece, the values shown in Table 1 were calculated for the different angles of the workpiece being tested.

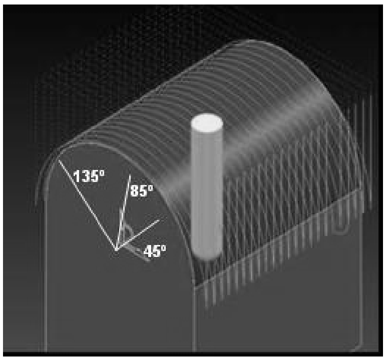

Table 1. Effective parameters

Angle [º]	D_e [mm]	v_{ce} [m/min]
45	5.42	226
85	2.50	104
135	2.57	107

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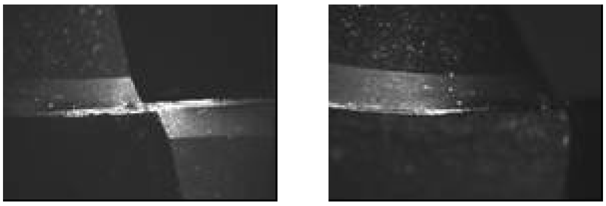
Figure 1. Machining angle and feed direction

We measured the amount of tool wear for different machined lengths. We took photographs and measurements of the wear of the clearance surface of the two flutes and of the front by means of a Vision Measuring Machine Mitutoyo Quickvision.
We measured the roughness at three angles of the workpiece being studied (45º, 85º, 135º) (Fig.1) by means of the roughness meter Taylor-Hobson Form Taylsurf Series 2, at the midpoint of every test piece, in the direction perpendicular to the feed rate. The roughness measurements at 45º and 85º were used to analyse the roughness in upward milling with different effective cutting speeds and the measurement at 135º was used to analyse the roughness in downward milling. Furthermore, in each one of the roughness measurement areas photographs were taken of the workpiece surface with different magnifications.

3. ANALYSIS OF RESULTS

The results of the experiments showed that the wear between the two flutes of tool *T1* was greater than in the case of the second tool *T2*, as is shown in Figure 3. As far as the wear rate is concerned, the behaviour of both tools is similar. For a total machining time of 1419 minutes and a machined length of 1504 m, the flank wear, the average of both flutes, for tool *T1* was *VB1*= 0.069 mm, and for tool *T2* was *VB1*= 0.084 mm. At this machined length the difference in wear between the two flutes (*f1* and *f2*) of tool *T1* was 0.008 mm and of tool *T2* was 0.002 mm.

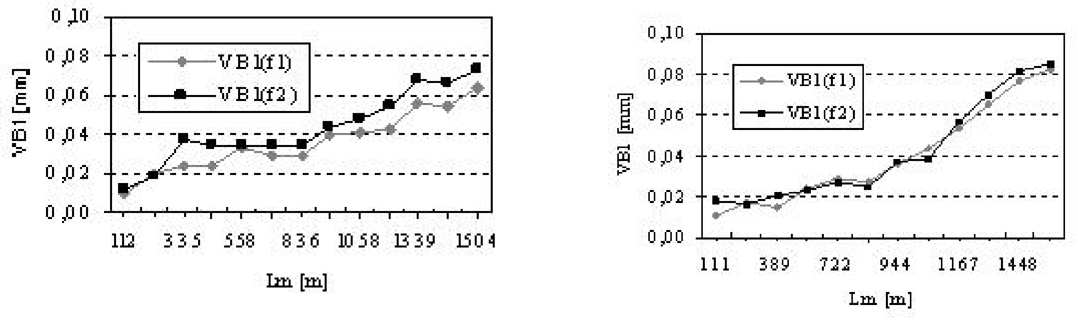


(a) (b)

VB1(f1):0.083 mm
VB1(f2):0.085 mm

Figure 2. Flank wear on cutting edges of tool T2. Scale Photo 3.134 mm x 2.339 mm.

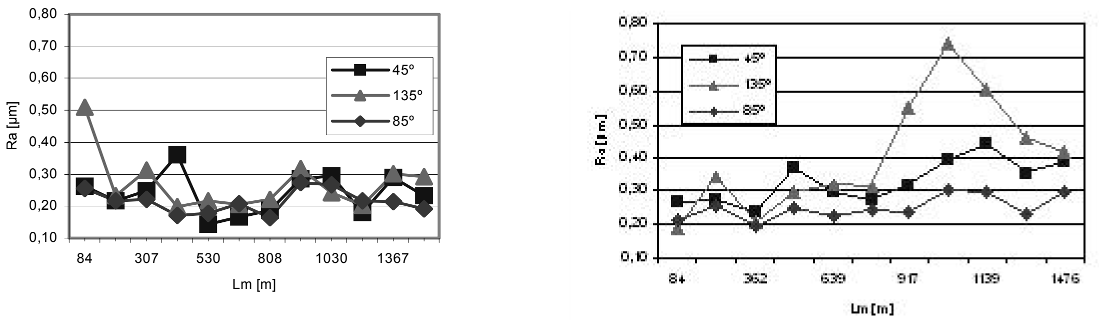
Figure 2 shows a photograph of the front view (a) and a photograph of the clearance face (b) of the wear of tool *T2* for the machined length of 1504 m. Figure 3a shows chips in the rake face of the flute *f1*.



(a) (b)

Figure 3. Relationship between flank wear and machined length of tool T1 (a) and T2 (b).

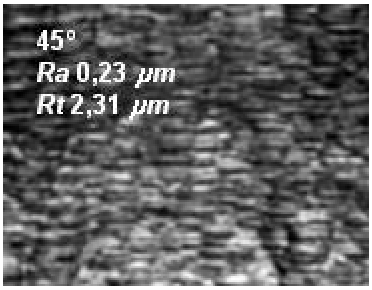
We determined the repeatability of the measure in the flank wear measurements for tool *T1* and flute *f1*. With a machined length of 335 m, a sample of 5 measurements was taken and an average value of 0.025 mm was obtained, with a standard deviation of 0.003 mm and a repeatability error of 0.007 mm. Because of the radius tolerance of the tools (<±0.005 mm) given by the manufacturer, one of the flutes may have a greater radius than the other one and, therefore, the flute with the greater radius will suffer a greater amount of wear. In the case of the two tools tested, the runout between the two flutes for the two tools was less than 0.001 mm, measured with a millesimal comparator at 45º of the tool's axis. Due to the repeatability error of the tool wear measurements, of the results obtained for each one of the tools (Fig. 3), it is not possible to conclude that the wear between the flutes is different. As far as the wear of the two tools is concerned, tool *T2* showed a slightly higher amount of flank wear at the end of the test.
Figure 4 shows the roughness Ra measured in relation to the machined length, for the angles being studied and the two tools. Figure 4b, between a machined length of 805 m and 1028 m, shows a clear increase of the roughness at the 135º angle, probably due to the occurrence of a chip in one of the flutes of tool *T2*.

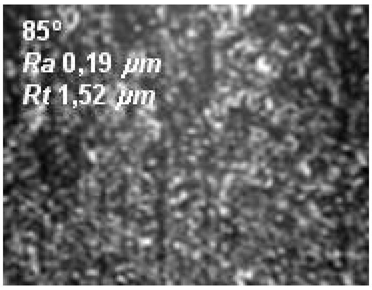


(a) (b)

Figure 4. Relation between Roughness Ra and machined length of tool T1(a) and tool T2(b).

We also determined the repeatability error of the measure in the roughness *Ra* measurements for several machined lengths and at different angles of the workpiece. The measure was repeated 3 times in every zone and the results led to a repeatability error of 0.05 µm.
As Figure 4 shows, there tends to be less roughness Ra at the 85º angle. In that zone, because of the tool wear and the effective cutting conditions, the surface texture shows a matt finish of the workpiece compared to the textures at 45º and at 135º (Fig. 5). A future paper will study the level of difficulty involved in subsequent manual polishing to obtain a mirror finishing according to the roughness and type of surface texture obtained in the finishing milling operation.





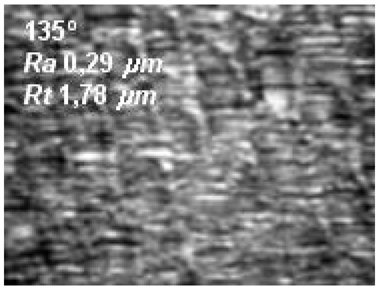


Figure 5. Surface appearance for the different angles, T1, Lm 1476 m.
Scale Photo 1,048mm x 0,783mm

Table 2 shows the average and the standard deviation of the roughness *Ra* at the 3 angles studied, calculated on the basis of all the measurements made during all the machined lengths studied. In general, a greater dispersion of the roughness measurements is found in the downward milling zone (135º angle). According to López de Lacalle [5], these strategies produce a greater tool flexion, which is why it clearly affects the stability of the surface finish. Through the 45º upward milling strategy a roughness Ra halfway between the 85º and 135º angles is obtained.

Table 2. Roughness statistics, Ra, for the analysed machined lengths of tool T1

***Ra* [µm]**	**45º**	**85º**	**135º**
Average	0.24	0.21	0.27
Std. deviation	0.06	0.036	0.09

4. CONCLUSION

The tool life has been studied and, under the selected cutting conditions, with a machined length of 1500 m, the flank wear was less than 0.1 mm. We have studied the influence of the tool wear on the roughness and we have seen that the said wear does not significantly influence the roughness Ra throughout the machining areas in the tests. The main wear phenomenon observed during the tests was the abrasion wear on the clearance face of the tool. The least roughness Ra was obtained at the angle of the slowest effective cutting speed (85º), but showed a rough surface texture, matt in colour.

5. ACKNOWLEDGEMENTS

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