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A Comparative Study of the Cutting Parameter in Milling Process Under Different Material

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Abstract

In the present study, the incidence of the variation in feed rate per tooth and depth of cut for SAE 4340 alloy steel and SAE J431 steel castings was analysed and in which material this variation is most noticeable. For this purpose, the machining process studied was milling. This is a machining operation in which a workpiece is passed in front of a rotating cylindrical tool with multiple cutting edges. For this study, the feed rate per tooth and depth of cut were varied by 4 values each. The feed rate ranged from 0.002 mm to 0.008 mm and the depth of 2 mm to 8 mm found that for both parameter variations cutting speeds always decrease with increasing both feed per tooth and depth of cut and that feed per tooth and depth of cut significantly affect process costs.

Keywords: depth of cut, feed rate, milling process, cutting parameter

1. Introduction

The optimization of manufacturing processes has been under study since the beginning of its application. For this reason, researchers have used various methods to improve the milling parameters. One of these methods is the control, by means of which it is sought to diminish the vibrations in the process [1]–[3]. A cutting force model based on chip thickness has also been developed for non-uniform propeller tools in the five-axis milling process [4]. In addition, we have sought to model the thickness of the milling chip for low to medium cutting speeds [5].

On the other hand, in order to reduce surface defects on the part, a vibration detection method based on energy entropy was developed. The vibration signal containing the frequency was simulated and three groups of experiments representing three cutting conditions were performed [6]. In addition, with the combined use of variational analysis and finite element analysis of geometric characteristics, the error of position of the tool tip is predicted in order to reduce dimensional and geometric defects [7].

In the same way, the milling process has been combined with other methods such as the use of laser to improve the productivity of the process [8]. An analytical approach to modeling turning and milling was also presented. This novel method would be used especially in difficult to machine or large diameter materials. The geometry of the uncut chip and the coupling limits of the tool were defined for orthogonal, tangential and coaxial chip milling. This model shows a good agreement with the experimental data where the error in the force calculations is less than 10% for different cutting parameters and less than 3% in the quality analysis of the machined part [9]. Also, MATLAB programmed correlation software and CAD programming software were developed. First, mathematical machining models are introduced during the surface milling process in order to analyze the influence of the different machining process parameters on the pattern geometry [10].

Finally, the contribution of this work is to make a comparative analysis of the incidence of tooth feed and depth of cut in alloyed steels and steel casting. In order to find out which variation generates the greatest influence on output parameters such as cutting speed, cutting time costs and tool costs.

2. Methodology

A detailed explanation of the process studied will be presented in the following text. It will be possible to observe the components that were part of it and clarify the variations in the conditions used to carry out the case studies presented. The fundamental equations that govern the process will also be presented.

2.1 Process description

The machining process studied in this article was milling. This is a machining operation in which a workpiece is passed in front of a rotating cylindrical tool with multiple cutting edges. It basically has a workpiece (1) and a cutting tool (2) as shown in the figure below Figure 1.

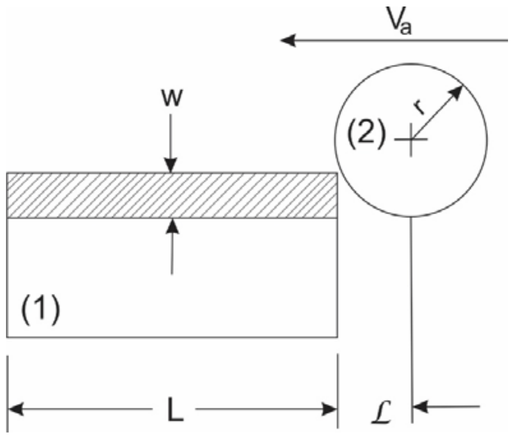

Figure 1. Process Diagram

For this study, the feed rate per tooth and depth of cut were varied by 4 values each. The feed rate ranged from 0.002 mm to 0.008 mm and the depth from 2 mm to 8 mm in SAE 4340 alloy steel and SAE J431 steel casting, using an algorithm designed in a spreadsheet.

2.2 Fundamental equations

The milling process is governed by fundamental equations that have been widely studied and extensively explained in the literature [11]. In this one we find fundamental parameters such as the spindle rotation speed, which is calculated with using the equation 1

$$\mathrm{N} = \frac{v}{(\pi)(2r)}. \tag{1}$$

Similarly, the feed rate for milling can be determined by taking into account the feed rate per tooth (f), the spindle speed (N) and the number of teeth of the cutter (z). Equation 2 shows the mathematical expression used to calculate the feed rate taking into account the variables mentioned above

$$f_r = (\mathrm{N})(\mathrm{z})(\mathrm{f}). \tag{2}$$

In addition, the time to mill a part of length L is calculated with equation 3. This time is important because it can be used to calculate various costs such as those generated by the use of the machine

$$T_m = \frac{L + \mathcal{L}}{(\pi)(2r)}, \tag{3}$$

where $\mathcal{L}$ is calculated using equation 4

$$\mathcal{L} = \sqrt{w(2r - w)}. \tag{4}$$

Another important parameter to evaluate how much money is lost per unused material is the chip volume calculated with equation 5 where p is the part width

$$\mathrm{V} = \frac{(a)\ (f_z)(p)\ V_f}{1000}. \tag{5}$$

On the other hand, a reduction of the costs in the process has been sought and for this purpose the minimum cost method has been proposed, which seeks the appropriate operating conditions for the production of parts with the lowest cost in the process. Parameters such as cutting speed are calculated with equation 6, where X is the operator and machine costs per unit of time, Y is the cost per sharpening, V_1 speed limit and t_{rf} is the tool reset time. In addition, the life time of the tool calculated with equation 7

$$V_{mc} = V_1 \cdot \left(\frac{n}{1-n} \cdot \frac{X \cdot T_1}{(X \cdot t_{rf} + Y)}\right)^n \tag{6}$$

$$T_{me} = \frac{1-n}{n} \cdot \frac{X \cdot t_{rf} + Y}{X}. \tag{7}$$

Another method was developed which, like the minimum cost method, seeks to improve the process, but focuses on obtaining the greatest possible production with the resources available. This is the method of maximum production. The machining speed and minimum production time are also calculated for this with equation 8 and 9 respectively

$$\mathrm{V_{mp}} = \mathrm{V_1} \cdot [\mathrm{n} /(1 - \mathrm{n}) \cdot \mathrm{T_1} / \mathrm{t_{rf}}\ ]^{\mathrm{n}} \tag{8}$$

$$\mathrm{T_{mp}} = (1 - \mathrm{n}) / \mathrm{n} \cdot \mathrm{t_{rf}}\ . \tag{9}$$

3. Result and discussion

The variation in feed per tooth reflects a significant variation in cutting speed as shown in Figure 2a. This shows the minimum cost and maximum production for alloyed steel and for steel casting.

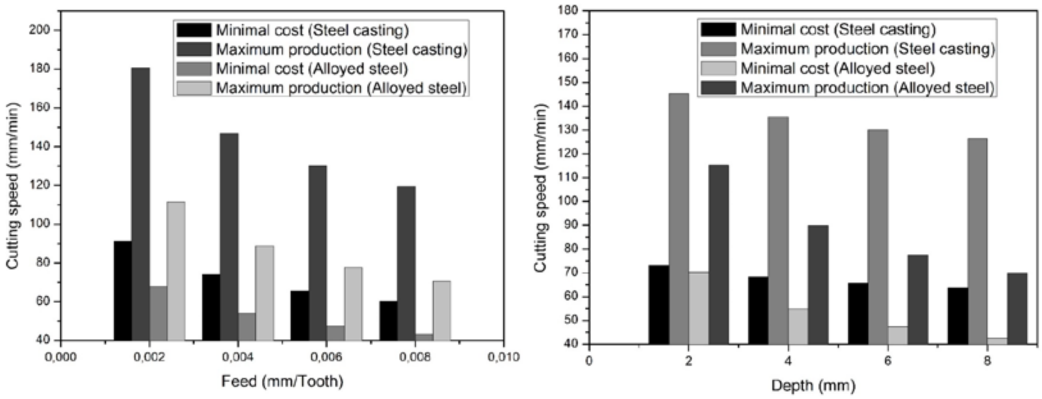

Figure 2. Cutting time, a) for feed rate, b) for depth

As for maximum production, increasing the feed per tooth decreases the cutting speed of both steel casting and alloy steel. The difference is that the steel casting reaches a feed rate of 180.883 mm/min for the feed per tooth of 0.002 mm, which is 38.33% higher than the value of the alloy steel. This behaviour is due to the hardness of SAE 4340 (280-340HB) alloy steel which is higher than that of steel casting (187-241HB). Therefore, to be able to cut the alloyed steel, it is necessary to slow down in order to achieve greater power in the rotation of the cutter. On the other hand, the cutting depth was varied to compare the behavior of these two materials. Figure 2b shows a pattern similar to that shown in the figure above, but with significantly different results.

When the depth varies, the difference between the results in maximum production reaches a peak value of 44.63% between the steel casting and the alloy of this one. Showing this, that increasing the cutting depth affects the alloy more than casting due to the difference in hardness. If only the highest production is observed, it is shown that the smallest variation in the cutting speed for both cases is seen in the depth of 8 mm, reaching a variation of 2.83% with respect to the depth of 6 mm in the steel casting and 13.58% in the steel alloy for the same point studied in the casting, showing a smaller affectation of the depth in the casting, showing an optimum effect on the casting and being optimal to play with these parameters. Similarly, the incidence of feed per tooth on cutting time costs and tool costs for the two materials studied was compared. Figure 3 shows how increased feed per tooth decreases costs.

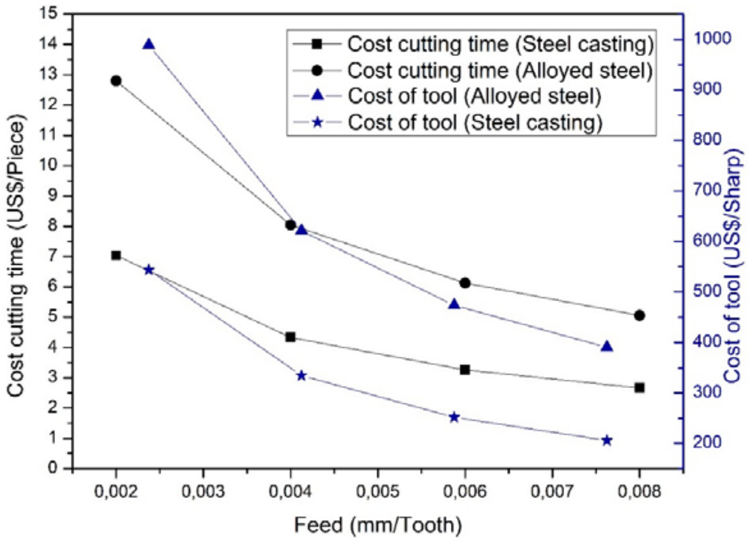

Figure 3. Costs for feed

Looking at time costs first and foremost, it is observed that as the feed per tooth increases, the cutting time decreases, this is due to the greater amount of material pulled out per pass from each tooth. The difference in cutting time costs between materials is also observed, this is because the cutting time of alloyed steel is almost double that of steel casting as shown in Figure 4a and Figure 4b. This is due to the hardness of the material, therefore the higher hardness of the alloy steel requires a lower RPM, thus increasing the cutting time and therefore the costs.

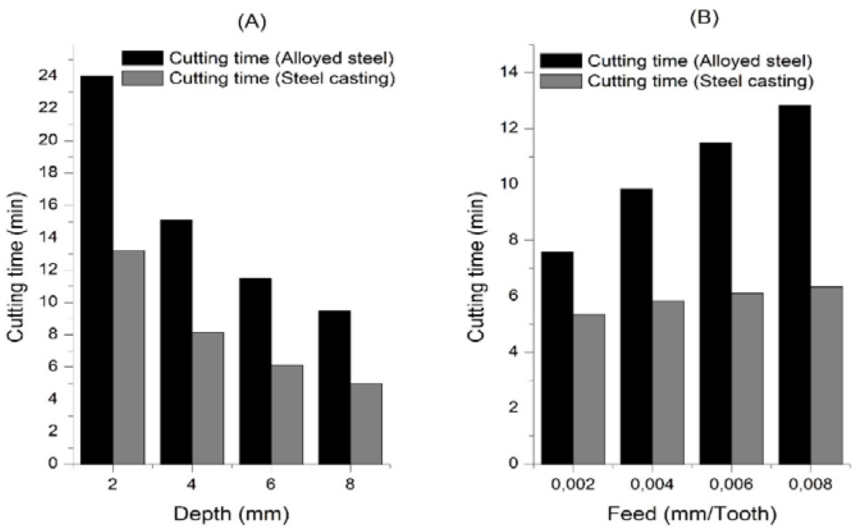

Figure 4. Cutting times, a) Depth, b) Feed

Finally, Figure 5 shows the influence of increased cutting depth on cutting time costs. In contrast to the previous case, increasing the cutting depth has a negative effect on the cutting speed, which increases the difficulty for the cutter when cutting and leads to a reduction in spindle RPM.

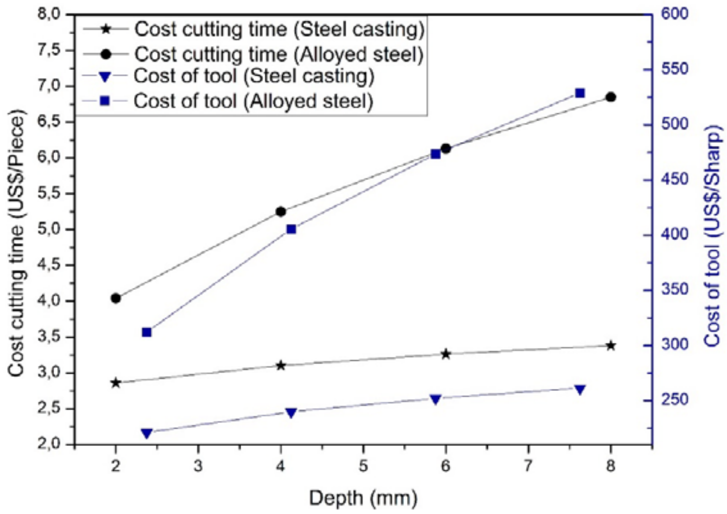

Figure 5. Costs for depth

This negative effect is aggravated by the increased hardness of the alloy steel which increases the cutting time as seen in

(A) and thus increases the costs of this time.

4. Conclusions

After analysis, we can conclude that feed per tooth and depth of cut affect costs significantly differently. Being directly proportional to the increase in cutting depth and inversely proportional to the variation in feed per tooth, they are always more expensive in alloy steel. In addition, for both parameter variations, cutting speeds always decrease with increasing feed per tooth and cutting depth. All this showed that for harder materials the variation of parameters affects their results to a greater extent.

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