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INFLUENCE OF THE REFRIGERATION-LUBRICATION SYSTEMS ON THE SURFACE ROUGHNESS IN THE HIGH SPEED SIDE MILLING OF MOULD STEELS

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ABSTRACT
This paper deals with the experimental development and the results from the study and analysis of the influence on the surface roughness obtained by high speed milling when machining different mould steels, when using different cutting methods (down cutting, up cutting), and when using different refrigeration-lubrication systems (air injection, cold-air injection and minimal quantity of lubricant). It applies to the basic operation of side milling of vertical surfaces of prismatic workpieces during the finishing phase.
Keywords: high speed side milling, surface roughness, refrigeration-lubrication systems, mould steels, cutting method.

1. INTRODUCTION

The objective of this study is to know the degree of influence on the surface roughness obtained by a process of high speed milling, applied to the basic operation of side milling, depending on the type of mould steel (which may present different compositions and hardness), on the cutting method (down cutting or up cutting), and also on the refrigeration-lubrication system (air injection, cold-air injection and minimal quantity of lubricant-*MQL*).

Kitaura et al. [1] carried out a study on the tool wear in high speed milling, in a basic operation of side milling, using down cutting, machining the hardened steel W Nr. 1.2344, and with different refrigeration-lubrication systems, dry cutting, emulsion and air injection. The minimum wear and a more stable process were obtained using air injection. As regards the cutting method, in a study by Vivancos et al. [2] on the roughness obtained through the side milling of different die steels, hardened at 60-64 HRC, using only air injection, the use of the down cutting rather than the up cutting method allowed to obtain a lesser and more stable roughness.

2. EXPERIMENTAL DEVELOPMENT

The machining centre Deckel Maho DMU 50 *Evolution* was used to carry out the various experiments. The side milling operation was directly programmed in the Numerical Control, so that for each experiment, the corresponding surface was machined in the Y-axis direction. A mechanical clamp was used to fix the tested workpieces. The tool fixing system consists of a prebalanced shrink fit collets holder system. Solid carbide end mills with a new (Al, Ti) N nanocoating, reference VFSDD0600 [3], with a flat end geometry, a diameter of D = 6 mm, six flutes, and a diameter tolerance between 0 and -0.02 mm were used as cutting tools. A minimum tool overhang of 15 mm was established. The test workpieces with prismatic geometry and a size of 50 mm x 50 mm x 40 mm were defined. For each workpiece, eight experiments were carried out by machining eight surfaces with a length of 50 mm and a cutting height of 8 mm, in four of these experiments up cutting was used, and in the other four, down cutting. So that the test workpieces surface and dimensional finishing, previous to experiments, did no affect the experiment results, after the previous face milling of workpieces and its corresponding thermal treatment, all sides of tested prismatic workpieces were

grinded, and an average roughness *Ra* = 0.24 µm was obtained, with a standard deviation equal to 0.06 µm. After carrying out the respective thermal treatments, the hardness of those test workpieces for the various tested materials was checked.
In this study, for each one of the eight selected materials, six experiments were made, combining both cutting methods with each one of the three refrigeration-lubrication systems. Thus, a total of 48 experiments were carried out. Four replicas of each experiment were executed, which makes a total of 192 experiments.
These are the main data about the refrigeration-lubrication systems which were used:

- The device *VIP4TOOLS* with dual function: Air injection system with a pressure of 6 bars, at 20 ºC, and *MQL* system with an oil flow of 0.06 ml/min at 6 bars.
- The cold-air injection device *VORTEX AIR GUN 610* with a nozzle outlet temperature of 0 ºC.

Table 1 shows the tested materials, which were selected because they are the most representative, such as mould steels [4].

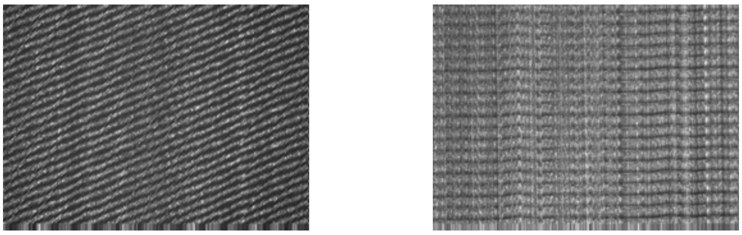
Table 1. Selection of moulds steels.

W Nr. Standard	Böhler Standard	Hardness [HRC]
1.2344	W302	52-54
1.2083	M310 (STAINLESS S.)	52-54
1.2738	M238	30-32
-	M333 (STAINLESS S.)	52-54
1.2343	W400	52-54
1.2085	M314 (STAINLESS S.)	30-32
-	M390 (STAINLESS S.)	56-58
-	M340 (STAINLESS S.)	54-56

The following cutting conditions, equal for the machining of all tested materials, were used: Cutting speed *Vc* = 250 m/min, feed per tooth *fz* = 0.04 mm/tooth, axial depth of cut *Ad* = 8 mm, and radial depth of cut *Rd* = 0.1 mm. Eight tools were used, and after each change of tool, the maximum runout between flutes was controlled, being 6 µm the maximum value recorded. The tool wear was also controlled, being *VB* = 0.05 mm the maximum flank wear recorded. After each change of tool, the machine spindle cone was cleaned, and the spindle temperature was stabilized between 29 and 32 ºC, turning the spindle as much time as necessary. A photograph of the central area of the machined surface was taken for each experiment. Photographs of the flute flank face of each tool, at 4 mm from the tip of the tool, with three different enlargements, and photographs of the frontal view were also taken.
A rugosimeter Taylor Hobson Talysurf Series 2 was used to measure the surface roughness, with an uncertainty, set by the manufacturer, of ±(0.004 µm + 2%). Three roughness measurements at three points located at different heights from the central area of the machined surface were made. These measurements were made at each side surface for each corresponding experiment.
A significant variation of roughness was observed at the beginning of the machining process with a new tool. Thus some experiments to determine the point from which the tool machining length stabilized as regards the roughness obtained were carried out. Then it was necessary to machine 250 mm with each new tool in order to stabilize it, before using it for the experiments.

3. EXPERIMENTAL RESULTS

Figure 1a shows the surface texture of a test workpiece made by the material M333 obtained after 200 mm of machining length (*Lm*) by down cutting, applying air as refrigerant. And Figure 1b shows the surface texture obtained with a machining length of 1400 mm. With the new tool not being stabilized, marks or lines at 45º appear (see Figure 1a). These lines match up with the tool helix angle (45º) and the distance between them reflects the established revolution feed (*f* = 0,24 mm/rev). Once the tool is stabilized, after a certain machined length, the tilted marks disappear and only the predominant horizontal lines remain. The distance between these lines reflects the revolution feed, and the roughness value *Ra* decreases (see Figure 1b).



(a) *Lm* = 200 mm , *Ra* = 0.85 μm (b) *Lm* = 1400 mm , *Ra* = 0.41 μm

Figure 1. Surface texture obtained in a test workpiece made by the material M333 (Photograph size 6,324 mm x 4,717 mm).

Figure 2 shows a graphic about the average value *Ra* of roughness for each material, according to the refrigeration-lubrication system (A: Air, CA: Cold Air, M: *MQL*), as well as the cutting method (D: Down cutting, U: Up cutting).

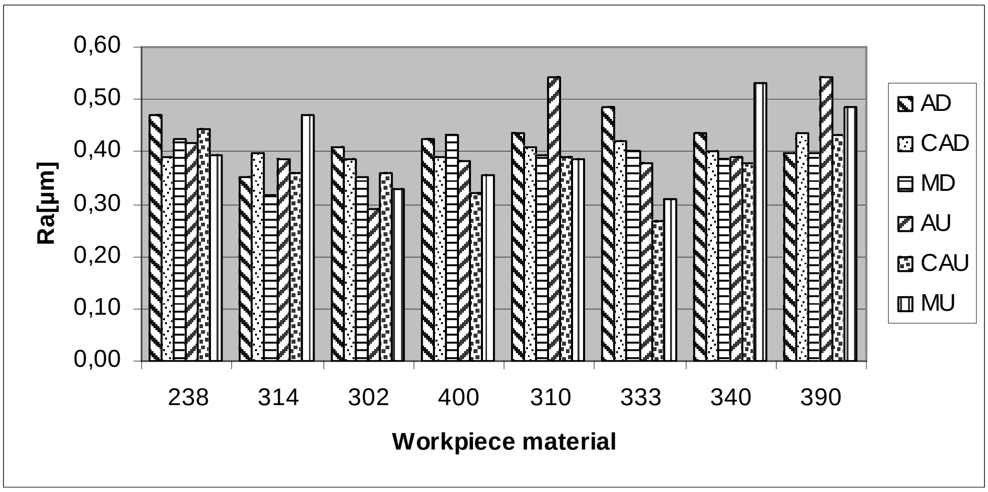


Figure 2. Average value Ra of roughness for each material, refrigeration-lubrication system and cutting method.

Figure 3 shows the average value *Ra* of roughness resulting from calculating the average of all refrigeration-lubrication systems for each material, according to the cutting method.

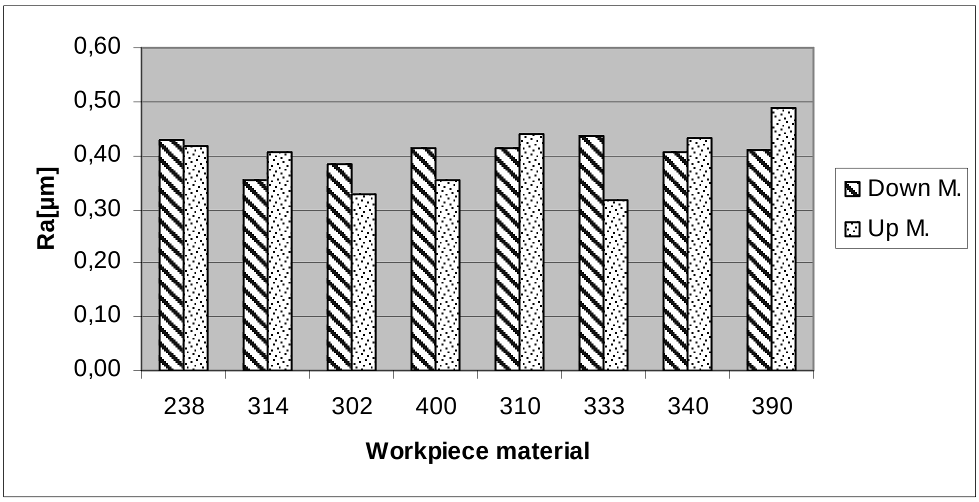


Figure 3. Average value Ra of roughness for each material and cutting method.

4. ANALYSIS OF RESULTS

In many of the experiments, a significant variation between the *Ra* values of the average roughness at the three points located at different heights from the central area of the same machined surface was observed, as well as a substantial dispersion between the *Ra* values of those measurements made in the four replicas of each experiment; this dispersion was higher than the repeatability error of the roughness measurements. In consequence, the central point of the central machined area was taken as point representative of each machined surface, and a statistical study on the 48 experiments was carried out, with their corresponding four replicas of each one of them, from the average values obtained by calculating the average of four *Ra* values of the four replicas of each experiment, and from the analysis of variances.

As regards the influence of the material and the cutting method on the roughness obtained, Figure 3 shows a greater influence on the material M333 (stainless steel hardened at 52 HRC), being better the up cutting, and on the material M390 (stainless steel powder metallurgy hardened at 58 HRC), being better the down cutting, although all these influences are not statistically significant.

In general, using the up cutting method, chips adhere more easily to the workpiece and to the tool from certain machined length. The tool manufacturer does not recommend the milling with up cutting in its technical documentation [3].

5. CONCLUSIONS

From the statistical study one can conclude that, for the testing conditions used, none of the studied variables (materials, cutting methods and refrigeration-lubrication systems) has any statistically main effects nor crossed effects, on the *Ra* value of the surface roughness obtained.

The significant variation of the *Ra* value at different heights from the same machined area may be caused by the own errors of the geometry of the tool cutting edge, by the runout between its flutes [5], and by its possible flexion. The dispersion of the results among replicas may be due to the same previous causes, adding too the possible errors of the process reproducibility. The repeatability errors of roughness measurements have proven to be appreciably lower than the variations and dispersions previously mentioned.

6. ACKNOWLEDGEMENTS

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