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Statistical analysis of cutting tool wear in machining centers

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Abstract. Cutting tools have great use in the industry for their great effectiveness at the time of use, but it is important to know what the proper use is, because the misuse or constant use of such tools, can cause excessive wear and tear that will reduce tool life. There are different methods and equations to measure the useful life of the tool, it is important to know its state so that at the time of being used in a machining process does not cause irreversible damage to the part. One of the most well-known equations is the Taylor equation where they relate useful lifetime to cutting speed. This project was developed in order to demonstrate, by means of equations and graphs, the lifetime and wear of the cutting tools, as well as the application of statistical equations that allow the analysis of the results obtained in the laboratory; a statistical study was able to evaluate the wear on the cutting tool, obtaining statistically the useful life of the tool in each machining process and calculate in the same way the total useful life of the tool.

1. Introduction

The reliability of cutting tools influences all manufacturing efficiency. In most cases the same cutting tool can be used for different operations, which makes it difficult to estimate the remaining life of the tool [1]. When using any tool, it is important to know it's useful life and the correct way to use it to obtain a good machining and less wear of it. The lack of edge of the tool can generate premature wear on the tool, said wear can damage the finish of the part and for processes where precision is needed the productivity of all work can be lost [2].

There are different methods to be able and identify the wear of cutting tools, can be direct, which are the systems that identify the wear by means of a computational vision and the indirect ones are those that relate the state of the tool with some cutting process [3]. Machining production times can be shortened by combining multiple operations on a machine where each operation may require different sets or types of tools, and this is possible by using turret loaders or automatic changers, tool turrets allow the machine to carry several cutting tools at the same time and deliver a sequence of them to the cutting position according to the process plan [4]. Sustainable assisted machining techniques have been suggested by different researchers to improve the machining performance of difficult to machine material [5].

Manufacturing companies aim to improve and optimize production processes related to the manufacture of parts with cutting tools, mechanical stresses and temperatures in the tool-chip interface and cutting area, may be too high due to high cutting and feed speeds, which results in premature tool wear or failure [6].

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In 1907 Taylor observed experimentally that the gradual wear of the flank increases as the cutting time increases, relating different variables that determine the useful life of the cutting tool, considered parameters such as the cutting speed, tool lifetime and two dimensionless parameters that can be found experimentally depending on the material to be worked [7]. Due to the variability and dispersion of the tool's life data, the logarithmic equation is more effective. Although the variability and dispersion of the tool's life data have been known for a long time, it was not until 1960 that statistical methods were used to measure changes in the tool's life [8].

Regardless of the accuracy of the wear prediction, two key factors have been identified: the first factor involves the node wear rate and the displacement calculation. The calculation of the displacement rate of each node along the tool-workpiece interface depends largely on the contact simulation state, which is very complicated in the cutting of metals [9]. Despite this, no formal study has been found to determine approximately the lifespan of a cutting tool, and many of these studies are impractical to be applied in a real production process [10].

The purpose of this research is to determine the useful life of the cutting tool used in machining centers, using applications of equations such as Taylor's and ISO 8688-1 [11]; then perform a statistical study to be able to monitor the status of the cutting tool on each of the roughing paths when a machining process is performed, in the same way to be able to determine the total lifetime of the tool and its behavior, which depend to a great extent on the cutting speed, feed, material to be machined and cutting depth, all these parameters allow the execution of machining processes, thus determine the conditions or states in which the cutting tool is located and the remaining useful life.

2. Methodology and materials

To calculate the useful life of a cutting tool there are several equations which will give us an estimated value of the tool lifetime, one of them is the Taylor's equation which relates the cutting speed (V), and the tool lifetime (T), said equation is expressed as follows, see Equation (1) [7].

$$C = T^{n}V. \tag{1}$$

Analyzing Equation (1), we conclude that the speed (V) and lifetime of the tool are inversely proportional, where C and n represent two contants that are already tabulated, see Table 1. To assign the values of said constants, it is necessary to consider the material of the cutting tool for this process, in the process of the investigation the coated carbide-based cutting tools were available, therefore, the data of the constants were obtained see Table 1.

Table 1. Taylor's constants.

Tool material	n	C (m/min)	
		Materials that are easy to machine	Soft steel not hardened
Steel for carbon tool	0.100	70	20
High speed steel	0.125	120	70
Cemented carbide	0.250	900	500
Cermet	0.250		600
Coated carbide	0.250		700
Ceramic	0.600		3000

Another factor to consider is the machining time per pass (t), this process is calculated depending on the diameter of the cutting tool, the length of the part and the feed rate see Equation (2) [12].

$$t = \frac{l+D_0}{A_m}, \tag{2}$$

where D_0 is the tool diameter, l is the part length, according to ISO 8688-1 [11] it is expressed as $3\times D_0$ and the part width would be $0.6\times D_0$ on the other hand A_m represents the feed rate and is given by Equation (3) [12].

$$A_m = A_z \times Z \times N, \tag{3}$$

where Z represents the number of inserts in the cutting tool, A_z represents the advance per edge, and N is the number of revolutions per minute, which is calculated by applying Equation (4) [12].

$$N = \frac{1000\,V}{\pi\,D_0}. \tag{4}$$

We can also calculate the total volume of material removed per unit of time (MRR), which is expressed in Equation (5) [5].

$$MRR = A_m \times d \times b, \tag{5}$$

where d represents the cutting depth, b the cutting width. To calculate the specific energy, we can do it by applying the power formula, Equation (6) [12].

$$P = w \times MRR, \tag{6}$$

where P is the power, w is the specific energy; the power of the machine can be obtained from the manufacturer's technical specifications, which is 10 HP. In any type of research, it is important to apply a statistical analysis to be able to see of the results obtained, according to ISO 8688-1 [11] when performing a statistical analysis Under the criterion of the standard it is necessary to apply the Equation (7).

$$\overline{x} = \frac{\sum_{i=1}^{u} x_i}{u}, \tag{7}$$

where $\overline{x}$ is the primary arithmetic value; for our study, u represents the total number of machinings, x_i represents the value of tool wear per machining. On the other hand, there is Equation (8), which shows the standard deviation (s) [12].

$$s = \sqrt{\frac{\sum_{i=1}^{u}(x_i-\overline{x})^2}{u-1}}. \tag{8}$$

We can observe in Equation (9) the maximum value of the confidence interval ($\overline{x}_{max}$), and Equation (10) represents the minimum value of the confidence interval ($\overline{x}_{min}$).

$$\overline{x}_{max} = \overline{x} + t\frac{s}{\sqrt{u-1}}, \tag{9}$$

$$\overline{x}_{min} = \overline{x} - t\frac{s}{\sqrt{u-1}}, \tag{10}$$

when t is a constant obtained from Table 2, by the confidence level of 95.0%, 99.0% and 99.9%, the values of t are dependent on the number of "tests performed", expressed with the number of degrees of freedom [12].

Table 2. Degrees of freedom.

Number of degrees of freedom (u − 1)	Students t value		
	95.0% confidence level	99.0% confidence level	99.9% confidence level
1	12.7060	63.657	636.500
2	4.3027	9.925	31.600
3	3.1825	5.841	12.940
4	2.7764	4.604	8.610
5	2.5706	4.032	6.858
6	2.4469	3.707	5.959
7	2.3646	3.499	5.405
8	2.3060	3.355	5.041
9	2.2622	3.250	4.781
10	2.2281	3.169	4.587
11	2.2010	3.106	4.437
12	2.1788	3.055	4.318
13	2.1604	3.012	4.221
14	2.1448	2.977	4.140
15	2.1315	2.947	4.073
16	2.1199	2.921	4.015
17	2.1098	2.898	3.965
18	2.1009	2.878	3.922
19	2.0930	2.861	3.883
20	2.0860		
30	2.0423		
40	2.0211		
60	2.0003		
120	1.9799		
∞	1.9600		
Degree of significance	●	●●	●●●
	Significant	Well significant	Strongly significant

3. Results

To plot the useful life of the cutting tool according to Equation (1), the cutting speed according to ISO 8688-1 [11] (180 m/min) and that of the insert manufacturer (220 m/min) were considered, opting to use three intervals between these two speeds, resulting in shelf-life Table 3. The behavior of this process can be observed in Figure 1.

The process ended with a total of 45 machined as the last course of machining 46 the cutting tool damages the surface of the treated material. Considering the manufacturer's parameters in the latter process, the total life of the cutting tool was calculated using the Equation (1) to Equation (10), resulting in a wear value of 0.170 mm and a total machining time of 23.49 min see Table 4. The behavior of this process can be seen in Figure 2, where tool wear and service life are represented with respect to the number of machining performed by the cutting tool.

With a 95% confidence level, the alpha value represents the remaining 5% of the confidence level, and the value of t for this study is calculated by making a linear interpolation of the values in Table 2. At the time of statistical analysis, it was possible to establish the number of samples that at a confidence level of 95%, are within the confidence interval see Figure 3.

It can be seen in Figure 1 that represents the cutting speed of the tool in relation to the useful life, the most suitable trend line for this process is the exponential line, which yields a standard deviation of 99.92%. This shows that the calculation is reliable and can be used to improve the working conditions of the tool, thus extending the useful life of the tool. Considering that the higher the working speed, the lower the useful life of the tool, it can also be observed that at lower speed, the longer its useful life, as shown in Figure 2.

This study shows that the total tool life is 23.49 min, and the total wear is 0.170 mm, indicating that the initial parameters, especially the cutting depth, significantly affect the tool life. The cutting tool causes more wear in a short period of time, reflecting 95% of the utility of the insert, as shown in Table 4 and Figure 3.

Table 3. Constant.

C	n	v	t
700	0.25	180	228.7189
700	0.25	200	150.0625
700	0.25	220	102.4947

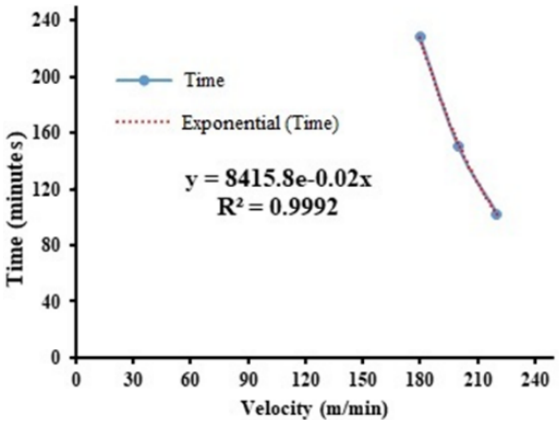


Figure 1. Service lifetime.

Table 4. Machining data.

Machining	Wear (mm)	Machining time (min)	Machining	Wear (mm)	Machining time (min)	Machining	Wear (mm)	Machining time (min)
1	0.024	0.522	16	0.082	8.352	31	0.094	16.182
2	0.049	1.044	17	0.084	8.874	32	0.101	16.704
3	0.048	1.566	18	0.077	9.396	33	0.107	17.226
4	0.053	2.088	19	0.090	9.918	34	0.110	17.748
5	0.054	2.610	20	0.084	10.440	35	0.107	18.270
6	0.077	3.132	21	0.082	10.962	35	0.104	18.792
7	0.069	3.654	22	0.082	11.484	37	0.114	19.314
8	0.060	4.176	23	0.090	12.006	38	0.115	19.836
9	0.052	4.698	24	0.077	12.528	39	0.115	20.358
10	0.079	5.220	25	0.065	13.050	40	0.123	20.880
11	0.089	5.742	26	0.078	13.572	41	0.122	21.402
12	0.097	6.264	27	0.097	14.094	42	0.124	21.924
13	0.090	6.786	28	0.093	14.616	43	0.137	22.446
14	0.091	7.308	29	0.111	15.138	44	0.125	22.968
15	0.085	7.830	30	0.100	15.660	45	0.170	23.490

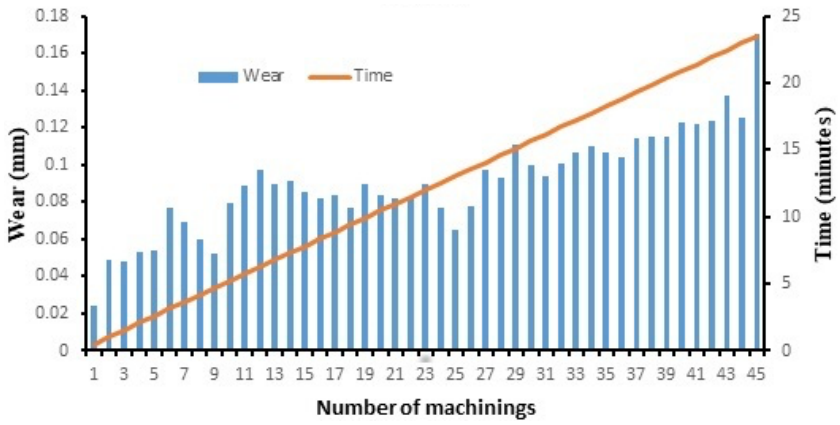


Figure 2. Behavior of the tool.

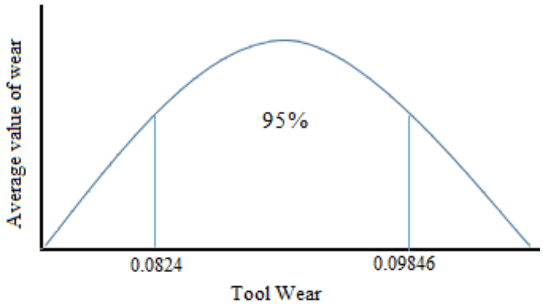


Figure 3. Level of confidence.

4. Conclusions

This research evoked the ISO 8688-1 standard and the physical concepts of Frederick Winslow Taylor, which allowed to determine the wear on the cutting tool and its useful life through a statistical study. It is concluded that as the cutting speed increased the tool's useful lifetime was lower; the tool's useful lifetime decreases even more if only the parameters of ISO 8688 standard are considered, producing greater wear on the tool, affecting the surface finish of the machined part.

This investigation yielded a useful life of the cutting tool of 23.49 minutes and wear of the tool of 0.170 mm, indicating that, under the initial parameters, especially the cutting depth significantly affected the useful life of the tool, reflected in a 95% profit. The trend line that was adjusted to the machining process was the exponential line considering the manufacturer's parameters and specifications and the ISO 8688-1 standard, yielding a standard deviation of 99.92%; this indicates that the calculations are reliable and that they can be used to improve the working conditions of the tool and to obtain an extension in the useful life of the tool. Thus, the higher the cutting speed, the shorter the tool duration, showing an inverse relationship between the cutting speed and the tool lifetime.

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