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ANALYSIS OF THE EFFECT OF THE THREADING HEAD WITH AXIAL COMPENSATION ON THE AXIAL FORCE OF ADVANCE AND RETURN IN THE THREADING

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Abstract. *The internal or external threads are manufactured to allow a perfect and precise assembly of mechanical components. Its applications are presented in the manufacture of commercial screws used in fixations, passing through spindles for transmission of movements, micrometric screws of measuring instruments, screws used in dental and bone implants are some of the applications of this process. In internal threading, numerous factors can influence the premature breakage of taps during the process. Among them, material ductility, hardness, machine synchronization error, excessive cutting speed, dimensional error, geometric error of holes, chips at the bottom of the hole, lubricity of the cutting oil used, tool coating and type of threading head used. Considering the dynamics of the internal threading process, the lubrication-cooling systems and the threading heads are of great importance in the quality and time of production of threads. The latter is the reason for this investigation, to analyze how axial compensation threading head from different manufacturers affect the axial forces of advance and return in the threading of aluminum alloy AA6063. M8 x 1.25 mm taps coated with DLC with a helix angle of 45º were analyzed. Machining was carried out on a CNC machining center, model 1250D, manufactured by ROMI, with three axes. They were attached to two threading heads with different axial compensation, from two different manufacturers, with pressurized cutting fluid with a working pressure of 35 kgf.cm^{-2}, with a cutting speed of 40 m.min^{-1} and 60 m.min^{-1}. The material used in the tests was aluminum AA6063 and the axial force in non-passing threaded holes was 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 axial threading head has an influence on the axial force in the process, and that it can lead to premature breakage of the internal threading tool.*

Keywords: *Tap, DLC, Axial Force, Axial tapping head.*

1. INTRODUCTION

The 6XXX series aluminum-magnesium-silicon (Al-Mg-Si) alloys are widely used in the aerospace and automotive industries due to their favorable mechanical properties, low density, and high corrosion resistance, coupled with lower energy consumption during machining and forming processes (Zhang et al., 2017).

The microstructure of as-extruded AA6063 alloys in T4 and T6 temper exhibits equiaxed grains with an average size of 94 µm, containing substantial Al-Si-Mn-Fe intermetallic particles formed during solidification. In the T6 temper, needle-shaped precipitates align along the <100> crystallographic directions, ranging in length from 15 to 120 nm, with an average of approximately 35 nm. These precipitates, comprising magnesium and silicon, enhance the alloy's strength, thereby illustrating the significant impact of heat treatment on microstructural characteristics (Kula and Niewczas, 2024). This material is characterized by high ductility and toughness.

Threaded components are vital in both industrial and daily applications due to their ability to facilitate quick assembly and disassembly. Nuts are the most common element in mechanical assemblies, although internal threads are also employed for clamping. Internal threads primarily experience tensile forces, while screws are subjected to both tensile and torsional forces (Brandão et al., 2020).

In CNC machining, threading heads are employed to increase productivity through higher cutting speeds. Common threading heads include fixed, self-reversing, floating, and axial compensation heads, with the latter designed to address synchronism errors and radial and axial runouts. High-speed steel is predominantly used for taps, sometimes manufactured through powder metallurgy for enhanced durability. Coatings, including diamond-like carbon (DLC), are applied to taps to reduce friction and wear. Bhowmick et al. (2010) demonstrated that DLC coatings improved tool life and reduced torque by minimizing aluminum adhesion during the dry machining of Al-Si alloys.

Steininger et al. (2015) used a variety of physical vapour deposition (PVD) coatings like TiCN, CrN, and TiB_2 on carbide and two types of DLC coatings with the main reason being to monitor the torque and force. The results demonstrated that the highest performance was achieved when employing tools with DLC coatings considering the torque measured and the analysis of the tendency to generate BUE, BUL, and the chip morphology. Furthermore, the chip morphology produced by the DLC coated tools exhibited smoother surfaces, straighter edges, and reduced fringes. Thus, the probability of clogging the pitches and the flutes could be decreased significantly. When drilling aluminum with high-speed steel tools coated with a dense layer of DLC, with around 18% carbon in a diamond structure, there was no significant influence on the roughness of the holes, but tests with dry machining revealed levels of adhesion low cutting speeds (high speed), which can establish itself as an alternative for "green manufacturing" (Ba et al. 2023).

Peng et al. (2016) analyzed cutting forces during threading in Ti-6Al-4V alloy, showing that increasing the hook angle and passivation edge radius reduced cutting forces, while spindle speed also played a key role. Optimal parameters included a tap angle of 11°, relief angle of 12°, passivation radius of 0.015 mm, and spindle speed of 250 rpm. Steininger et al. (2015) further demonstrated the superiority of DLC-coated tools, which reduced torque and the likelihood of built-up edge formation, while improving chip morphology during aluminum drilling.

Siqueira et al. (2019) investigated threading in SAE 1020 steel using taps with different helix angles and TiN coatings, showing that torque increased with cutting speed, while axial force decreased, using axial compensation heads. Coelho et al. (2019) compared threading heads under various cooling conditions, finding that minimal quantity lubrication (MQL) combined with self-reversing heads provided the lowest torque, while emulsion systems with axial compensation yielded the best thrust force results.

Given the lack of research on high-pressure fluid application in threading, especially with aluminum and its alloys, and considering studies like those by Siqueira et al. (2019) and Steininger et al. (2015) on DLC-coated tools, further investigation into high-speed threading and the efficiency of these coatings is necessary.

2. MATERIALS AND METHOD

AA6063-T6 is a widely used and readily available Al-Si-Mg alloy with low silicon content, sufficient to form magnesium silicates. Table 1 shows the typical composition of this alloy. Primary aluminum alloys are widely used in the automotive sector.

Table 1. Chemical composition of 6XXX series aluminum alloys

Registered International Name			Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others		Aluminum (minimum)
Nº	Date	Country									Each	Total	
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 Associação Alumínio Inc.

The experiments were carried out at the Mechanical Engineering Laboratory of the Federal University of Triangulo 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 axial force and torque during operation, a Kistler dynamometer model 9123 C1211 was used, along with a Kistler multi-channel signal conditioner model 5223131. For signal acquisition, a DAK 6202 signal acquisition plate was used at an acquisition rate of 100 Hz. Four taps with a cut coded by the manufacturer as HSS-E M8 x 1.25 mm were used, with a 45º helix angle, with an IKZ-type internal lubrication channel, with a C-type chamfer, manufactured by EMUGE, coated with Diamond-Like-Carbon (DLC), by company Oerlikon Balzers, Figure 1, the pre-holes had an average diameter of 6.81mm (Lins et al. 2023).

Figure 1. DLC coated M8 cutting tap with 45º helix angles

The taps were fixed in a threading head with axial compensation, in two different mandrels, called Head 1, model Softsynchro® Modular, manufacturer EMUGE and Head 2 model Synchro-Gewindefutter WN-GM300, manufacturer GUHRING.

Figure 2. Head with axial compensation, in two different mandrels

The increase in productivity is directly related to the behavior of the cutting tap when subjected to high cutting speeds. Concomitantly, the axial force compensation capacity promoted by the tapping head. The synchronization during the advance and return in the internal tapping process, in the CNC Machining Center model 1250D is limited to 2400 RPM, which is the determining factor in the study developed.

A factorial design with 2 levels and 2 factors was used, which are: cutting speed (40 and 60 m/min); threading head (type 1 and type 2), with response variable Axial force Fz in advance and return. The works were carried out with the application of cutting fluid at constant high pressure (35 kgf.cm^{-2}), and the helix angle of the tool constant at 45º, as shown in Table 2.

Table 2. Cutting parameters and their respective levels

Levels	Factors			
Testes	V_c [m.min-1]	Tapping head	Helix angle	Fluid pressure [kgf.cm^{-2}]
-	40	1	45º	35
+	60	2	45º	35

The threading tests were carried out continuously, without breaking strategy. of the chip, for a length of 20 mm, as shown in Table 3. Replicates were performed for all conditions.

Table 3. Matrix of experiments

Terms	V_c [m.min-1]	Tapping head
1	-	+
2	-	-
3	+	+
4	+	-

ANOVA analysis of variance was performed, obtaining Pareto charts of standardized effects, interaction graphs and surface graphs to determine whether there is a difference between the means for each cut-off condition. Graphs were also obtained that show the axial forces in the advance and return of the tap as a function of the cutting speed, and the type of axial threading head.

3. ANALYSIS OF THE RESULTS

The experimental design and methodology described above, it was possible to collect and generate the data presented in this section. Table 4 presents the statistical difference and the effects of the comparisons of the output variables as a function of the input factors (Vc, f and pressure). For p-values smaller than the significance index (p-value ≤ α), the input factors influenced the response parameters. Influential factors are highlighted in bold in Table 4. The influence can be visualized through Pareto charts and interaction charts that were analyzed together with the three input factors.

Table 4. Statistical difference and the effect of comparisons between results in relation to input factors

Answers		Cutting speeds (v_c)	Tapping head (T_h)	v_c*T_h	S	R^2	R^2(aj)	R^2(pred)
Advance axial force [N]	p-*value*	**0,000**	**0,000**	0,095	2,12783	80,42%	76,75%	69,41%
	Efeito	4,550	5,998	1,686				
Axial return force [N]	p-*value*	**0,000**	**0,000**	0,066	5,38207	85,25%	80,12%	73,84%
	Efeito	14,23	15,36	4,74				

Figure 2 demonstrate that comparing the p-value with a significance index α =0.05 for each condition of Cutting Speed (Vc) linked to the Pressure of the cutting fluid (P) analyzed, it presented a higher p-value than the significance index, so these two input variables did not influence the response surface for the Axial thrust force (Fz). Since the threading head factor with axial compensation, with p-value = 0.000, has the greatest influence on the response surface, with R2 = 0.8042, which can be proven by the Pareto chart that in the joint analysis of the two factors Vc and Threading head, with the possibility of discarding a joint analysis of these factors, with p-value = 0.095.

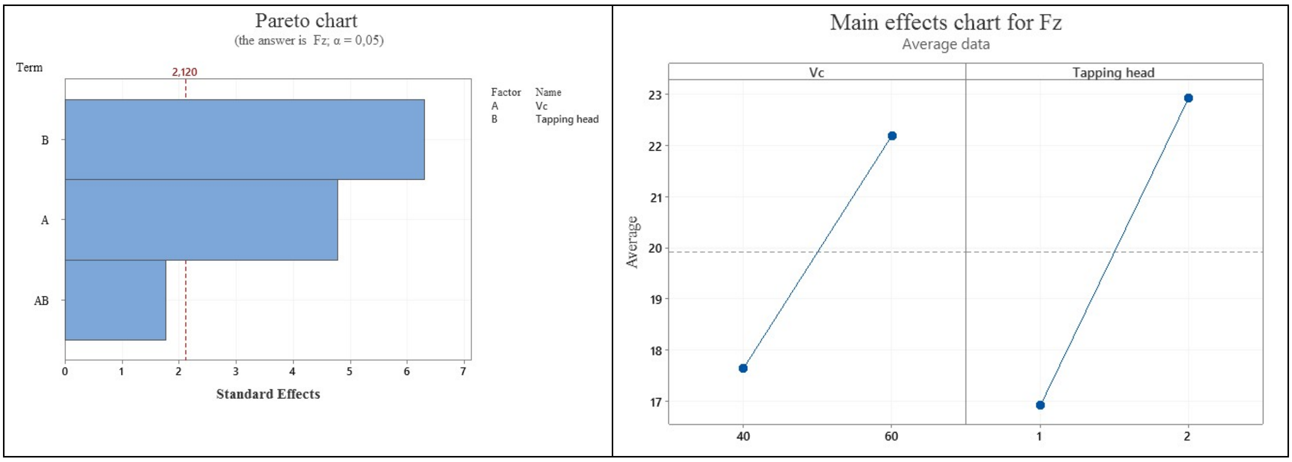

Figure 3. Pareto Chart of standardized effects for Fz (a), Interaction Chart for means for Fz (b)

Figure 3 indicates that the average axial force increases with a cutting speed of 60 m/min in all experiments. This trend was proportional when the type of axial compensation head for attaching the tap cutting machine was varied. For a cutting speed of 40 m/min the axial cutting feed force (Fz) had an average variation of 17.8 N, and for a cutting speed of 60 m/min the axial cutting feed force (Fz) had an average variation of 22.3 N. Considering the two threading heads for type 1, the average Fz in the cutting feed was 17 N, with the average Fz values for the type 2 head being 23.1 N.

To Fz return there is a tendency was proportional when the type of axial compensation head for fixing the taps cutting machine was varied. For a cutting speed of 40 m/min the axial cutting feed force (Fz) had an average variation of 51.2 N, and for a cutting speed of 60 m/min the axial cutting feed force (Fz) had an average variation 65.7 N. Considering the two threading heads for type 1, the average Fz in the cutting feed was 50,6 N, with the average values of Fz for the type 2 head being 66 N, Figure 4.

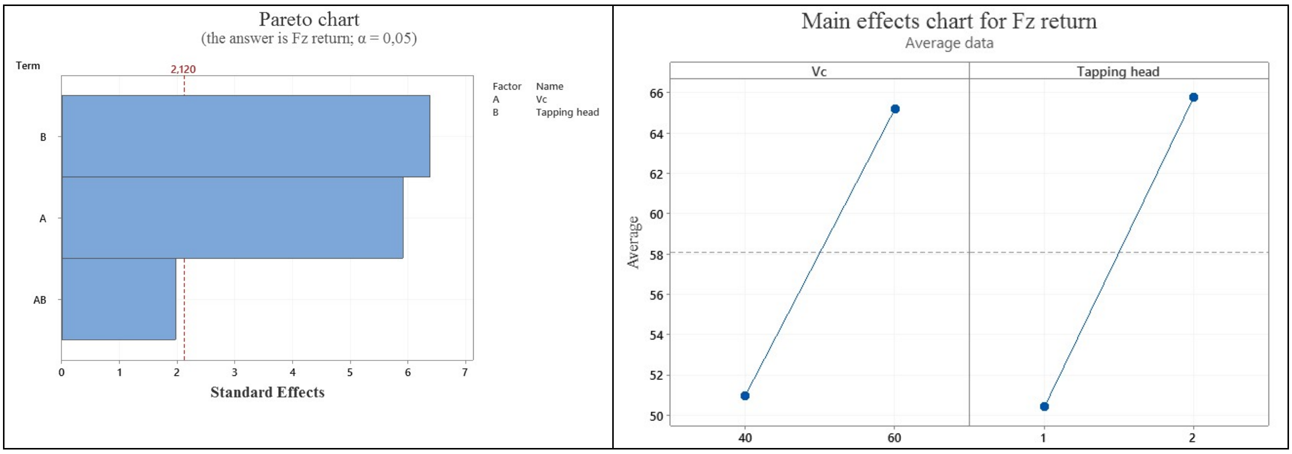

Figure 4. Pareto Chart of standardized effects for Fz return(a), Interaction Chart for means for Fz return (b)

Through the surface graph it is possible to identify the difference between the different types of axial compensation head and their respective influence on the axial forces during the machining of threaded holes in advance and retraction. It is also noted that a lower cutting speed generated lower values of Fz in the advance and return regardless of the cutting speed used, Figures 5 and 6.

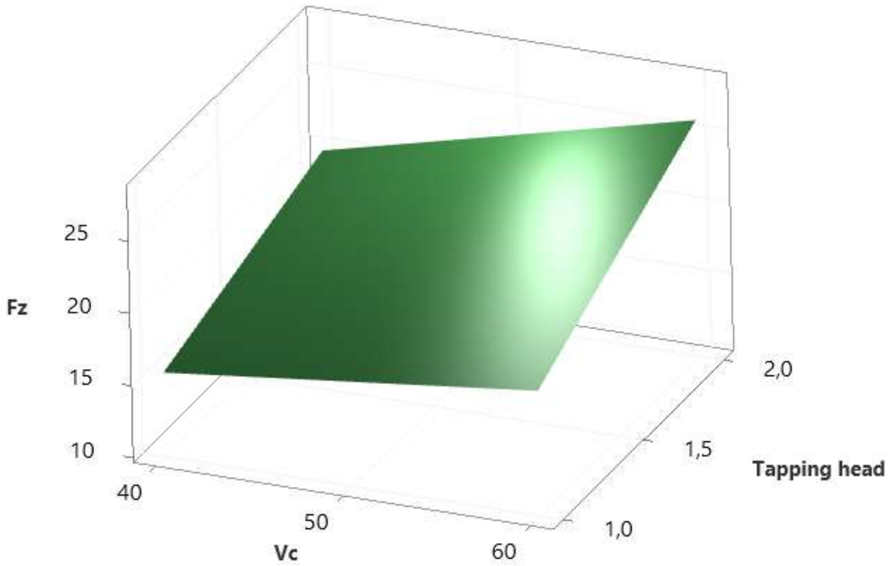

Figure 5. Surface Chart de Fz versus V_c versus Tapping head

The return axial forces, regardless of the cutting speed used or the threading head used, were greater, due to ductility and the tape chip generated by the 6063-aluminum alloy, which acts as a barrier to the exit of the threading tap, disturbing the return timing and filling the tool clearance surface increasing the friction region. Figure 6 illustrates the threading process with an M8 x 1.25 mm tap, coated with DLC, with a cutting speed of 40 $m.min^{-1}$, with a coolant working pressure of 35 $kgf.cm^{-2}$, with a helix angle of 45º, using a type 2 axial threading head, it can be seen that during the cutting feed (Fz) the process takes 1.2 seconds, a programmed pause of 1 second is performed and the return feed occurs in 1.5 seconds.

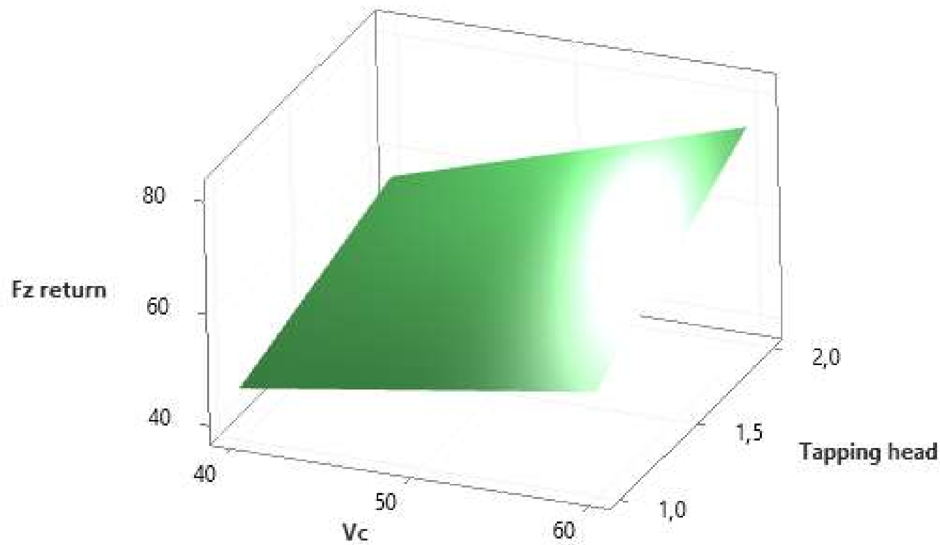

Figure 6. Surface Chart de Fz return versus V_c versus Tapping head

Disregarding the coolant pressure in the manufacturing process, since it is the same in advance and return, as well as the helix angle and the cutting advance of 1.25 mm. The cutting speed appears as the main influence on the axial force (Fz) because it is higher in the cutting advance than in the return, because due to the total stop and the resumption of synchronism, the threading tool does not reach the initial cutting speed of the process, due to the cutting length being insufficient to reach 1600 revolutions per minute. It appears that the average axial force amplitudes are greater in the return, which indicates that there is an obstruction caused by the ribbon chip during the return, since there is no cutting force acting on the return of the cutting tap. This requires greater axial compensation of the threading head.

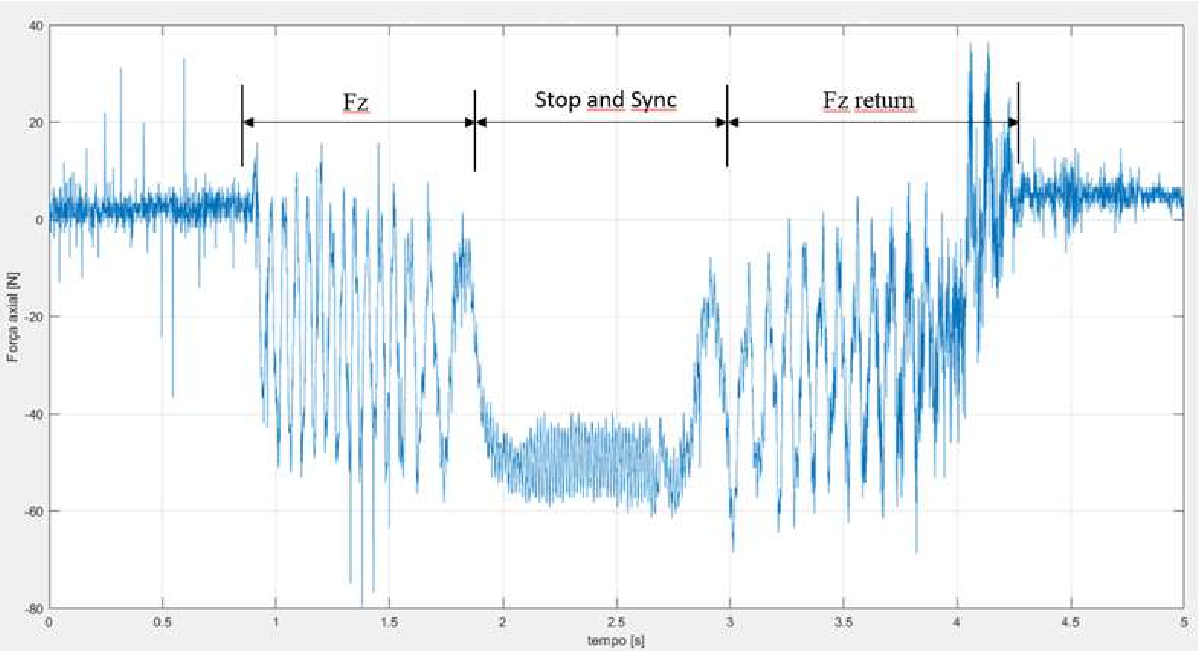

Figure 7. Axial tapping force for V_c of 40 m.min^{-1}, with helix of 45º, pressure of 35 kgf.cm^{-2} and tapping head type 2

The Fz averages in feed using the tapping head type 2 are 36% higher compared to the tapping head type 1. The averages of Fz return were 2.5 times higher for type 2 compared to type 1. Clearly demonstrating the influence of axial threading head type on force Fz.

A ductility of the AA6063-T6 alloy is the main reason for its poor machinability; the chip does not shear, resulting in a continuous, stringy chip. The application of cutting fluid at a pressure of 35 kgf.cm² proved to be an excellent alternative for the internal threading process, preventing damage and breakage of the tested cutting taps.

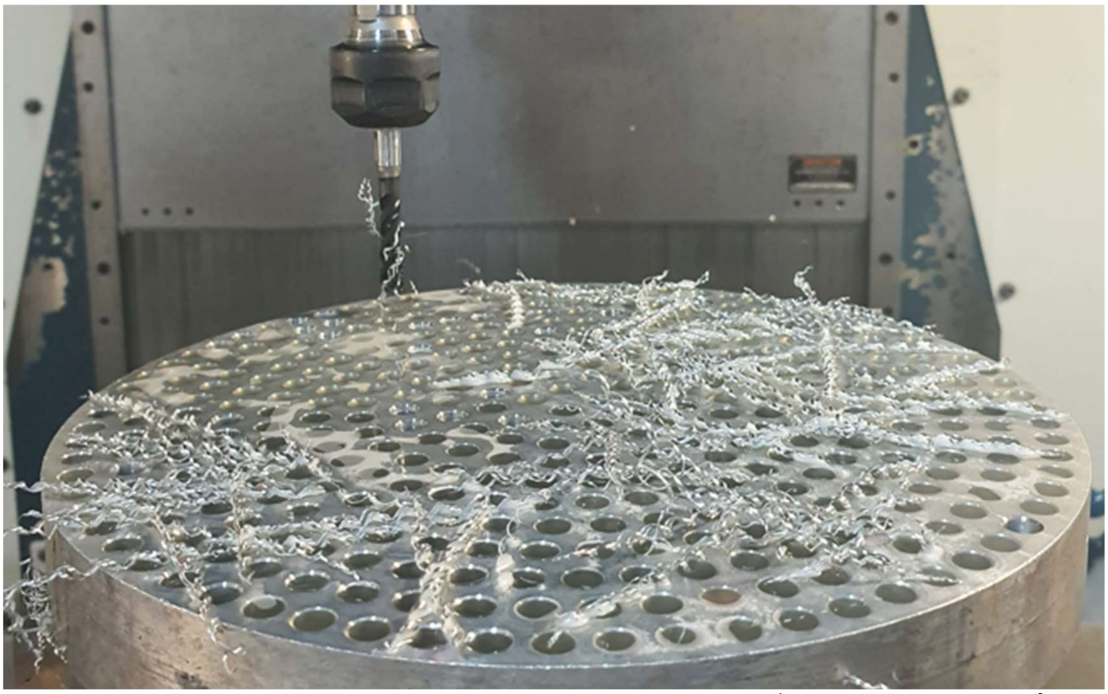

Figure 8. Threading process with cutting parameters:.V_c 40 m.min^{-1}, pressure of 35 kgf.cm^{-2}

The DLC coating for cutting taps presents itself as a good alternative for machining aluminum alloys using high pressure cutting fluids. The low adhesion on the outlet surface of the taps tested characterizes the use of this coating for moderate and high cutting speeds.

4. CONCLUSION

According to the results obtained in the experimental tests of high-pressure threading, with an M8 x 1.25 mm cutting tap, coated with DLC, in the AA6063 aluminum alloy, the following conclusions could be obtained from this study:

1. The axial cutting force values showed the highest mean variations for Fz return in the experiments carried out, regardless of the cutting speed or axial compensation head in the internal threading processes.
2. The behavior of the axial force both in the advance and in the return increases with the increase of the cutting speed;
3. The threading head with axial compensation has the greatest influence on the response surface, being decisive in increasing the axial force of advance and return.

5. REFERENCES

Ahn J.H., Lee D.J., Kim S.H., Kim H.Y., Cho K.K., 2003, "Effects of synchronizing errors on cutting performance in the ultra-high-speed tapping". CIRP Ann 52(1):53–56

Associação Alumínio. "Chemical composition of 6XXX series aluminum alloys". Disponível em: <https://abal.org.br/aluminio/caracteristicas-quimicas-e-fisicas/> Acesso em: 06/06/2022 09:00.

Brandão, G.L., Silva, P.M.d., de Freitas, S.A, et. al. 2020. "State of the art on internal thread manufacturing: a review". Int J Adv Manuf Technol 110, 3445–3465. https://doi.org/10.1007/s00170-020-06107-x

Bhowmick, S., Lukitsch, M.J., Alpas, A.T., 2010. "Tapping of Al-Si alloys with diamond-like carbon coated tools and minimum quantity lubrication". J Mater Process Technol 210:2142–2153.

Coelho, C.C.F., Pereira, R.B.D., Lauro, C.H., Brandão, L.C., 2019, "Performance evaluation of tapping processes using a 7075-aluminium alloy with different cooling systems and threading heads". Proc Inst Mech Eng C J Mech Eng Sci 233(19-20):6793–6806

Ba, E.C.T., Martins, P.S., Dos Santos, C.E., Maia, L.H.A., Barbosa, J.W., Dumont, M.R., "Study of the behavior of skewness (Rsk) and kurtosis (Rku) parameters in the dry drilling process of Al-Mg-Si alloy 6351 T6 using a Diamond-Like Carbon coated high-speed steel tool", Tribology International, Volume191, 2024, 109149,ISSN0301679X, https://doi.org/10.1016/j.triboint.2023.109149

Zhang Y., Wu, Y., Chen, D., Wang, R., Li, D.,Changhong Guo, Guirong Jiang, Dejiu Shen, Shengxue Yu, Philip Nash, Micro-structures and growth mechanisms of plasma electrolytic oxidation coatings on aluminium at different current densities, Surface and Coatings Technology, Volume 321, 2017, Pages 236-246, ISSN 0257-8972, https://doi.org/10.1016/j.surfcoat.2017.04.064.

Lins, R. S.; Fernandes, L.A.; Teixeira, V. P.; Guimarães, T. A.; Martins, P. S.; Da Silva, M. B. Análise da qualidade de furos não passantes em liga de alumínio AA 6063-T6 com o uso de fluido de corte a alta pressão. In: Anais do COBEF 2023. Anais.Processes with *Material* Removal. Brasília (DF) UNB, 2023. Disponível em: <https://abcm.org.br/anais-de-eventos/COF23>>. Acesso em: 06/06/2023 09:00. doi://10.26678/ABCM.COBEF2023.COF23-0311

Kula, A., Niewczas, M., "Mechanical properties and rate-sensitive deformation of AA6063 aluminum alloys at 298 K, 78 K, and 4 K", Materials & Design, Volume 237, 2024, 112601, ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2023.112601.

Peng F, Yan X, Guo H, Lu L, Zhang S, Li J, 2016. "Research on the effects of tapping performances with multiple-type parameters". Key Eng Mater 693:1114–1120.

Ribeiro Filho SLM, Oliveira JA, Arruda EM, Brandão LC, 2015. "Analysis of burr formation in formtapping in 7075 aluminum alloy". J Mater Process Technol 212(4):766–775.

Siqueira B.S., Freitas S.A., Pereira R.B.D., Brandão L.C., 2019, "Influence of chip breaker and helix angle on cutting efforts in the internal threading process". Int J Adv Manuf Technol 102:1537– 1546.

Steininger A, Siller A, Bleicher F., 2015. "Investigations regarding process stability aspects in thread tapping Al-Si alloys". Procedia Eng 100:1124–1132.

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