Methodology to determine the wear on the cutting tool during milling-planning in a computer numerical control machining center

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Abstract. The increased service life of cutting tools used in material removal processes results in significant savings in terms of production time and costs. Machining downtimes, especially those related to tool changes, represent a significant percentage of machine downtimes, which reduces efficiency. A proposed methodology is presented for the analysis of the behavior of the cutting tool through the application of the ISO standard, for which roughness and wear were determined and micrographs were used as indicators for the verification of the condition of the tool. The effectiveness of the proposed methodology that can be used in manufacturing processes to avoid failures in the workpiece due to improper use of the cutting tool was tested.

1. Introduction

The cutting tools that are used in different processes can present significant savings in terms of time and production costs by estimating their useful life. In the same way, nowadays the quality control of the surfaces of molds and dies becomes essential for the success of the production, only in the machining operations when milling is used, there are a series of variables that interfere in the quality of the machined surface [1].

A fundamental factor in the useful life of the cutting tool is the wear or deterioration that can occur in three parts of the tool: crater, tip or flank. The standardized way to evaluate wear is done in accordance with current standards, that is to say, ISO 8688-1 which recommends that tool deterioration in the form of wear can be used to determine the tool life [2]. Also, this standard mention that each type of deterioration can occur in different ways depending on the cutting conditions, in other words, to help both the test report and its interpretation, a codified classification system is recommended that allows a detailed description of the deterioration form. On the other hand, in practice the different types of deterioration will occur simultaneously with machining. Therefore, it is necessary to obtain information concerning the deterioration of the tool as a function of its usefulness, that is to say, to detect the wear level of the tool while it can machine parts that maintain a surface finish and dimensional control. Similarly, the roughness Ra parameter is one of the most used parameters by the molds and dies industry to characterize surface finish and wear on cutting tools [3]. The roughness is obtained after performing the downward milling regardless of the cutting conditions; these paths generate higher roughness values
than in the upward milling. In general, machining with upward and downward movements called raster milling is not advisable in terms of obtaining an optimum roughness value [4].

Different authors have raised the importance of rugosity measurements in tools and the techniques used [5,6]. However, sometime later, methods of roughness decomposition based on frequency analysis were proposed to identify tool marks on a machined surface [7], and subsequently, surface roughness became more relevant through an image, through a system of Haralick texture features that facilitates the recognition of surface roughness by means of a neuron network [8]. Other authors used other techniques such as soft computing, which creates a pre-process model of surface roughness based on experimentation with different characteristics of the high-speed milling process [9]. Likewise, during the milling of inclined surfaces with round end herringbone cutters, high interruptions occur during cutting and appear dynamic phenomena different from those that occur during the milling of flat surfaces. The finish is determined by the quality of the surface and the dimensional precision required [10-12]. Another of the important researches is the technique that allows visualizing the wear suffered by the tool, in which the use is determined by means of a laser displacement sensor [13]. However, in 2013 the relationships between cutting conditions cutting speed (Vc) and feed speed (Va) and roughness were established, developing second order mathematical models [14].

Dry milling of a flat surface does not cause changes in the steel microstructure as long as the surface roughness values are appropriate [15]. Another cutting tool used is cemented carbide tools used to investigate the influence of cutting parameters, number of inserts and cutting length on the milled face and surface roughness [16], requiring modeling the tool wear by means of Weibull distributions, while failures to external stresses are applied by a homogeneous Poisson process [17].

2. Materials
The methodology used allows verifying the condition of the cutting tool used in the manufacturing processes based on measurements of roughness and wear of the machined part, in order to avoid damage to the piece, see Figure 1.

![Figure 1. Methodology used according to the requirements established [2].](image)

2.1. Process, tool, and piece
The ISO 8688-1 [2] guidelines establish, according to the process to be carried out, the specifications of the cutting tool and the characteristics of the material, which are the parameters and requirements necessary to determine the wear of the cutting tool in a given manufacturing process.

In this work, the methodology was applied by selecting a milling-planning process in a numerical control machining center, LEADWELL model V32i, Figure 2.

According to the milling and planning process following the specifications of the ISO 8688-1 standard [2], an 80 mm diameter milling cutter with seven Tiger-Tec inserts model SNMX1205ANN-F57 WKP35S shown in Figure 3 was selected as a cutting tool. Each insert has 8 cutting edges.

In order to verify the wear of the cutting tool in the milling and planning processes, the ISO 8688-1 standard [2] defines the material of the part to be worked, in this case it is a C5 steel [3]. The characterization was performed to know the chemical composition of the material: C = 0.43/0.50, Mn = 0.6/0.90, P_max = 0.040 and S_max = 0.050.
In addition, the workpiece has a hardness of 174.7 HB, a rectangular cross-section with a width of 0.6 times the diameter of the cutter and a minimum length of 3 times the diameter of the cutter, as defined in ISO 8688-1 [2].

2.2. Programming machining in Mastercam
In order to carry out this process, the cutting parameters recommended by the ISO 8688-1 standard [2] and by the manufacturer's manual of the cutting tool were considered, which were corroborated and adjusted to be used in the tests: \( F = 0.1 \text{ mm/rev}, \quad V_c = 220 \text{ m/min}, \quad a_p = 2.0 \text{ mm}, \quad \text{cutting length: } 240 \text{ mm}, \quad \text{insert: } \text{SNMX1205ANN-F57 WKP35S and zoom: } 300\times \).

The cutting speed was determined by clearing Equation (1) and the tool feed rate during machining by applying Equation (2).

\[
N = \frac{V_c \times 1000}{\pi \times D_H} \quad (1)
\]

\[
F_z = F \times N \times #_S \quad (2)
\]

Where: \( N \): spindle speed of the machining center, \( V_c \): cutting speed, \( D_H \): diameter of the cutting tool, \( F_z \): feed speed, \( #_S \): number of inserts in the piece, \( F \): feed parameter for the tool. With the parameters defined, the sequence of operations was programmed using the commercial computer-aided manufacturing (CAM) software called Mastercam.

2.3. Definition number of passes
In order to determine the number of passes of the cutting tool on the workpiece that are necessary to guarantee an adequate inspection and to determine the wear of the tool, the value of surface roughness reported by Groover [3] was considered for a milling and planning process, corresponding to a value of 0.4 µm, and based on those described in [5] for machining of average application in a range between 0.4 µm and 1.6 µm.

The roughness limits described in the literature were considered for the number of passes of the cutting tool performing the milling-planning process on the piece. Each pass was carried out as shown in Figure 4, with the objective of measuring the wear produced in the tool. Each pass with a depth of 2 mm and a cutting speed of 220 m/min according to the hardness of the material and the manufacturer's catalogue of the cutter (cutting tool).
2.4. Measurement of roughness and wear

After each pass, longitudinal roughness measurements were made with respect to the machining direction of the cutting tool. The measurement of the surface roughness considering the geometrical product specifications (GPS), in order to be able to compare with the tolerance limits of the values obtained based on the parameters of the surface finish.

Since the generated profile is not periodic, the theoretical value of Ra assigns the value of the basic length of the sample corresponding to the interval in which it is located. According to the specifications of the piece, a basic sampling length of 2.5 mm was used [4]. After each pass, roughness measurements were made on the piece using a TIME roughness meter reference TR200 (Figure 5). Wear measurements on the inserts were made using the Renishaw reference OMI-2T (Figure 6).

![Figure 5. Roughness data collection.](image1)

![Figure 6. Renishaw OMI-2T.](image2)

To determine the roughness of the piece after each milling pass, measurements were taken in different positions following the recommendation of [4]. The mean roughness (Ra) was obtained using Equation 3 from the theoretical relationship between surface roughness, feed, and cutter diameter for the milling and planning process. The surface roughness is represented as the mean arithmetic roughness of the profile in the measured length (see Figure 7) and mathematically defined as shown in Equation (3).

\[
Ra = \frac{0.0642}{D_h} \times Fz^2,
\]

where: Ra: mean roughness, Fz: feed speed, D_h: diameter of the cutting tool.

![Figure 7. Roughness profile [4].](image3)

2.5. Verification by micrographs

To observe the notch left by the roughing carried out by the cutting tool during the milling-planning in each pass, the OPTIKA SMZ 800 optical electron-microscope with a built-in camera for taking high-resolution images was used.

The most important factor in image acquisition is lighting. The effects produced by the type of lighting also depend on the type of surface and the distribution of light on it, as well as its reflectance properties.
3. Experimental setup
Measurements of roughness and wear were made to the piece, as well as micrographs to each of the milling cutter inserts (cutting tool) after each of the 46 passes made during the machining.

3.1. Roughness
10 roughness values were taken after each pass of the values corresponding to Ra (surface roughness) and Rz (valley roughness), finding the average to make a subsequent correlation between surface finish and tool wear.

Figures 8 and Figure 9 show an increase from 0.412 µm to 2.748 µm in the surface roughness of the material between pass 45 and 46. This last value is outside the range between 1.4 µm and 1.6 µm defined in [5] for the milling and planning process.

The Rz parameter is the average of the heights from peak to valley and is defined as the difference between the average of the heights of the five highest peaks and the average height of the five deepest valleys [18]. The sudden increase of the two parameters from pass number 45 is evident.

3.2. Wear
The trend of the tip wear graph (Figure 10) shows a continuous variation after each machining pass of the cutting tool. During the first five passes the variation between peaks and valleys is not as marked, but wear increases progressively. Between passes 11 to 33 the size of the peaks and valleys increases as does the tendency to wear.

Figure 11 shows the general curves obtained from tool wear tests. A total of 46 measurements were made, one for each pass to each of the 7 cutter inserts (cutting tool), resulting in the unfiltered curve, the robust curve, and the Rmr curve for each of the tests performed.
3.3. Micrography

A micrograph was taken on each insert after each pass, a total of 46 micrographs were taken on each of the 7 inserts. In other words, 322 images were used to track wear on the cutting tool in order to compare its condition with the roughness and wear measurements of the machined piece. Figure 12 shows from left to right the micrographs taken at insert number 7 after passes 1-15-30-35-40-46 respectively.

Figure 12, shows the progressive increase in wear until the 46th pass, where the increase in wear on the entire surface of the insert is observed.

4. Conclusions

The degree of BRINELL hardness was determined for the workpiece by means of tests, a value that was considered to define the operating parameters of the machining center during the tests carried out. It is important to consider the manufacturers' specifications of both the cutting tool and the material of the piece in order to define the appropriate operating parameters adjusted to the type of process to be carried out.
The measurement of roughness and wear on the workpiece as a follow-up strategy during the execution of this type of manufacturing processes is a viable alternative, supervising that the roughness values presented after each operation do not exceed the allowed limits depending on the type of process performed.

This methodology based on the measurement of roughness and wear of the piece was corroborated with the wear micrographs in the cutting tool. This becomes in a technically and economically more viable alternative than others that can include digital image processing or forecasts based on probabilistic functions or heuristic systems, which require greater development, level of expertise, and computational cost for its implementation in a productive process.

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