STUDY ON CHIP CONTROL IN LOW STEEL MACHINING CRACKED CARBON

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In this context, this study aims to improve the production process causing chip breaking in low carbon steel, by determining the best parameters, tool and machining strategy for chip breaking in the manufacture of the part in question.

The experimental procedure is divided into two stages: first test with the cutting tool currently used in the process that generates long chips, varying the cutting parameters.

And, in the second part, with another specific tool geometry chosen, also varying the cutting parameters. It is concluded that the cutting parameters have an important influence on the shape of the chip, but the factor that proved to be most crucial to the success of this research was the choice of cutting tool geometry appropriate to the material and the specific operation.

Keywords: Machining; Insert; Cavaco.

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Keywords: Machining. Insert. Chip.

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1. INTRODUCTION

In a small company in the metal mechanic segment, located in Vale do Itajaí (SC), the machining process of a specific part in hardened low carbon steel, resulting from a cold forming process, on a multi-spindle lathe with automatic part feeding, it generates very long chips, which harm operator productivity, quality and safety.

The volume of chips generated inside the machine causes problems in their removal and positioning in the lathe's automatic feed, wrapping around the tool, the workpiece or jamming the chip transport belt.

In this context, this study aims to determine the best cutting parameters, tools and machining strategy for chip breaking in the manufacture of a specific low carbon steel part that previously underwent a cold forging forming process.

Starting from the current process already implemented, modifications were made to machining parameters such as cutting speed, depth, feed speed, as well as tool geometry: chip breaker, tool class, insert shape. Machining strategy: roughing and finishing, on a conventional CNC lathe.

This work is divided into four moments: Starting with the theoretical foundation that addresses issues related to machining, chips and inserts. Afterwards, the work methodology is presented. Then, the analysis and discussion of the data will be addressed and, finally, the final considerations.

2 THEORETICAL FOUNDATION

2.1 MACHINING

Machining is a material removal process that occurs when a tool penetrates the part material. Upon reaching the shear force, this material flows through the tool (Baptista; Nascimento, 2012).

Machado and team (2011) define machining as a process of manufacturing parts with chip removal. The definition complements: “Operation that, by giving the part shape, dimensions and finish, produces chips. And by chip we mean: portion of material from the part removed by the tool and characterized by having an irregular geometric shape”. (Machado, et al, 2011, p. 17).

Machado and team (2011) state that machining is the most popular process in the world, however, despite this popularity, it is a very unpredictable process due to the rigor of the entire system that involves it.

> It is a complex process due to the difficulties in determining the unpredictable ideal cutting conditions. It's simple because, once these conditions are determined, the chip forms correctly, eliminating any type of operator intervention. The ideal cutting conditions are those capable of producing parts within shape, size and finish specifications at the lowest possible cost (Machado, et a/, 2011, p. 18).

Factors linked to machining such as tool wear, heat generated during machining and cutting efforts can cause changes in chip formation. In this way, it can be identified that, through chip formation, it is possible to reduce or increase the cost and quality of the part, as well as promoting operator safety. (Diniz, et al, 2008).

Other important factors in machining are cutting speed (Vc), feed speed (Fz) and cutting depth (Ap). “Cutting speed is the instantaneous speed of the reference point of the cutting edge, according to the direction and feeling of cutting” (Ferraresi, 1977, p.5).

For Ferraresi (1977, p. 9) “Advancement is the path of advancement in each turn or in each course”. The cutting depth “is the depth or width of penetration of the main cutting edge, measured in a direction perpendicular to the work plane” (Ferraresi, 1977, p. 10).

The external or internal cylindrical turning process and the facing operation consist of the part rotating around its own axis while the cutting tool performs longitudinal or transverse feed movements (Machado, et al, 2011).

2.2 CHIP

The chip is formed at high deformation speeds, accompanied by rupture of the workpiece material. This process is divided into four stages, presented by Machado and team (2011): initial repression; deformation and rupture; slippage of the lamellas and; chip exit.

Chips can be classified into three types:

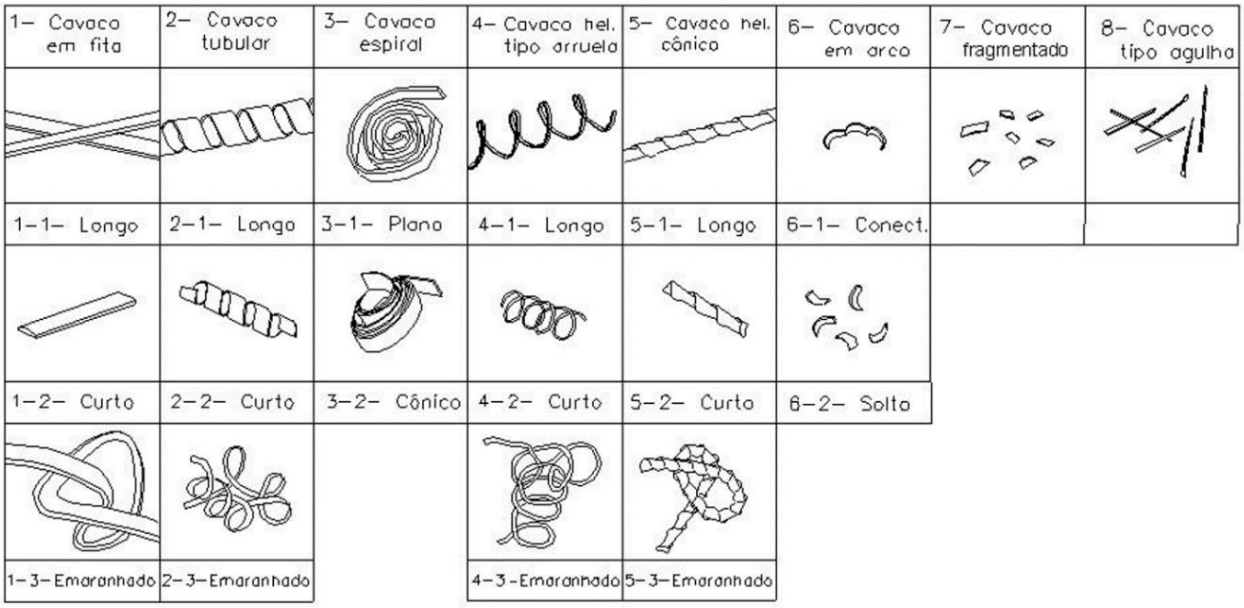
Continuous chips: formed when machining ductile and homogeneous materials, such as steel, forged and low-alloy steels, as well as when machining copper and aluminum. Continuous chips can occur both at low or medium feed speeds and at high cutting speeds (Machado, et al, 2011; Silva, 2007). Silva (2007, p. 8) suggests that this type of chip “is extremely undesirable, due to the problems generated, such as danger to the machine tool operator and difficulty in removing and transporting”.

Partially continuous chips: this type of chip is classified between continuous and discontinuous chips, also known as shear chips. “It is formed when there is a decrease in the resistance of the material in the shear plane, due to increased deformation, there is heterogeneity in the metallographic structure, or there are external vibrations that lead to variations in chip thickness” (Ferraresi, 1977). For Diniz and team (2008), this type of chip is made up of very distinct overlapping lamellae.

Discontinuous chips: generated when machining brittle materials, and this type of material cannot withstand large deformations without breaking. However, if machined at low cutting speed, small rake angle and large feed, they can also produce discontinuous chips in low ductility materials (Machado, et al, 2011).

Machado and team (2011) and Ferraresi (1977) present four forms of chips, which are: ribbon chips, helical chips, spiral chips and chips or pieces, as shown in figure 01:

Figure 01: Shapes of chips produced when machining metals (ISO 3685, 1993)



Source: MACHADO et al, 2011, p. 72.

Figure 01 presents the classification of chip shape details according to ISO 3685 of 1993. For Machado and team (2011) the shape and types of chips are influenced by the type of material of the part and the geometry of the tool.

Ribbon chips can create a high risk of accidents and are difficult to transport as they take up a lot of space. The most suitable chip is helical in shape and the flake chip is indicated for processes where space is limited (Ferraresi, 1977).

When turning or facing low-carbon steels, the chip can generate unscheduled stops to remove it, which is imperative for production, as long chips can generate the following problems:

> - The low effective densities of this type of chip, due to the high volume they occupy, make subsequent handling and disposal processes difficult.
> - They can become entangled in the workpiece, in parts of the machine, or in the tool, creating dangerous situations for the operator due to the high speeds and the cutting edge in chips made of material hardened by hardening.
> - They can harm the surface finish by adhering to the part, or even lead to cutting edge breakage.
> - Increases machining force, temperature and, in general, reduces tool life.
>
> - They hinder the access of the cutting fluid to the chip formation area, causing the umbrella effect (Machado, *et al,* 2011, p. 74).

Chip breakers are classified as embedded and integral, with a modification of the tool surface with characteristic shapes. These changes act by controlling the radius of curvature of the chip, ensuring that, when it collides with an obstacle, it reaches the critical deformation value in the fracture and promotes its breakage (Machado, et al, 2011).

Silva (2007, p. 12) corroborates the idea “In addition, the chip breaker grooves are also designed to further shape the chips, in order to make them more brittle and reduce the value of the critical deformation necessary for fracture ”. Typically, the manufacturing of chip breaking tool designs is specific to each type of operation, covering a certain cutting depth and feed rate.

3 MATERIALS AND METHODS

3.1 METHOD

The experimental procedure, which is in a turning process in SAE1008 steel, which is in the hardened state (after a cold forging process), having as its main point the study of chip control in ductile material that generates long chips with ease.

Another important detail of this research was the verification that the literature clearly shows that better chip control is achieved by increasing the cutting depth and feed speed. But in the process under study, the cutting depth is a process restriction, being fixed at 0.5mm, so the impact of feed speed and cutting speed within the turning process was studied.

In this way, the experimental procedure is divided into two stages: first test with the cutting tool, currently used in the process that generates long chips, varying the cutting parameters. And, in the second part, with another specific tool geometry chosen, also varying the cutting parameters, with the expected result of finding the best parameters and machine conditions during machining that promote the chip breaking into short segments, reducing downtime problems. unexpected result caused by the long chip, thus generating improvements in production processes in companies.

3.1.1 First step: Current process cutting tool

This first stage consists of describing the tests with the tool currently used in the process, with the aim of analyzing whether the tool has the correct parameters and also to have data for a subsequent comparison between different cutting tool geometries.

In the current process implemented, machining takes place on a multi-spindle lathe, with six spindles, being able to make up to two parts simultaneously, which does not occur due to the problem with long chips that makes it difficult to feed and remove already machined parts.

As the objective of the study was to analyze tool parameters and geometries, the tests were carried out on a common CNC lathe, as it was not possible to stop production to carry out the tests, due to the long SET-UP and part preparation time.

A center hole was made in the conventional lathe in the test bodies to serve as a support, as the “nut grip” of the lathe was only eight millimeters. And, as high cutting and feed speeds were used, there is a concern that no accidents occur in the strategy chosen to generate more chips, which facilitated the analysis of the chips generated.

In the process, machining occurs only in this area where the part is fixed, and would generate few chips, which would make their analysis difficult.

Figure 02: Sample of the part fixation

Source: Developed by the authors, 2024.

The cutting tool currently used in the process that was analyzed in this first stage of the experiments is a WNMG-060404 M3 TP300 insert. A matrix was then created with five cutting speeds and eight different feed rates, as shown in table 01:

Table 01: First model of the experiments carried out

Cutting Speed (m/min)	Rotations per minute	Feed in mm/revolutions
250	1500	0.20
333	2000	0.26
416	2500	0.33 – 85% of tip radius
500	3000	0.40
583	3500	0.46
-	-	0.53
-	-	0.56
-	-	0.60

Source: Developed by the authors, 2024.

The machine used in the tests is a CNC lathe, where the part was fixed in a small recess and with the support of the tailstock, a machining pass of approximately 40mm in length was carried out with the parameters determined in table 01. Afterwards, they were records were made of the types of chips obtained and the surface roughness generated. It is worth mentioning that the parameters that varied in the tests are only the cutting speed and the feed speed, with the cutting depth being standardized at 0.5mm, since this is a restriction of the studied process.

3.1.2 Second step: Specific cutting geometry

This second stage first consists of consulting a cutting tool manufacturer's catalog and, after an in-depth analysis of the catalogue, the choice was made of a WNMG 060404 MF5 TP2500 tool, with a specific chip breaking geometry for semi- finishing with high advances in steel and stainless steel with open geometry and very smooth cutting. This tool, according to the manufacturer, has the following working ranges for cutting parameters: Feed speed of 0.2 to 0.8mm/rev, cutting depth of 0.2 to 2.7mm and maximum cutting speed of 545m/min.

Figure 03: Sample of the insert used in the research

Source: Developed by the authors, 2024.

To maximize the tests, parameters were eliminated, the results of which were already verified in previous tests as unusual, due to the feed being greater than 85% in relation to the tool tip radius, the matrix was reformulated for fifteen tests, with five speeds of cuts and three feed speeds, as shown in table 02:

Table 02: Second model of the experiments carried out

Cutting speed (m/min)	**Rotations per minutes**	**Feed in mm/revolutions**
250	1500	0.20
333	2000	0.26
416	2500	0.33 – 85% of tip radius
500	3000	0.40
583	3500	0.46

Source: Developed by the authors, 2024.

The procedure for this stage of testing, as shown in table 02, was similar to the previous ones, where a 40mm long turning pass was carried out with specific parameters stipulated, recording the type of chip generated and surface roughness.

Thus, as before, the tests were all carried out with a cutting depth of 0.5mm (restriction of the studied process).

3.2 MATERIALS

3.2.1 The machine

The machine tool used in the manufacture of the component is a “METRA MH” multi-spindle lathe with six spindles and a tool driven with a Mutiplic command. This machine underwent adaptations to manufacture this specific part. The machine has six axes and they are arranged in two sets of three axes, machining two parts at a time. It works with constant rotation at 1500RPM with the possibility of being changed up to 2000RPM. It also has automatic feeding of parts.

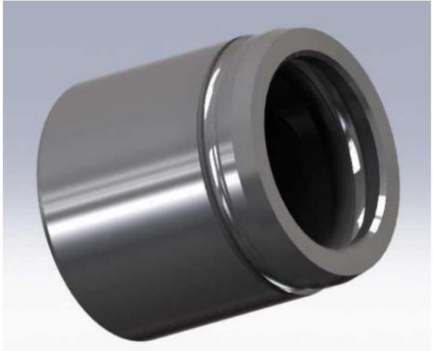
Figure 04: METRA MH multi-spindle machine tool

Source: https://www.flickr.com/photos/multispindle/, 2024.

3.2.2 The piece

The piece has a cylindrical shape measuring 60mm in length with an external diameter of 53mm and an internal diameter of 40mm.

Figure 05: Sample piece



Source: Developed by the authors, 2024.

3.2.3 The tools

Roughing, external finishing and facing: WNMG insert.

Figure 06: WNMG 060404 M3 TP300 Insert

Source: SECO Catalog, 2015.

Figure 07: SECO WNMG 060404 MF5 TP2500 Insert

Source: SECO Catalog, 2015.

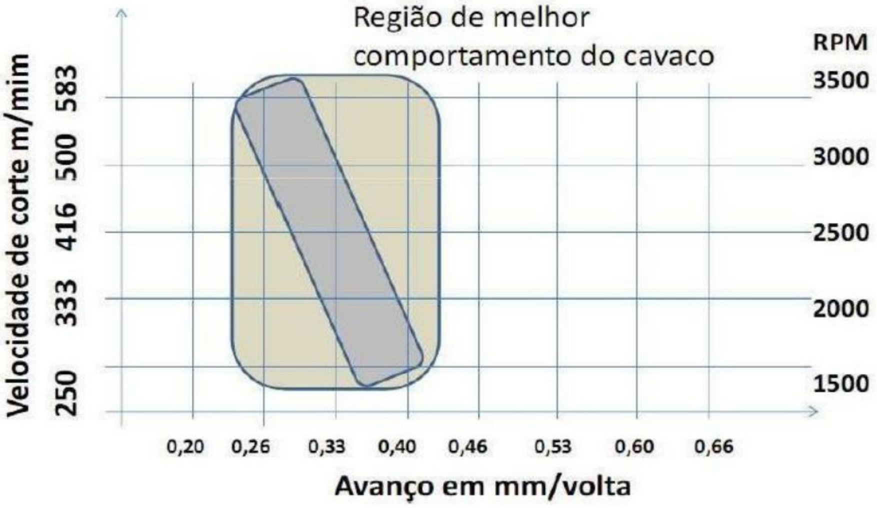
4.0 DATA ANALYSIS AND DISCUSSION

4.1 Process current cutting tool

In this first stage of the tests, which was carried out with the tool currently used in the process, some cutting parameters were defined (cutting speed and feed speed) to have a database of how the chip currently behaves.

The objective of this step is to generate a chip map using the results obtained in testing the chip matrix with five cutting speeds and eight feeds, in order to visualize where it behaves most appropriately. In this way, the following results were obtained:

Figure 08: Chip map



Source: Developed by the authors, 2024.

- Execution of tests with a 5X8 matrix (Vc X Fz).
- Constant cutting depth of 0.5mm.
- Tool currently used in the process (WNMG 060404).

It was possible to verify in the test results that already predicted, according to literature research, where the cutting depth must be greater than the tip radius of the tool and, in the process studied, this is a critical item, as it is at the limit of this depth which is constant at 0.5mm and a tool with a tip radius of 0.4mm.

It can also be seen that the feed must be a maximum of 85% of the tool tip radius, since, from this point onwards, the chip breaker geometry already appears to be inefficient due to the high feed speed and, in tests starting from 0 4mm/revolution, the chip began to form a tangle, which was undesirable.

Another finding was that with an increase in cutting speed, better chip shapes were obtained. However, at the end of this first stage of testing, it was found that, with modifications to the cutting parameters, the control of the trough was improved, but not
It was possible to obtain a satisfactory result that would be a short helix, spiral helix or spiral shaped chip.

Using this tool, a maximum of one oblique helix tangle chip was achieved, these shapes being still undesirable.

4.2 Specific cutting geometry

After completing this first stage, in an in-depth analysis of a cutting tool manufacturer's catalogue, a tool with specific cutting geometry was defined to carry out the second stage and comparison with the results of the previous stage.

The selected cutting tool contains a chip breaking geometry, recommended for semi-finishing with high feeds of steels and stainless steels. It has a very smooth open cutting geometry, as it has a sharp wedge angle and no reinforcement
edge.

At this stage of the experimental procedure, the matrix was redefined with fifteen tests, with five cutting speeds and three feed speeds, with a maximum feed rate of 0.4mm/revolution, as, above that, the chip appears in an undesirable way.

Analyzing, then, the test results, it was immediately noticed that the cutting geometry has the greatest influence on chip formation, as there was a significant improvement in the shape of the chip, which now appears in the form of a short helix and, with the increase in cutting speed, the length of the helix was further reduced, reaching a helix approximately 10mm long at 583m/min cutting speed.

The results are described below:

Table 3: Test results

Cutting speed (You)	**Rotations per minutes (Fz)**	**Chip obtained**
250 m/min	0.26 mm/revolution	Short propeller measuring approximately 40 to 60mm
	0.33 mm/revolution	Short propeller approximately 70 to 100mm
	0.40 mm/revolution	Tangled
333 m/min	0.26 mm/revolution	Short propeller approximately 20mm
	0.33 mm/revolution	Short propeller approximately 50mm
	0.40 mm/revolution	Oblique helix
416 m/min	0.26 mm/revolution	Short propeller approximately 20mm
	0.33 mm/revolution	Short propeller measuring approximately 30 to 40mm
	0.40 mm/revolution	Oblique helix
500m/min	0.26 mm/revolution	Short helix measuring approximately 10 to 20mm
	0.33 mm/revolution	Short propeller approximately 10mm
	0.40 mm/revolution	Oblique helix
583 m/min	0.26 mm/revolution	Short propeller approximately 10mm
	0.33 mm/revolution	Short propeller approximately 20mm
	0.40 mm/revolution	Approximately 50mm propeller

Source: Developed by the authors, 2024.

- Turning cutting tool WNMG 060404 class MF-5
- Recommended cutting parameters:
- Vc of 545m/min, Fz of 0.2 to 0.8mm/revolution and Ap of 0.2 to 2.7mm
- Execution of tests with a 5X3 matrix (Vc X Fz)
- Constant cutting depth of 0.5mm

It is possible to verify that with the increase in cutting speed the shape of the chip improves, with the best condition being obtained at 500m/min, while at 583m/min the chip also behaved in a desirable manner. However, according to the manufacturer, the maximum permitted cutting speed is 545m/min. In this way, this limit would be exceeded and theoretically there would be a reduction in the useful life of the tool.

Also, it was noticed that, with the increase in cutting speed, it is possible to increase the feed speed, where the chip behaves better, with a limit of 0.33mm/revolution which is the limit of 85% of the radius of the tool tip which is 0.4mm, already at 0.4mm/revolution, the chip appears in the form of a tangle and long helix.

4.3 Variation of cutting depth

Tests were carried out varying the cutting depth, where six tests were carried out, with a feed speed of 0.33mm/ revolution, which was the feed speed that presented the best results, using the cutting tool with specific geometry WNMG060404 MF- 5.

This tool also presented the best results to date, with two cutting speeds: 250 and 416m/min and the cutting depth varying from 0.25mm, 0.5mm and 1mm. The results are presented in table 04:

Table 4: Variation of cutting depth

Cutting speed (You)	**Cutting Depth (Ap)**	**Chip obtained**
250 m/min	0.25mm	Tangled
	0.50mm	Propeller approximately 50mm
	1.00mm	comma type
416 m/min	0.25mm	Tangled
	0.50mm	Short propeller approximately 30mm
	1.00mm	comma type

Source: Developed by the authors, 2024.

- For turning WNMG 060404 class MF-5
- Recommended cutting parameters:
- VC of 545m/min, Fz of 0.2 to 0.8mm/revolution and Ap of 0.2 to 2.7mm
- Execution of tests with a 2X3 matrix (Vc X Ap)
- Constant feed speed at 0.33mm/revolution

Considering the two cutting speeds with a cutting depth equal to 0.25mm, the chip appeared in a tangled shape. This is due to the cutting depth being smaller than the tool tip radius, which is 0.4mm.

It was also noticed that increasing the cutting speed and increasing the depth improved the shape of the chip. With a cutting depth of 0.5mm, the results were the same as those obtained previously with the same parameters and at a cutting depth of 1mm, the chip appeared in the shape of a comma.

5.0 FINAL CONSIDERATIONS

It is concluded that the development of this study presented satisfactory results, corresponding and affirming what the existing literature on chip control in the machining of hardened low carbon steels showed. It is interesting to note that the cutting parameters have an important influence on the shape of the chip, but the factor that proved to be most crucial to the success of this research was the choice of cutting tool geometry appropriate to the material and the specific operation.

It was also possible to analyze that the cutting depth also has a great impact on the type of chip, but as it is a process restriction of 0.5mm, it made it difficult to achieved satisfactory results, then this must be an important piece of information to be taken into consideration for subsequent projects.

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