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# Effect of supply conditions of liquid nitrogen on the cryogenic assisted machining of the Ti64 Titanium alloy

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## Abstract

This study focuses on the optimization of the machining assisted by cryogenic cooling. The main objective is to analyze the effect of the pressure and the flow of liquid nitrogen on tool life when machining titanium alloy Ti-6Al-4V using the cryogenic assisted machining. A nozzle holder has been specially developed for this study to ensure positioning and the replacement of calibrated nozzles of different diameters. Several nozzle diameters have been therefore used in order to vary the pressure and the flow according to tests to be conducted. The flow rate has been varied between 1.2 l/min and 3.4 l/min for two pressure ranges 8-10 bar and 4-5 bar respectively. The machining tests have allowed to highlight the effect of the pressure and flow rate of liquid nitrogen jet on the tool life. Indeed, the results showed that increasing the flow rate increases the tool life. In addition, the increase in pressure slowed down the evolution of the wear and further improves the tool life. Indeed, in all tested cases, the cryogenic assistance improves the tool life but the best results have been obtained for the highest pressure and flow rate. Moreover, surface integrity has been greatly improved

## Keywords:

Tool wear, Titanium alloy, cryogenic assistance, residual stress

## 1 INTRODUCTION

Titanium alloys present very interesting assets in the aerospace, marine and biomedical fields especially for their excellent mechanical characteristics, their corrosion resistance and their low density. However, machining these alloys is often challenging. Among the solutions that have been developed to overcome this problem is machining assistance. In the recent years, research about the cryogenic assistance is continually growing. Most of these studies were focused on the impact of this assistance on tool life. It has been shown that the phenomenon of wear is greatly reduced which leads subsequently to a considerable increase of tool life. [1,2,3]. Other studies had as object to study the impact of the cryogenic lubrication on surface integrity (residual stress and surface roughness). Again, the results were very encouraging especially with the considerable improvement found compared to conventional machining [4,5]. According to [6] surface integrity could be improved by 35% when machining Ti-6Al-4V titanium alloy.

However, influence of the liquid nitrogen parameters such as its pressure and its flow rate is unknown. Thus, this study aims to assess the impact of these parameters on tool life and residual stresses.

## 2 EXPERIMENTAL SETUP

In order to determine the influence of the liquid nitrogen parameters (pressure and flow rate) on tool life, several wear tests have been carried out. These experimental trials were conducted on Leadwell LTC25iL (2 500 rev/min, 24kw) lathe. The liquid nitrogen is conditioned in a 180 liter tank. It is supplied to the tool through thermally insulated pipes. H13A uncoated carbide inserts have been used (CCMT 12-04-08KM). Different flow rates have been tested (1.4 l/min, 1.8 l/min and 3.4 l/min) for two different pressure levels. These tests have been accompanied by the measurement of surface roughness, cutting forces, tool wear and residual

stresses. The study has been funded by *Air Liquide* and only a part of these results will be presented in the present article for reasons of confidentiality.

The cutting conditions are listed below:

- Cutting speed  $V_c$ : 80 m/min.
- Depth of cut  $a_p$ : 1 mm.
- Feed rate: 0.2 mm/rev.

A new nozzle holder has been specially developed for this study (Figure 1). It allows the positioning and the supply of calibrated nozzles of different diameters.



Figure 1: New nozzle holder

The correspondence of the flow rate with the nozzle diameter, for a given pressure, has been carried out experimentally. Table 1 summarizes the results of the preliminary tests.

Liquid nitrogen pressure: 8-10 bar	
Nozzle diameter (mm)	Flow rate (l/min)
1,6	1,8

2,5	3,4
Liquid nitrogen pressure: 4-5 bar	
3	3

Table 1: Calibration of the flow rate and pressure

### 3 TOOL WEAR

Tool wear has been controlled every minute using a stereo microscope and basing on the ANSI/ASME B94.55M-1985 standard. The tool is considered as worn if the flank wear (VB) exceeds 0.3 mm.

The first series of tests consists in varying the flow of liquid nitrogen while maintaining an elevated pressure (8-10 bar). Figure 2 shows the results of these trials.

First of all, it could be remarked that the cryogenic assistance permits to significantly increase the tool life. It allows, in the worst case, to increase the tool life of about 5 times compared to the dry machining. Moreover, these tests show that the flow rate has a great influence. Indeed, with a flow rate of 1.8 l/min tool life is about 12 min while when using a flow rate of 3.4 l/min the flank wear does not exceed 0.15 mm.

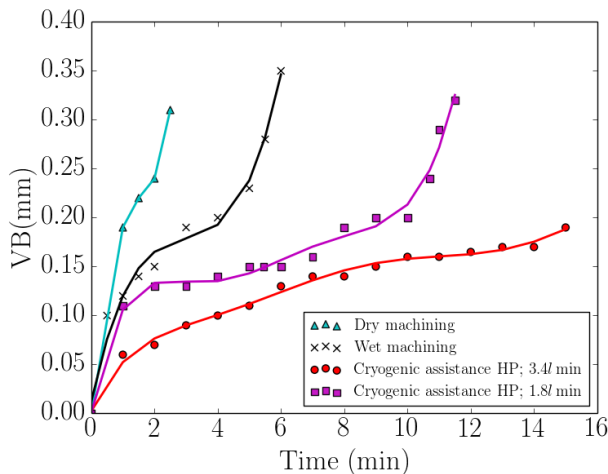


Figure 2: Liquid nitrogen flow rate influence

The second series of tests consists in varying pressure of liquid nitrogen while maintaining the flow rate. Figure 3 shows the results of these tests.

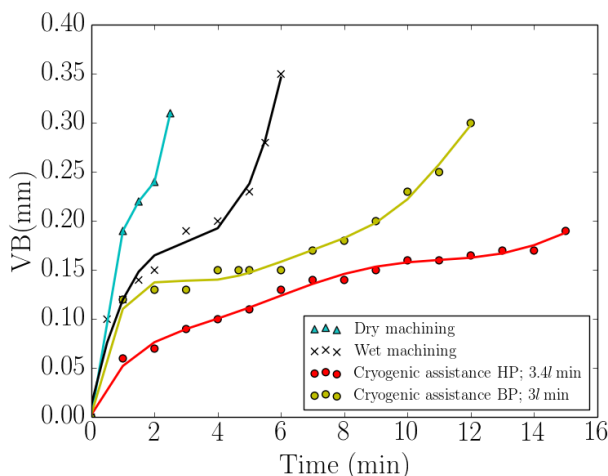


Figure 3: Liquid nitrogen pressure influence

As well as the previous tests, the variation of the liquid nitrogen pressure impacts the tool life. In fact, when reducing the pressure from 8-10 bar to 4-5 bar the tool life drops.

Finally, it should be noted that the tool life obtained for a high pressure (8-10 bar) and a low flow (1.8 l/min) corresponds almost to the tool life obtained at low pressure (4-5 bar) and a high flow rate (3 l/min)

### 4 RESIDUAL STRESS

The last part of this study focuses on the influence of liquid nitrogen parameters on surface residual stress. Indeed, in dry machining the level of residual stress does not exceed -200 MPa. However, it reaches -330 MPa at low pressure (3 l/min) and -433 MPa at high pressure (3.4 l/min). Figure 4 shows these results.



Figure 3: Residual stress

Basing on these results it could be noted that cryogenic assistance improves the work piece surface integrity. This improvement is more marked with the highest pressure and the most important flow rate.

### 5 CONCLUSION

From the experimental results it can be concluded that the pressure of the liquid nitrogen and its flow rate have a significant impact on the tool life and residual stress. Indeed, the best results have been obtained with the highest pressure and the highest flow rate. It can be noted also that whatever the parameters of liquid nitrogen, cryogenic assistance can significantly increase the tool life. In addition, it improves considerably the surface integrity.

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