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STUDY ON THE INFLUENCE OF MACHINING PARAMETERS ON MEAN CUTTING FORCE IN MILLING OF 2024 T351 ALUMINIUM ALLOY

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Abstract: *Determining the cutting force is a fundamental aspect of the machining process, influencing the quality of the machined surface and the durability of the tools. As is known, machining duralumin can be difficult due to its tendency to form built up edge, which affects accuracy and surface finish. Knowing the cutting force allows adjusting the parameters of the cutting and tool geometry to achieve efficient and stable machining. By determining the cutting force, energy consumption can be reduced. In this paper, the average cutting force per tooth during milling was calculated, starting from the specific cutting force determined experimentally. The obtained results were compared with the experimental ones, which allowed the identification of correction coefficients dependent on the cutting speed.*

Key words: *cutting force, duralumin, milling.*

1. INTRODUCTION

Machining duralumin alloys by cutting is a process used in various industrial fields, due to the combination of the low weight and high mechanical strength of this material. Especially in the aerospace, automotive and lightweight structures manufacturing industries, the use of duralumin is preferred due to its superior mechanical properties compared to pure aluminum, conferred by the presence of alloying elements such as copper, magnesium and manganese. These characteristics make it ideal for components that must withstand intense mechanical stress, while maintaining a low mass.

The machining process of duralumin is influenced by several factors, including the nature of the alloy, the cutting parameters and the type of tools used, [1,2]. One of the essential aspects of this process is the determination and control of the cutting force, which influences both the quality of the machined surface and the durability of the tools. Cutting force is dependent on factors such as cutting speed, feed, depth of cut, and tool geometry, [3]. Understanding and optimizing these parameters can improve productivity, reduce manufacturing costs, and achieve higher-quality machined surfaces, [4].

One of the main obstacles in machining duralumin is its tendency to form a built-up edge, a phenomenon that can affect the accuracy and finish of the machined part. This requires the use of appropriate machining parameters and tools with special coatings designed to reduce the phenomenon of material adhering to the edge, [2]. Proper management of cutting forces also helps to avoid premature tool wear, prevent tool breakage, and reduce stress on machine tools. Excessive forces can generate vibrations, leading to defects such as burr formation or loss of dimensional accuracy, which affects the quality of the finished part.

Cutting force monitoring and control play a key role in extending tool life and optimizing energy consumption, [5, 6]. An efficient cutting process involves maximum material removal with minimal energy consumption, thus contributing to high production efficiency. By experimentally and theoretically determining the cutting force, engineers can identify correction coefficients dependent on the cutting speed, thus

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allowing for the optimal adjustment of the machining regime.

In this paper, the average cutting force per tooth during milling was calculated, starting from the experimentally determined specific cutting force. Comparing the results obtained by calculation with the experimental ones allowed the identification of correction coefficients, essential for improving the accuracy of the cutting process modeling. This information contributes to the development of more efficient machining methods, having a direct impact on the quality of finished products and on production costs.

2. EXPERIMENTAL DETERMINATION OF SPECIFIC CUTTING FORCE

The experimental determination of the specific cutting force was carried out using an Oxford-Airey pendulum which, as is known, allows the direct measurement of the energy consumed to detach a unit volume of material, [7].

The specific cutting force is defined as the cutting force required to detach a unit section, and the chip thickness is the parameter with the greatest influence on the specific cutting force, [8].

The use of the Oxford Airey pendulum involves determining the difference between the height to which the pendulum rises after detaching a chip with thickness *a* and, respectively, the height to which the pendulum rises when no chip is detached, [9]. The equation used is, [9]:

$$k_C = \frac{G \cdot L \cdot \left(\sin\alpha - \sin\alpha_0 \right)}{a \cdot b \cdot l} \text{ [daN]}. \qquad (1)$$

where: G=15.6 daN pendulum weight, L=500 mm pendulum arm length, α=62° pendulum return angle when no chip is detached, l=b=10 mm specimen section dimensions, a chip thickness and α_0 pendulum return angle after chip detachment of thickness a.

Determinations were made for chip thicknesses between 0.02 and 0.6 mm, with a ratio of 0.02 mm. The results of the determinations are presented in Table 1.

Based on these values, the law of variation of the specific cutting force as a function of the chip thickness was identified, by determining its parameters. For this purpose, the "curve fitting" toolbox in the Matlab program was used, choosing as the general form a hyperboloidal dependence, [8]:

$$k_C = \frac{k_{C1,1}}{a^z} \text{ [daN]}. \qquad (2)$$

Table 1

Results of measurements of return angles corresponding to chip thickness.

a [mm]	α_1 [°]	α_2 [°]	α_3 [°]	α_{med} [°]	k_C [daN]
0.02	20	20	22	22.667	2067.066
0.04	22	22	22	22.000	991.265
0.06	17	17	17	17.000	767.749
0.08	15	15	15	15.000	608.525
0.10	15	15	14	14.667	491.207
0.20	13	14	15	14.000	250.000
0.30	11	11	9	10.333	182.929
0.40	7	7	9	7.667	146.160
0.60	1	1	1	1.000	127.763

The results provided by the Matlab program in the case of approximating the values presented in Table 1 are: $k_{C1,1}$=65.19 daN and z=0.87. The graphical representation of the approximation function is presented in figure 1, and the parameters reflecting the quality of the approximation are: R_{square}=0.9966, $RMSE$=1132.

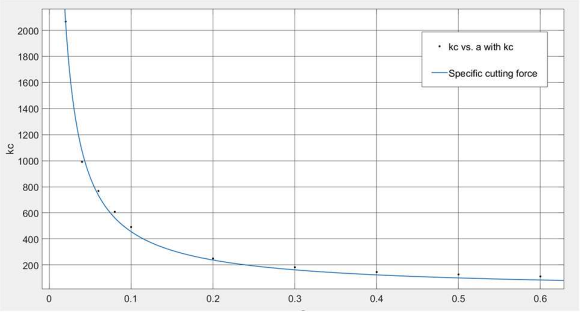


Fig. 1. The dependence of k_C on a.

Next, the values determined for the specific cutting force and the z-coefficient were used to verify the results obtained by measurement with the Kisler dynamometer.

3. MEASURING CUTTING FORCE IN MILLING

In order to verify the experimental results obtained with the Oxford Airey pendulum, the cutting forces were measured when milling a 2024 T351 duralumin sample. The measurement was performed with a Kisler dynamometer type 9257B and the values were collected with the DynoWare program supplied with the dynamometer.

To verify the influence of the cutting regime parameters on the forces that occurred, measurements were made with three values of the feed per tooth, f_Z, respectively 0.2, 0.1 and 0.05 mm, and three values of the cutting speed, v_C 700, 550 and 400 rpm. The cutting depth was 3 mm and the contact width 3 mm. These parameters were not modified because their influence is quite intuitive, in the sense that with their increase it is expected that the cutting force will also increase.

A five tooth, 50 mm diameter tool was used for machining. These dimensions allowed only one tooth to be in the cut at a time, which made it easier to identify how the cutting force varies with chip thickness. For each of the nine combinations of feed and cutting speed, the forces were measured in the *X* and *Y* directions, as shown in Fig. 2.

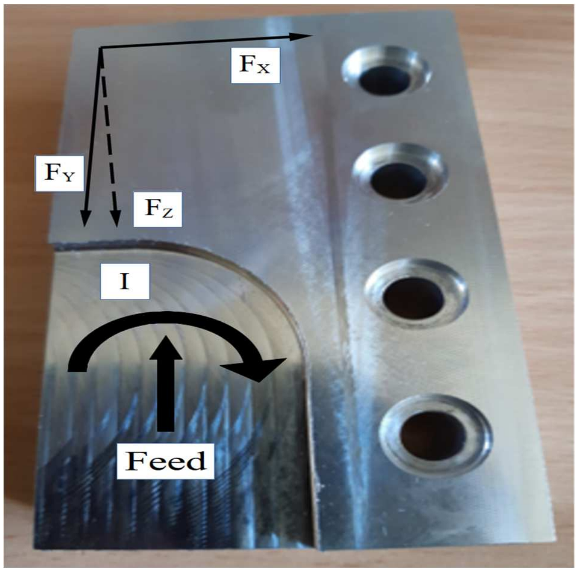
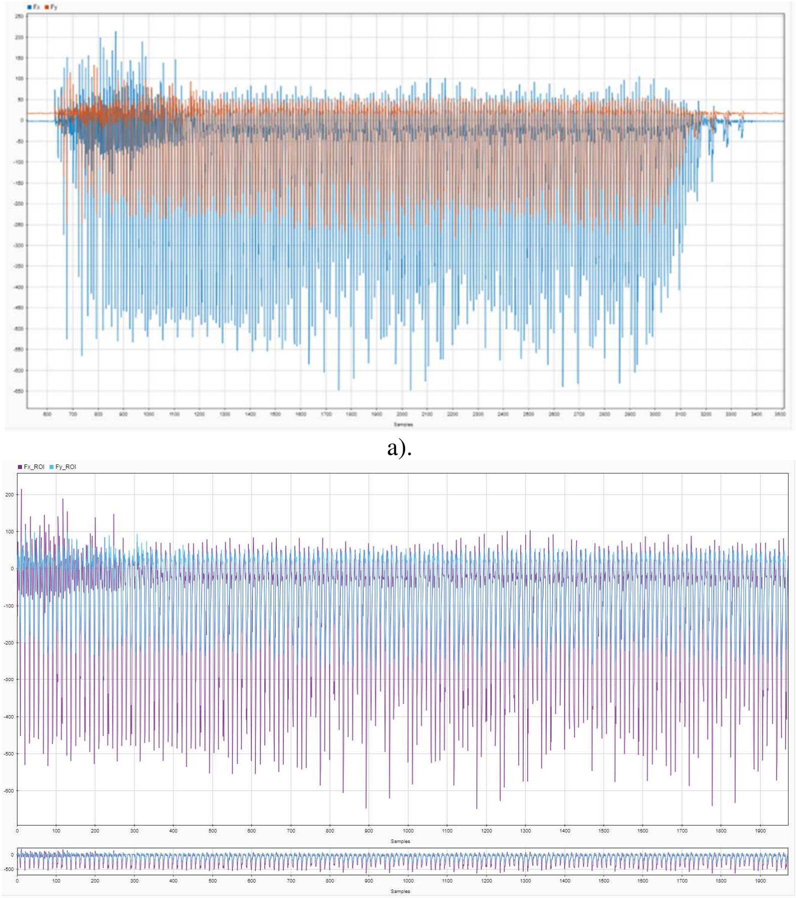


Fig. 2. Machined specimen and force measurement directions

The measurements were performed with a frequency of 2500 Hz. and from the obtained data string the area where the cutting forces stabilized was selected, see Fig. 3.



a).

b).

Fig. 3. a). Totality of measured values; b). Selection of stabilized areas.

Next, we worked only with the stabilized value series. The tangential force on the tooth was calculated using the formula:

$$F_T = \sqrt{F_X^2 + F_Y^2} \text{ [N]}. \qquad (3)$$

To calculate the average main force on the cutting edge, the local maxima of the tangential force were identified, using the "findpeaks" command in the Matlab program, and between two local maxima the average value was calculated, using a dedicated application, designed in MatLab. Subsequently, the average value of these averages was calculated, identifying the value of the average force on the cutting edge.

The calculated values, corresponding to the various combinations of the cutting regime parameters, are presented in table 2.

The experimental results were compared with those calculated corresponding to the determined specific cutting force. For this, the following are calculated: the contact angle, the average chip thickness and the correction coefficients corresponding to the specific situation in which the process is carried out.

The contact angle is calculated with the formula:

$$\varphi_S = acos\left(\frac{D - 2 \cdot a_e}{D}\right), \qquad (4)$$

D=50 mm being the cutter diameter and a_e=3 mm the cutting depth. For the mentioned values a contact angle of 28.36° is obtained.

Table 2

Average cutting-edge force corresponding to the cutting machining parameters.

Crt. no.	v_C [m/min.]	f_Z [mm.]	F_C [N]
1	400	0.2	149.25
2	400	0.1	120.98
3	400	0.05	85.27
4	550	0.2	172.33
5	550	0.1	131.51
6	550	0.05	99.04
7	700	0.2	203.87
8	700	0.1	152.58
9	700	0.05	114.9

The average chip thickness is given by:

$$h_m = \frac{360^{\circ}}{\pi \cdot \varphi_S} \cdot \frac{a_e}{D} \cdot f_z. \qquad (5)$$

For the three feed values, the average cutting force values are obtained using the equation:

$$F_C = a_e \cdot h_m^{1-Z} \cdot k_{C1,1} \cdot K_W \cdot K\gamma \text{ [N]}, \qquad (6)$$

where K_W is the correction coefficient for tool wear, which is chosen equal to 1.1 considering the low degree of tool wear, and K_γ is the correction coefficient depending on the clearance angle. The calculation equation for K_γ is:

$$K\gamma = \left[1 - \left(\gamma_a - \gamma_0\right)\right]/100, \qquad (7)$$

γ_a being the effective clearance angle of the tool used, which in this case was 9°, and γ0 is the clearance angle recommended for cutting the respective material, for aluminum being 20°. With these values a correction coefficient K_γ=1.1 is obtained.

The values of the average force calculated analytically and those measured are presented in table 3.

Figure 4 shows the variation of the average cutting force depending on the feed value, for the 3 cutting speeds considered, and figure 5 shows the variation of the average cutting force depending on the cutting speed for various feed values per tooth.

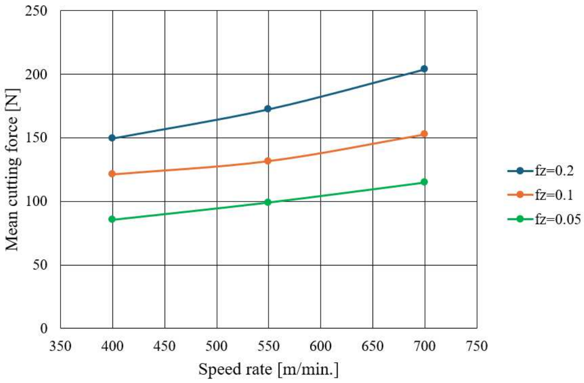


Fig. 4. Variation of average cutting force as a function of feed for various cutting speeds

Table 3

Measured (F_{CMa}) and calculated (F_{CC}) average cutting force.

Crt. no.	v_C [m/min.]	f_Z [mm.]	F_C [N]	F_{CMa} [N]	F_{CC} [N]
1	400	0.2	149.25	175.15	159.67
2	550	0.2	172.33		
3	700	0.2	203.87		

4	400	0.1	120.98	135.02	145.91
5	550	0.1	131.51		
6	700	0.1	152.58		
7	400	0.05	85.27	99.74	133.34
8	550	0.05	99.04		
9	700	0.05	114.90		

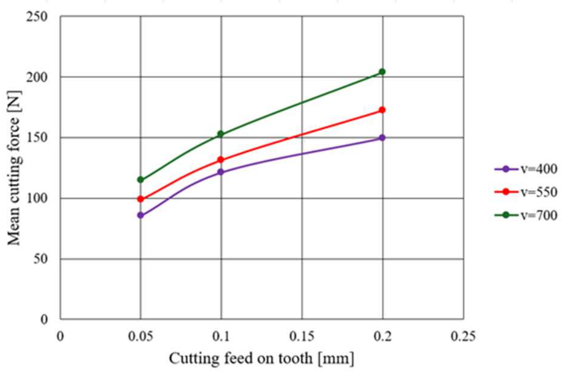


Fig. 5. Variation of average cutting force depending on cutting speed

4. CONCLUSIONS

In this paper, the specific cutting force was determined when machining duralumin alloy type 2024 T351.

The specific force was determined using an Oxford Airey pendulum, and the results were compared with the values measured for the average force on the main cutting edge of the tooth during milling.

For the purpose of comparison, the values were determined using a Kisler dynamometer type 9257B and the values were collected with the DynoWare program supplied with the dynamometer.

The results highlighted the variation of the force with the change in feed per tooth and cutting speed.

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Studiul influenței parametrilor regimului de așchiere asupra forței medii de așchiere la frezarea aliajului de aluminiu 2024 T351

Prelucrarea aliajelor de duraluminiu prin așchiere este un proces esențial în domeniile industrial în care se utilizează materiale ușoare, dar rezistente. Determinarea forței de așchiere este un aspect fundamental al acestui proces, influențând atât calitatea suprafeței prelucrate, cât și durabilitatea sculelor utilizate. Prin analiza corectă a forțelor implicate în procesul de așchiere, inginerii pot optimiza parametrii de prelucrare, reducând costurile și îmbunătățind productivitatea. După cum este cunoscut, duraluminiul este un aliaj de aluminiu cuprinzând cupru, magneziu și mangan, având proprietăți mecanice superioare față de aluminiul pur. Acesta oferă o bună combinație între rezistență mecanică și greutate redusă, ceea ce îl recomandă pentru aplicații structurale. Totuși, prelucrarea acestui material poate fi dificilă din cauza tendinței sale de formare a tăișului de depunere, ceea ce poate influența negativ precizia și finisajul suprafeței. Forța de așchiere reprezintă suma forțelor implicate în procesul de așchiere a materialului și depinde de mai mulți parametri, cum ar fi viteza de așchiere, avansul, adâncimea de așchiere și geometria sculei. Cunoașterea forței de așchiere permite ajustarea parametrilor regimului de așchiere și a geometriei sculei pentru a obține o prelucrare eficientă și stabilă. Forțele excesive pot duce la uzura accelerată a sculelor, ruperea acestora și suprasolicitarea mașinii-unelte. Prin monitorizarea și controlul forței de așchiere, se poate extinde durata de viață a sculelor și se pot evita costurile ridicate de înlocuire și întreținere. Forțele de așchiere mari pot duce la vibrații și la formarea bavurilor, afectând calitatea piesei prelucrate. Prin ajustarea parametrilor pentru a obține forțe optime, se asigură o suprafață netedă, fără defecte, ceea ce este esențial în aplicațiile de precizie. Pe de altă parte, un proces de așchiere eficient presupune un consum minim de energie pentru o îndepărtare maximă a materialului. Prin determinarea și optimizarea forței de așchiere, se poate reduce consumul energetic, contribuind astfel la eficiența procesului și la scăderea costurilor de producție. În prezenta lucrare a fost calculată forța medie de așchiere pe dinte la frezare, pornind de la forța specifică de așchiere determinată pe cale experimentală. Rezultatele obținute au fost comparate cu cele experimentale, obținute prin măsurare, lucru care a permis identificarea coeficienților de corecție dependenți de viteza de așchiere.

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