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INFLUENCE OF CUTTING PARAMETERS ON SURFACE QUALITY OF AL7075 ALLOY UNDER DRY AND LN_2 COOLING CONDITIONS

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Abstract: *The aim of the present paper was to investigate the influence of cutting parameter under dry and LN_2 (liquid nitrogen cooling) cooling condition on surface quality. Experiments were conducted on the AL7075 aluminum alloy and three cutting speeds and two cutting depths were tested in the presence and the absence of the cryogenic cooling. The increase of cutting speeds under the cryogenic cooling conditions led to a decrease of surface roughness from 0.28 µm (in dry condition) to 0.16µm (with LN_2 cooling). Similar behavior was observed in the case of the increase of the cutting depth, thus for higher cutting depths the use of cryogenic cooling liquid generated lower surface roughness values that the dry milling. In conclusion the use of the cryogenic cooling technique is recommended for AL7075 milling as it generated better results that the dry machining and it is also considered an environmentally friendly technique.*

Keywords: *Milling, AL7075 aluminum alloy, cryogenic cooling, liquid nitrogen. surface roughness.*

1. INTRODUCTION

The continuous advancement of the aeronautical sector has introduced new challenges in machining processes. The increasing demand for reducing production time and costs, while ensuring high-quality surface characteristics, has driven the development of innovative cutting techniques. In response, numerous studies have been conducted to explore optimization strategies for machining parameters that enhance surface quality by minimizing roughness, residual stresses, and improving microhardness [1].

Among the commonly employed manufacturing methods, turning, drilling, and milling play a crucial role in shaping components to meet strict dimensional and structural requirements [2]. Milling, in particular, is a highly intricate process that involves material removal using a multi-edged cutting tool performing dynamic movements. Unlike turning, where chip formation occurs continuously, milling is an intermittent process that generates periodic heat fluctuations, which significantly affect both the surface quality of the machined part and the durability of the cutting tool [3,4].

A key material extensively utilized in the aeronautical industry is the 7075-aluminum alloy, which undergoes various treatments to enhance its properties. When the primary objective is weight reduction alongside high mechanical performance, AL 7075 is often preferred over other aluminum alloys, such as AL 6061, due to its superior strength and fatigue resistance. However, despite these advantages, it presents higher manufacturing costs and increased processing complexity [5-8].

In recent years, extensive research has been conducted on improving surface integrity through optimized machining techniques. For instance, Pereira et al. [9] examined an internal cryolubrication approach for Inconel 718 milling, revealing notable improvements in tool wear and surface finish. Pop et al. [10] investigated parameter optimization in milling, emphasizing the significance of cutting speed and feed rate adjustments in achieving high-quality surfaces. Tampu et al. [11] analyzed the impact of cooling fluids on surface quality, demonstrating that effective cooling strategies contribute to lower surface roughness and prolonged tool lifespan. These studies provide a fundamental basis for our research by highlighting the influence of cooling techniques in machining efficiency and surface integrity.

Various studies in the literature discuss different types of lubricants and coolants used to improve machinability, including oil-based fluids, gaseous and vapor-phase coolants, solid lubricants, and nano-cutting fluids [12]. Among these approaches, cryogenic machining has gained attention as an innovative and environmentally sustainable technique. This method consists of spraying cryogenic liquids directly onto the cutting zone, effectively cooling both the cutting tool and the workpiece, thereby minimizing thermal effects and enhancing machining performance [13].

Cryogenic liquids are characterized by boiling points lower than -90°C, causing them to rapidly vaporize upon contact with the cutting zone [14]. These substances are typically colorless, odorless, tasteless, and non-toxic, making them suitable for a wide range of applications across industries such as aerospace, electronics, automotive, and medical fields [15].

Despite extensive research on cryogenic cooling in machining, existing studies primarily focus on its general effects rather than its specific impact on AL 7075 aluminum alloy. Moreover, previous works have not comprehensively analyzed the combined influence of cutting speed, depth of cut, and liquid nitrogen cooling on surface integrity. That is why the aim of the present paper was to analyze the influence of cryogenic cooling on surface quality (surface roughness; microhardness) generated by the milling process of Al 7075.

2. MATERIALS AND METHODS

Aluminum 7075 is widely used due to its excellent combination of mechanical properties, corrosion resistance, and lightweight characteristics. It belongs to the 7xxx series of aluminum alloys, which are known for their high strength due to the presence of zinc as the primary alloying element, along with magnesium and copper [16].

LN_2 was stored at 1.5 bar, in a tank with a capacity of 35L. The nitrogen was sprayed on the surface using a Cryotherm Apollo 50 system, that has mechanical control of the spraying speed based on the heating of the spraying core in the tank (Fig. 1).

Fig. 1. Spray nozzle Apollo 50

The machining process was realized using a CNC milling machine (Rapimill 700 from Knuth). Machining was performed on prismatic parts, with 150 x 60 x 50 mm dimensions and a radial width of cut was of 50 mm. The used tool was a Sanvik Coromil 490 cutting tool with 5 inserts type 490R-08T308E-ML H13A.

Surface hardness was measured with a Metkon IMM 901 hardness tester using Vickers method. Ten indentations were made on the surface and the average of the values obtained was considered as the sample microhardness.

In order to observe the surface topography and roughness an optical profilometer Zygo with an eyepiece of 10 X magnification was used. This eyepiece has a field of view of 0.83/0.83 mm.

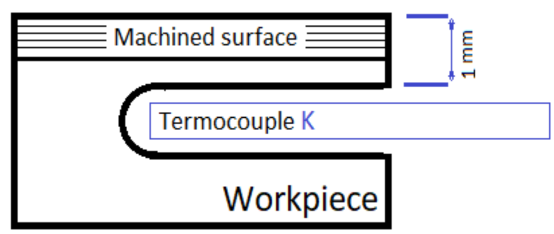

Fig. 2. Thermocouple position in the work piece.

In order to observe the influence of cryogenic cooling liquid, under the work piece surface a hole was drilled laterally at 1mm under the surface (Fig. 2) and a K type thermocouple (Testo 176-T4) was inserted for temperature measurement. Under these conditions, the temperature for all the dry and for the cryogenic cooled cuts were of 25ºC and -60 ºC respectively.

The material was machined using three cutting speeds, and two cutting depths under dry and cryogenic milling conditions (Table 1). For each experiment, a new cutting edge was used, thus eliminating the influence of tool wear.

Table 1

Milling parameters.

Experiment number	Cutting speed (Vc) m/min	N (RPM)	Deepth of cut (Ap) mm
1	314	2000	0,75
2	785	5000	0,75
3	1100	7000	0,75
4	314	2000	0,5
5	785	5000	0,5
6	1100	7000	0,5

3. RESULTS AND DISCUSSIONS

Surface quality in milling refers to the condition and characteristics of the surface produced on a workpiece after the milling process. It encompasses various attributes, including surface roughness, surface integrity, dimensional accuracy, and visual appearance [8]. A key element affecting machined items' mechanical characteristics and longevity is the surface roughness value. [3]

3.1 Influence of the cutting parameters on surface quality in dry milling conditions

From the results presented below, several interactions can be observed. The increase of the cutting speed from 314 m/min to 1100 m/min, led to a decrease of the surface roughness from 0.56 µm to 0.28 µm. This behavior is normal and is due to the increase in the rotation speed combined with the decrease in the feed per tooth. On the other hand, the increase of the cutting depth from 0.5 to 0.75mm led to a surface roughness decrease of 0.10µm (from 0.28µm to 0.18µm for the 1100 m/min cutting speed). This behavior can be credited to the thermal evacuation of heat from the contact surface which, in the case of a smaller chip, would "evacuate" a smaller amount of heat, thus favoring deposits on the surface and edge of the cutting tool (Fig. 3).

We can conclude that proper control of feed rates and chip management plays a critical role in minimizing surface deposits and ensuring a cleaner, higher-quality finish.

In terms of surface microhardness, we could see that there wasn't an important influence of the cutting parameters on its values. The increase of cutting speed or cutting depth led to a small increase in surface hardness (Fig. 4). This behavior can be attributed to the increase of cutting force, thus an increase of local heat that will affect the surface layer.

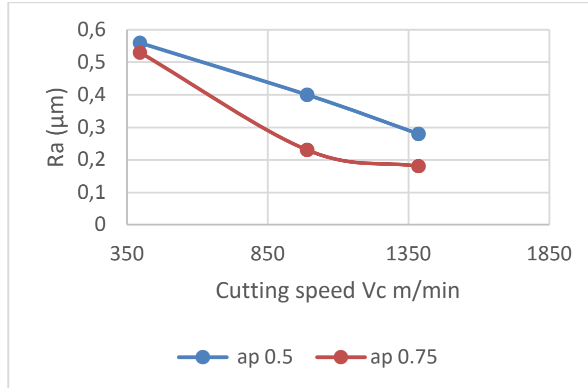

Fig. 3. Influence of cutting speed on surface roughness in dry milling condition.

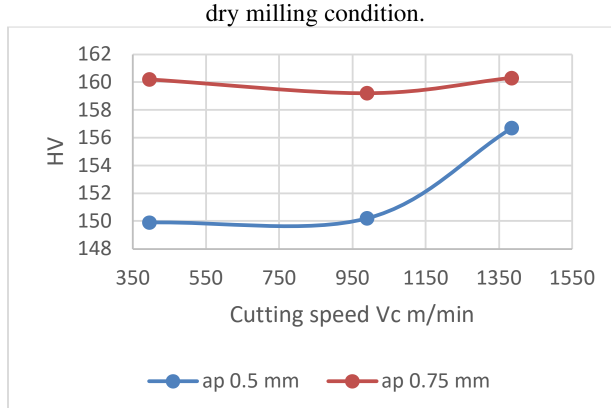

Fig. 4. Influence of cutting parameter on surface microhardness in dry milling condition.

3.2 Influence of the cutting parameters on surface quality in cryogenic milling conditions

The second part of the experiments has been made with cryogenic cooling, using liquid nitrogen to freeze the part.

During the milling process, the temperature of the part was monitored with the same type k probe inside the part, at a distance of 1 mm from the surface of the part. The processing temperatures reached approximately -60ºC at the tip of the spray nozzle. Roughness and hardness measurement were realized 24h after the machining process, allowing the parts to reach room temperature, in order to avoid any temperature interference caused by the material cooling.

The results revealed that the behavior was similar to the one observed under dry cutting conditions (no cooling) (Fig. 5). Nevertheless, smaller values of surface roughness up to 50% smaller than the ones observed for dry cutting were obtained. The use of a higher depths of cut lead to further decrease of the roughness values.

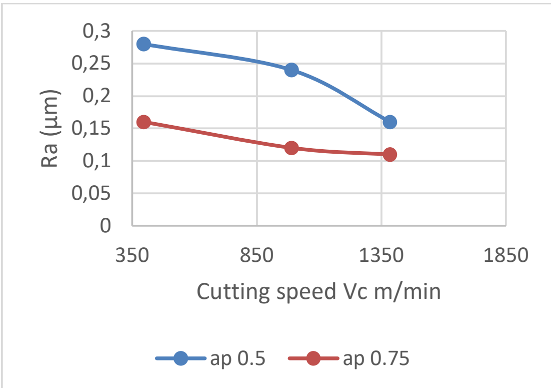

Fig. 5. Influence of cutting speed on surface roughness in cryogenic milling conditions.

Figure 6 presents the influence of the cutting parameters on the surface microhardness of the AL 7075 alloy milled under cryogenic cooling conditions. It demonstrates that under cryogenic cooling material`s the behavior was similar to the one observed under dry milling condition.

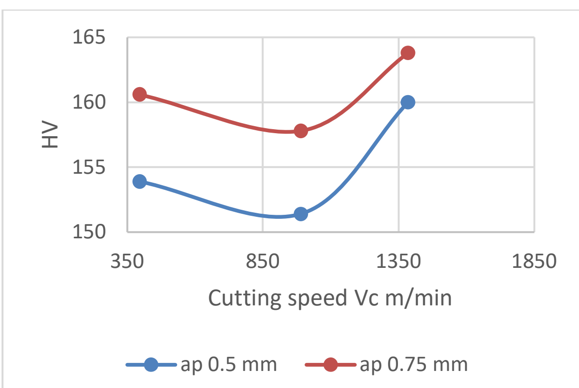

Fig.6. Influence of cutting parameter on surface microhardness in cryogenic milling conditions.

Basically, the use of a high cutting depth (0.75mm) led to a higher value of surface microhardness (up to 163.8 HV) while the use of a smaller cutting depth (0.5mm) generate smaller microhardness values (up to 151.4 HV). The increase of cutting speed led to an increase of the hardness at both depths of cut.

The use of cryogenic cooling demonstrated a significant improvement in surface quality, through enhancements in roughness and microhardness values.

Fig. 7a. Dry milling generated surface (Vc 314 m/min; ap 0.5 mm)

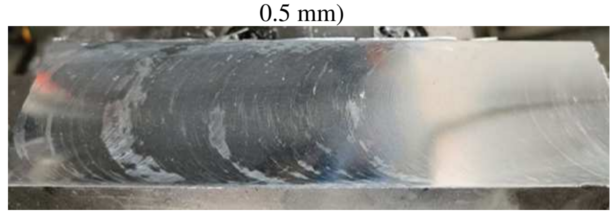

Fig. 7b. Cryogenic cooled milled surface (Vc 314 m/min; ap 0.5mm).

Figure 7 illustrates the notable surface quality differences between dry milling and cryogenic milling. The dry milling conditions led to deposits of aluminum that were frequently observed on the machined surface, particularly when employing a smaller feed per tooth and a reduced depth of cut. These conditions result in smaller chip dimensions, which can adhere to the cutting edge and subsequently transfer onto the finished surface, compromising its quality (Figure 7a). The use of cryogenic cooling lowers the working temperature in the tool-semifinished product contact area, thus making chip removal easier, thus avoiding adhesion to the surface or cutting edge of the cutting tool. This highlights the effectiveness of cryogenic cooling in improving machining performance and ensuring better surface integrity (Figure 7b).

To gain a better understanding of the deposits, a detailed image was captured of a piece that was milled at a cutting speed of Vc 314 m/min and a depth of cut (ap) of 0.5 mm (zone size of 10/7 mm). The machining was realized under dry conditions and the image of the machined surface magnified at 20x, is presented in Figure 8.

Among the experiments presented by the literature, a few indicate that cryogenic cooling alone does not significantly improve the surface roughness of aluminum [17]. However, notable improvements in roughness have been observed when cryogenic cooling is combined with Minimum Quantity Lubrication (MQL) [18]. Despite these findings, the tests performed in this study demonstrate that cryogenic cooling substantially improves the cleanliness of the machined surface. A significant percentage of aluminum deposits on the surface are effectively removed, contributing to improved surface quality and integrity.

Fig. 8. Detailed deposits on the surface 20x measured on Mitutoyo TM101 microscope.

4. CONCLUSION

Milling of Al7075 with different parameters and cutting conditions influence the surface quality. Regarding the surface roughness, we observe that it was affected by the cutting regime (dry and LN_2 cooled), the cutting parameter and the cutting depth. The increase of the cutting speed generated lower surface roughness for both types of machining (dry and LN_2). Additionally, the increase of the cutting depth positively influenced surface quality.

Significant improvement of the surface roughness was generated by the use of cryogenic cooling, with values up to 50% lower than the ones observed for dry cutting.

The microhardness was influenced by both the cutting parameters and the cutting regimes (dry and LN2). We observed that an increase in machining speed resulted in higher surface microhardness. Additionally, using a greater cutting depth (0.75 mm) also produced higher microhardness values, regardless of whether cryogenic cooling was present or not.

The limitation of this study is the lack of continuous temperature monitoring during the machining process, which could provide deeper insights into the thermal effects on surface quality and tool wear. Future research should integrate real-time temperature tracking to better understand the influence of thermal variations on machining performance.

In conclusion, cryogenic cooling is recommended for AL7075 milling, as it produces better surface quality results than dry machining and is considered an environmentally friendly technique.

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Influența parametrilor de prelucrare asupra calității suprafeței aliajului Al7075 în condiții de prelucrare uscată și cu răcire cu LN_2 (azot lichid)

Scopul prezentei lucrări a fost de a investiga influența parametrilor de prelucrare în condiții fără răcire și cu răcire cu azot lichid (LN_2) asupra calității suprafeței. Au fost efectuate experimente pe aliajul de aluminiu AL7075, fiind testate trei viteze și două adâncimi de prelucrare în prezența și absența răcirii criogenice. Creșterea vitezei în condiții de răcire criogenică a condus la o scădere a rugozității suprafeței de la 0,28 µm (în stare uscată) la 0,16 µm (cu răcire LN2). Comportament similar a fost observat și în cazul creșterii adâncimii de prelucrare, astfel încât pentru adâncimi de tăiere mai mari utilizarea lichidului de răcire criogenic a generat valori mai mici ale rugozității suprafeței decât frezarea uscată. În concluzie, se recomandă utilizarea tehnicii de răcire criogenică pentru frezarea AL7075 deoarece aceste condiții de prelucrare au generat rezultate mai bune decât prelucrarea uscată și este, de asemenea, considerată o tehnică prietenoasă cu mediul.

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