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INVESTIGATION OF THE EFFECT OF HELIX ANGLE VARIATION ON INTERNAL THREADING

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Abstract. Threading is one of the most used manufacturing processes in modern industrial products. Stoppages in production lines in the automotive industry can be caused by loss of quality and breakage of taps in the threading process. These stops entail losses of the item's added value at each stage, adding to the losses related to the tool costs and all the time spent on a production line. Breakages of cutting tools are mainly caused by the clogging of the exit channel caused by chips, which generates an increase in the torque value in the tap. This condition often damages the coating and compromises machining. For this, studies have been developed with the objective of analyzing the influence of the helix angle in the manufacturing process by threading. In this work, the effects of varying the helix angle on cutting forces with M8 taps of HSSE with a pitch of 1.25 millimeters coated with DLC were evaluated. Machining was carried out on a machining center at the CNC Machining Center, model 1250D, manufactured by ROMI, with three axes. Tools with two different helix angles 15° and 45° and pressurized cutting fluid with constant working pressure of 35 kgf.m⁻², with cutting speed of 40 m.min⁻¹ and 60 m.min⁻¹, were fixed in a threading head with compensation axial, Softsynchro® Modular in all experiments. The material used in the tests was the AA6063 aluminum alloy and the torque in non-passing threaded holes were measured. For statistical analysis, a complete factorial design with 2 factors and 2 levels was used, ANOVA was used to evaluate the effects of each level of the investigated factors. According to the results obtained, it can be concluded that the tool with a helix angle of 15° presented the highest torque values.

Keywords: Helix Angle, Torsional moment, Non-passing holes, Aluminum Alloy. (Times New Roman, italic, size 10)

1. INTRODUCTION

Modern industry faces a great challenge in the production of consumer goods based on a triangle formed by: reduced costs, minimum production time and high quality. Thinking about a large-scale production, such as in an auto parts industry, the loss of quality in the threading processes, changing cutting tools and stoppages in production due to breakage, are factors that contribute to great losses. Thus, ways to increase the life and durability of cutting tools have been developed, such as the application of coatings and cutting fluids.

The work (Korhonen et al., 2018) aimed to understand the performance of diamond cores in aluminum alloy 6082-T6. The influence of the Diamond-like Carbon coating (DLC) on the torque of M6 x 1 HSSE cutting taps (steel for high-speed tools with cobalt addition) was verified in 50 non-passing threaded holes, with a cutting speed of 6 m/min and 18 non-passing threaded holes at 35 m/min. Dry machining conditions and with a minimum amount of cutting fluid (MQL) were used. In the papers of (Biermann and Oezkaya, 2017) used computational fluid dynamics (CFD) software to understand the flow of coolants in the threading process. The simulation provided a theoretical model where a pressurized cutting fluid is injected through an internal channel passing through the center of the tool and branched out over the three straight flutes of the taps. The results provided information to modify a conventional straight flute tapping tool for through holes because, according to the analysis, the cutting edges of the faucets were not sufficiently supplied with coolant. Thus, the simulation enabled the development of a new design of the internal cooling channels, making it likely to increase the fluid velocity and the pressure on the cutting edges. Experimental threading tests were performed, and tool performance increased by 36%. Studies based on new fluids and lubrication systems aim not only to reduce friction in the cutting region, but also to reduce the temperature in the threading process (Brandão et al., 2020).

Recent work (Oezkaya and Biermann, 2018) also developed a finite element study to find torque values in the threading process. This work was implemented in the software system based on FEM ToolSimulation. An experimental validation, with four M8 Taps (1.25 mm pitch) were performed, to validate the FEM results. The best result for torque was defined when a small segment of the conical region in a part with a circle segment of 15° was simulated. However,

the torque simulation, considering the segmented model, did not exhibit stable local maximum torques due to intermittent deflections at intervals used in the model. However, local maximum partial torques can be accumulated up to a global maximum torque through a sequence of specific mathematical models.

Recently, (Monka et al., 2019) studied a threading process for manufacturing M12 threads with three different helix angles $\omega = 0^\circ, 15^\circ, \text{ and } 35^\circ$. Equations describing the tooling dependencies were developed with vibro-diagnosis in progress. Also, the stability monitoring with the possibility of predicting the behavior of the tool with the early identification of the faulty tool was studied. The results confirm that it is possible to identify faucet wear through vibratory diagnostics defining frequencies in the range of 800-850 Hz, which may be related to tool wear for specific devices. According to the authors, abrasion on the tool flank and plastic deformation also created a built-up edge on the face of the cutting tool, which could be a reason for the poor quality of machined surfaces and deformed threads. Among the main results studied in threading processes, thrust force and torque are significant responses due to their great influence on yarn quality. The importance of monitoring torque is mainly related to tool breakage due to the probable increase in cutting forces during the threading process. On the other hand, the thrust force is directly related to the pitch errors and the quality of the thread profile. Thus, the works cited below present a summary of the main articles where torque and impulse force were studied.

The work (Siqueira et al., 2019) studied threading operations with three types of taps, considering torque and axial thrust force as primary results. The authors used SAE 1020 steel parts due to its wide application in industry and mainly because the steel has excellent machinability. Metric M8 thread profiles with a pitch of 1.25 mm were manufactured with helical taps (15° and 35°) and straight flutes and the influence of the chipbreaker and coating was also tested. According to the authors, the axial thrust force decreased at a cutting speed of 45 m/min in relation to tests with cutting speed at a cutting speed of 15 m/min and this trend was proportional when the helix angle was changed, but in the analysis with lower cutting speed there was an increase in torque in relation to the cutting speed of 45 m/min. Taps with a helix angle of 15° provided greater axial thrust force than a helix angle of 35° for all input cutting parameters tested. Finally, taps with chip breakers generated higher values of torque and axial thrust force.

Alloy AA 6063-T6 has a low Mg+Si content, providing it with lower mechanical strength and greater ductility (METALS HANDBOOK, 1998). Said alloy tends to form continuous chips, directly interfering with machinability, in the case of internal threads with taps, the accumulation of chips in the cutting region provides an increase in torque and in some cases tool breakage inside the hole.

Studies involving threading using cutting fluid at high pressure are incipient, especially in aluminum and its alloys. In this way, the need was identified to associate the good results with DLC coatings described (Korhonen et al., 2018), using axial compensation head with M8 x 1.25 tap, with helix angle of 15° used (Siqueira et al., 2019) and investigate the influence of the 45° helix angle on the threading of AA alloy 6063-T6.

2. MATERIALS AND METHODS

AA6063-T6 is an Al-Si-Mg alloy, widely used and easily accessible on the market, with a low silicon content, sufficient to form magnesium silicates, Table1. Primary aluminum alloys are widely used in the automotive sector.

Table 1. Chemical composition of aluminum alloys of the 6XXX series.

Registered International			Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others		Aluminum
Designation											Each	Total	
Nº	Date	Country											
6063	1954	EUA	0,20- 0,60	0,35	0,10	0,10	0,45- 0,90	0,10	0,10	0,10	0,05	0,15	Remaining

Source: Adapted from The Aluminum Association Inc., 2022.

The experiments were carried out at the Mechanical Engineering Laboratory of the Federal University of Triângulo Mineiro. The equipment used was a CNC Machining Center model 1250D, manufactured by ROMI, with 18 kW of power on the main axis and maximum rotation of 12,000 rpm. Soluble cutting fluid MV AQUA 180, manufactured by VCI, was used at a concentration of 8%. The hydrogen ion potential (pH) was monitored throughout the experiment so that it remained between 8.1 and 9, values recommended by the manufacturer. To measure the torque during operation, a Kistler dynamometer model 9123 C1211 was used, along with a Kistler multi-channel amplifier and signal conditioner Kistler models 52231 and 5019A. For signal acquisition, a DAK 6202 signal acquisition plate was used at an acquisition rate of 200 Hz, and LabVIEW 7.6 software from National Instruments.

The torque signal after being collected was processed in MatLab/Simulink® R2018a, through the graph generated, the point with the highest value generated in the advance and return were plotted, and an average was taken throughout the threading period. The behavior of the threading head through its elastomers guarantees compensation to the threading tool, which appears on the torque graph as an oscillation between 0 and the measured peak, as if there were noise in the

collection, in this case the moving average at each 10 points proved to be the best way to monitor the increase in torque throughout the process.

In this work, for the internal threading tests, 4 taps will be used, coded by the manufacturer as HSS-E M8 x 1.25 mm with helix angle at 15°, with internal lubrication channel type IKZ, with chamfer type E, coated with DLC, called male type 1; 4 taps HSS-E M8 x 1.25 mm with helix angle at 45°, with internal lubrication channel type IKZ, with chamfer type C, coated with DLC, called tap type 2 will be used, fixed in a threading head with compensation axial, Softsynchro®. Images of two tools are shown in the Figure 1. The thread quality will be monitored using a buffer gauge that passes or does not pass, manufactured by EMUGE, coated with DLC, by the company Oerlikon Balzers, the pre-holes had an average diameter of 6.81mm.



Figure 1. DLC coated M8 cutting tap with different helix angles 15° and 45°.

A factorial planning of 2 levels and 2 factors was used, which are: cutting speed of 40 and 60 m.min⁻¹; 15° and 45° helix angle. Application of cutting fluid at constant high pressure 35 kgf.m⁻², as shown in Table 2 and Table 3. Internal threading was performed continuously without a chip breaking strategy for a length of 20 mm. A replica and a rejoinder were made for all conditions. The thread quality will be monitored using a plug gauge that passes or does not pass.

Table 2. Cutting parameters and their respective levels

Levels	Factors	
Tests	Vc [m.min ⁻¹]	Helix angle [°]
+	40	15
-	60	45

Table 3. Matrix of experiments

Terms	Vc [m.min ⁻¹]	Helix angle [°]
1	+	+
2	+	-
3	-	+
4	-	-

ANOVA analysis of variance was performed, obtaining Pareto charts of standardized effects and interaction graphs to determine whether there is a difference between the means for each cut-off condition. Graphs were also obtained that show the torque of the tap as a function of the cutting speed and the helix angle used.

3. RESULTS

The obtained torque results were analyzed in the Matlab software with the objective of verifying the behavior of the torque curves. After the individual analysis of each curve generated in each experiment, the maximum values for torque were collected and transferred to a MinTAB spreadsheet. After recording each experiment in this spreadsheet, the results of the analysis of variance (ANOVA) were obtained for each response separately. Figure 2 shows a typical torque graph. All graphs had the same behavior, however all showed different maximum and minimum values in each tested condition.

In this graph, the inclined region of the torque that corresponds to the conical part of the cutting tap can be seen. Then, for the torque, there is a stabilization of the effort with a small ramp in the opposite direction to the movement of the tool. In this region there is no more cutting, but only friction between the tool edges and the threads that have already been formed. When the tool is stopped before reversing the direction of rotation, with a programmed pause of 0.5 seconds, when starting to return, the elastomers act to compensate for any synchronization error that may occur when removing the tapping tap from the hole. The torque that initially appears high comes from the presence of chips inside the hole, associated with the moment of inertia caused after a programmed pause in the process. As the tap moves, the elastomers enable a reduction in torque. Furthermore, due to the Softsynchro® Modular threading head compensation system, for the torque graph the value can be considered as zero. The manufacturing time of each thread was proportional to the

cutting speed values used. For the graph in Figure 2, the speed cutting used was $40 \text{ m}\cdot\text{min}^{-1}$ with the tool with a 15° helix angle and without chip breaking. Thus, it is noted that the thread manufacturing time was 1,3 seconds and the total time including the return was 1.35 seconds. It presented a peak torque equal to 136.37 N.m and an average torque during machining of 82.045 N.m.

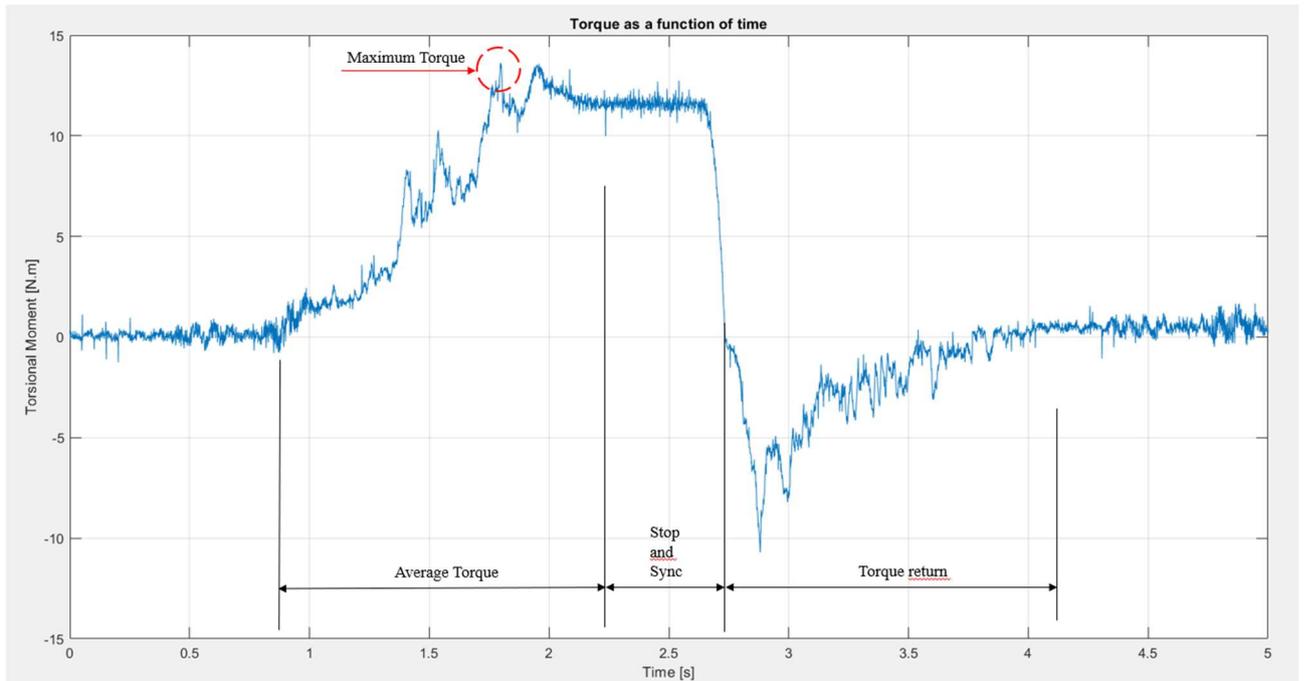


Figure 2. Torque for experimental test for helix angle of 15° , V_c of $40 \text{ m}\cdot\text{min}^{-1}$.

Figure 3 shows a peak torque equal to 3.379 N.m and an average torque during machining of 1.465 N.m. The 45° helix angle showed a reduction in average torque 4.5 times compared to the 15° helix angle during threading with a cutting speed of $40 \text{ m}\cdot\text{min}^{-1}$ and working pressure of $35 \text{ kgf}\cdot\text{m}^{-2}$.

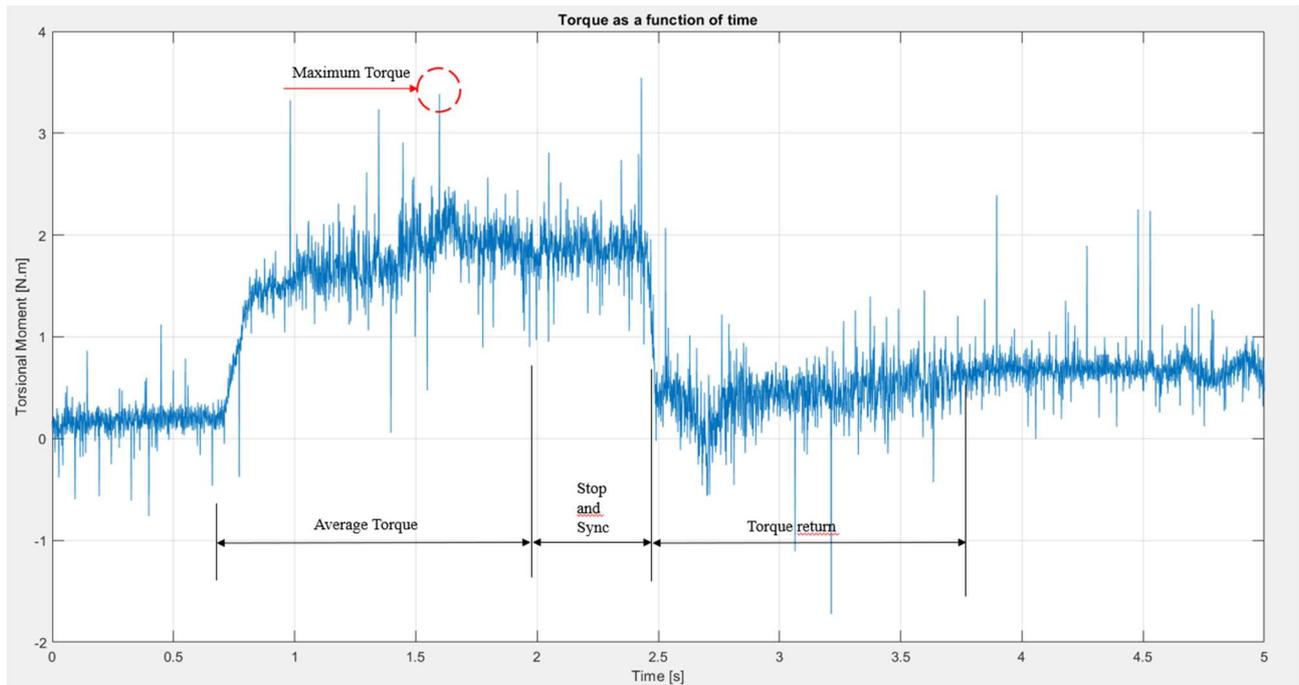


Figure 3. Torque for experimental test for helix angle of 45° , V_c of $40 \text{ m}\cdot\text{min}^{-1}$.

The manufacturing time of each thread was proportional to the cutting speed values used. For the graph in Figure 4, the speed cutting used was $60 \text{ m}\cdot\text{min}^{-1}$ with the tool with a 15° helix angle and without chip breaking. Thus, it is noted that the

thread manufacturing time was 0,9 seconds and the total time including the return was 1.3 seconds. It presented a peak torque equal to 4.926 N.m and an average torque during machining of 3.443 N.m.

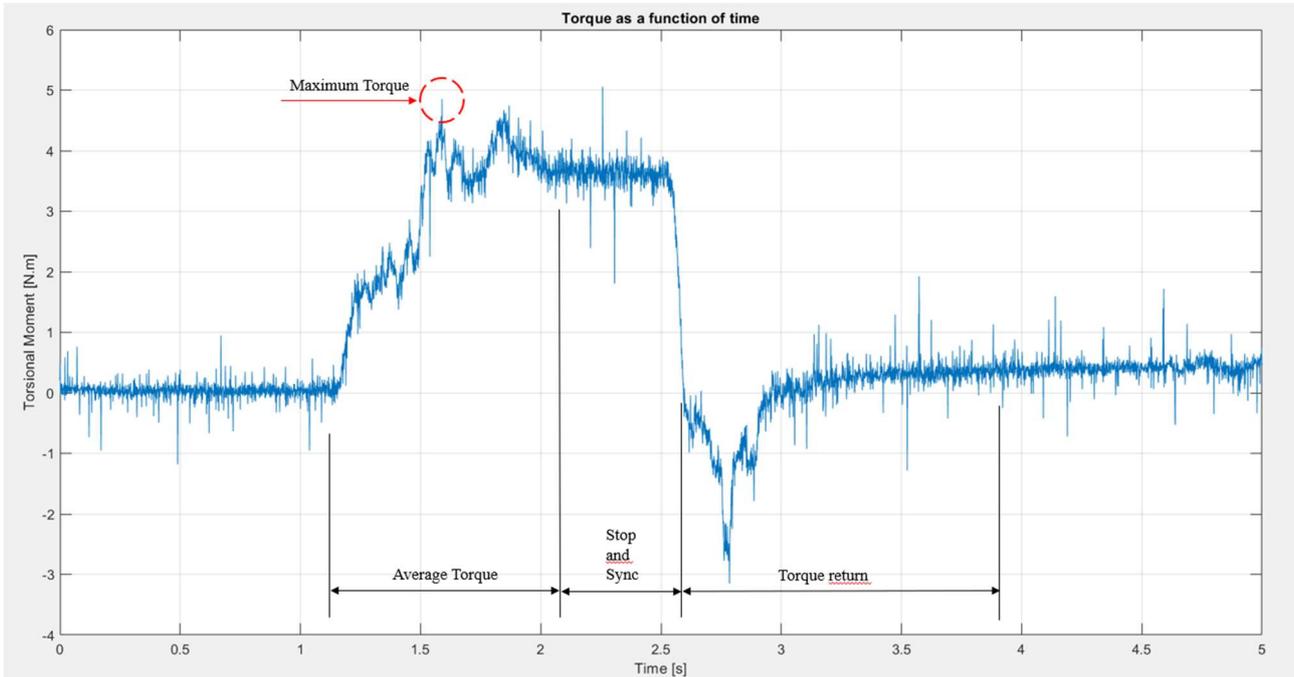


Figure 4. Torque for experimental test for helix angle of 15°, V_c of 60 m.min⁻¹.

Figure 5 shows a peak torque equal to 2.439 N.m and an average torque during machining of 1.453 N.m. The 45° helix angle showed a reduction in torque during machining 4 times compared to the 15° helix angle for a cutting speed of 60 m.min⁻¹ and working pressure of 35 kgf.m⁻².

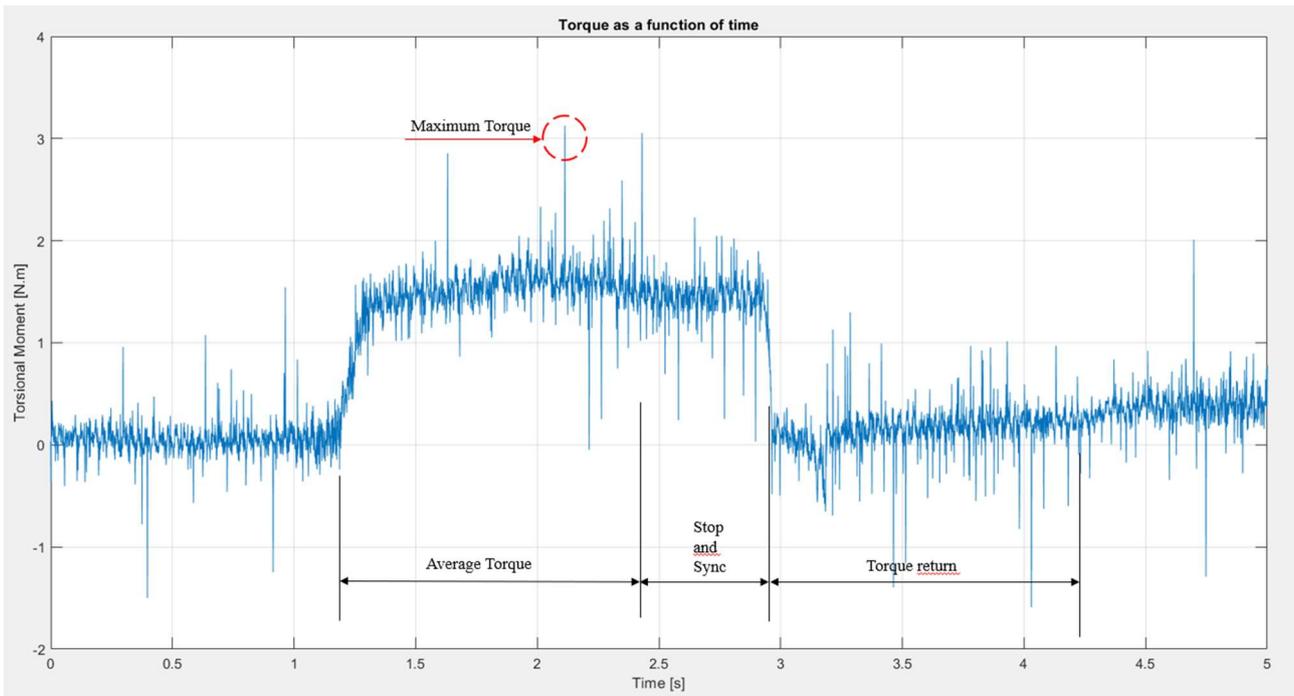


Figure 5. Torque for experimental test for helix angle of 45°, V_c of 60 m.min⁻¹.

In the factorial statistical analysis performed for the input factors cutting speed and helix angle, indicated in bold in Table 5, ANOVA analysis of variance and Pareto chart for standardized effects and also main effects chart for mean Maximum Torque were performed. The experimental design, shown in Tables 2 and 3, is a statistical approach to reaction

and process optimization that allows varying different factors at the same time, with the aim of selecting the reaction space to obtain optimal values

Table 5 shows that, for a significance index $\alpha \leq 0.05$ for each condition of helix angle and cutting speed analyzed, it presented p value = 0.000, lower than the significance index, thus the input variables influenced the response surface, with the interaction of these two factors determining the torsion moment obtained during machining, which can be proven by the Pareto chart, Figure 6.

Table 5 - Regression model fit analysis of variance

Fonte	GL	SQ (Aj.)	QM (Aj.)	F value	p value
Model	3	9399,19	3133,06	928,42	0,000
Linear	2	9307,86	4653,93	1379,10	0,000
Cutting speed[m.min ⁻¹]	1	159,78	159,78	47,35	0,000
Helix angle[°]	1	9148,08	9148,08	2710,85	0,000
Interaction 2 factors	1	91,34	91,34	27,07	0,000
Cutting speed * Helix angle	1	91,34	91,34	27,07	0,000
Error	16	53,99	3,37		
Total	19	9453,19			

Table 6 - Regression Model Summary

S	R ²	R ² (aj)	R ² (pred)
1,83701	99,43%	99,32%	99,11%

This model was validated due to high adjusted correlation value found ($R^2_{adj} = 0.9932$). This value indicate a good correlation between the model data obtained in the experimental tests of the internal threading process carried out, Table 6.

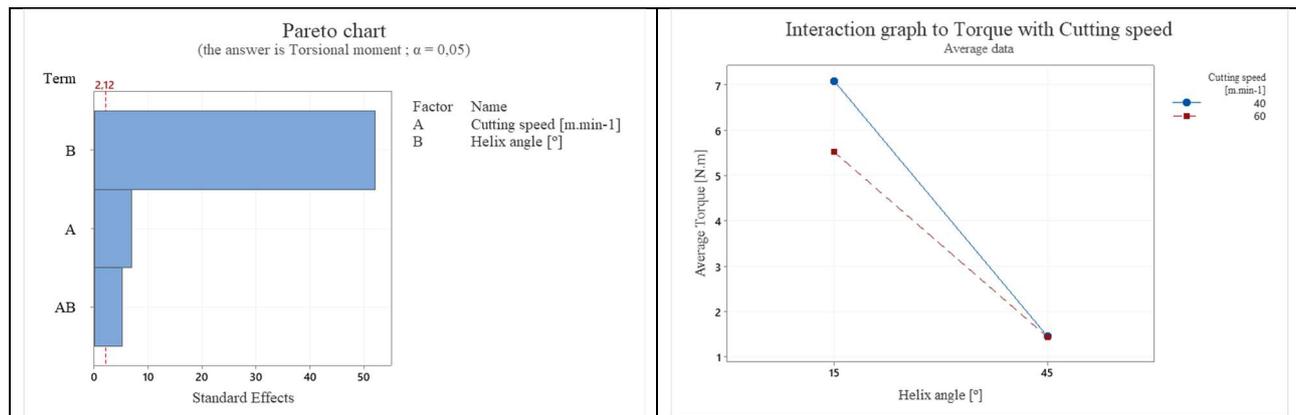


Figure 6. Pareto chart of standardized effects (on the left); Interaction graph for forward torque (on the right)

In the interaction graph of the average torque at the cutting advance, Figure 6, it can be seen that the torque increases for the helix angle of 15°, the best torque result was presented with the helix angle of 45° at both cutting speeds.

The parameters tested in this article were not able to broke the chips. Note that the working pressure of 35 Kgf.m⁻² unblocked the hole to be threaded, preventing the chip from getting tangled in the tool during the threading process.

The 45° helix angle allows a greater number of cutting fillets in contact with each complete 360° rotation. For higher cutting speeds that dictate higher revolutions per minute, the smaller amount of material removed by the cutting thread acts to reduce torque during the internal threading process.

4. CONCLUSION

The Pareto chart demonstrates that, for a significance index $\alpha \leq 0.05$, the helix angle and cutting speed jointly influenced the response surface.

The HSS-E M8 x 1.25 mm tap with a helix angle of 15° presented an average torque at cutting feed rate 4.5 times greater than the cutting tap with a helix angle of 45°. The ANOVA analysis of variance allowed us to infer that although the cutting speed of 60 m.min⁻¹ produced slightly lower torques compared to the cutting speed of 40 m.min⁻¹, this presented a p -value ≤ 0.05 , determining that there is no significant difference between the averages analyzed for the two speed cuts analyzed.

5. ACKNOWLEDGEMENTS

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