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Experimental evaluation of machining parameters in machining of 7075 aluminium alloy with cryogenic liquid nitrogen coolant

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Abstract. The experimental results on investigation on the turning of 7075 aluminium alloy, using Cryogenic Liquid Nitrogen (LN₂) as a coolant was analyzed in this paper. The influence of the cryogenic LN₂ coolant compared with that of the conventional coolant on the cutting performance parameters, such as the cutting force, cutting temperature, and surface finish was analysed and investigated. The use of the cryogenic liquid nitrogen coolant influenced the cutting temperature and the cutting force by about 17 to 29% and 11 to 20% reduction respectively. The surface finish value of the machined workpiece is about 15 to 23% better than that of the conventional coolant.

Keywords: 7075 aluminium alloy, LN₂ cooling, Tool wear, Cutting temperature

1. Introduction

Al-Zinc alloys are one of the indispensable materials of the present industry, because of their superior mechanical properties over other aluminium alloys. The Aluminium- Zinc 7075 alloy is predominantly used in aerospace and automobile industries due to its excellent mechanical strength.

Machining of Aluminium alloys causes Built Up Edge formation (BUE), which affects the surface roughness [1],[7]. When the cutting velocity is increased, the tendency of BUE vanishes, due to the low cutting force and high temperature [9].

Cutting fluids are used in turning operations primarily to improve the tool life and surface finish of the work-piece. They also help in reducing the temperature and removing the debris during the turning operation. However, the use of cutting fluids has many adverse effects. The cutting fluids used in machining, contain harmful chemical components which is harmful to environment. These conventional cutting fluids are difficult to dispose of and can cause harmful diseases to the operators. In the turning of the 6061 aluminium alloy under Minimum Quantity Lubrication conditions, the amount of cutting fluid influences the material adherence on the tool surface, and tools used for turning experienced nose wear and flank wear [11]. The elimination of cutting fluids in turning causes high friction between the tool and workpiece, which leads to higher temperature in the machining zone. Dimensional inaccuracies and excessive tool wear are also the problems in dry machining [12].

An environmentally safe coolant viz, cryogenic LN₂, is used to overcome these difficulties. Researchers carried out experiments earlier by using cryogenic LN₂ as a coolant for the turning other



materials, and obtained good results in reducing the cutting temperature, cutting force, surface roughness and tool wear [4],[6],[10]. It was also observed that when cryogenic LN₂ was used as a coolant in the turning of Ti-6Al-4V alloy and AISI 4045 Steel, the process parameters such as surface roughness, tool wear, cutting force and cutting temperature were reduced [3],[5]. The gases and water vapor also used as cutting coolants by researchers and contributed well to the metal cutting industry [1],[8].

This experimental work aims on investigating performance of cryogenic LN₂ as the cutting fluid in machining 7075 alloy and compare the results with conventional wet machining in terms of cutting temperature, cutting force and surface roughness .

2. Experimental procedure

In this experimental work, Al 7075 alloy was used as the workpiece material. A bar with dimensions of 75 mm diameter and 300 mm length bar was used for the experimental work. The following conditions are considered for the machining work, as mentioned in Table 1.

Table 1 Experimental conditions

Workpiece	7075 Aluminium alloy
Workpiece dimension	75 mm x 300 mm
Cutting tool insert	Uncoated Tungston carbide insert
Rake angle	0°
Process parameters	
Cutting velocity	51,118 and 181 m/min
Feed rate	0.079,0.159 and 0.205 mm/rev
Depth of cut	1 mm
Machining conditions	Wet and LN ₂

The main purpose of this experiment is to investigate the effect of LN₂ as a cutting fluid, and compare it with that of the conventional coolant in the machining of the 7075 Al alloy. The cryogenic LN₂ machining experimental set up used is shown in Figure 1. The various sets of experiments were performed by the turning operation on a High speed automatic lathe (NAGMATI175) shown in Figure 2. The Kistler type 9257B Piezoelectric Dynamometer was used to measure cutting force. The cutting temperature was measured using a non-contact type IR thermometer on the cutting face of the tool insert during the turning process. The Talysurf surface roughness tester was used for measuring surface roughness after completion of turning the workpieces at a constant cutting velocity of 51 m/min and constant feed rate of 0.079 mm/rev. conditions.

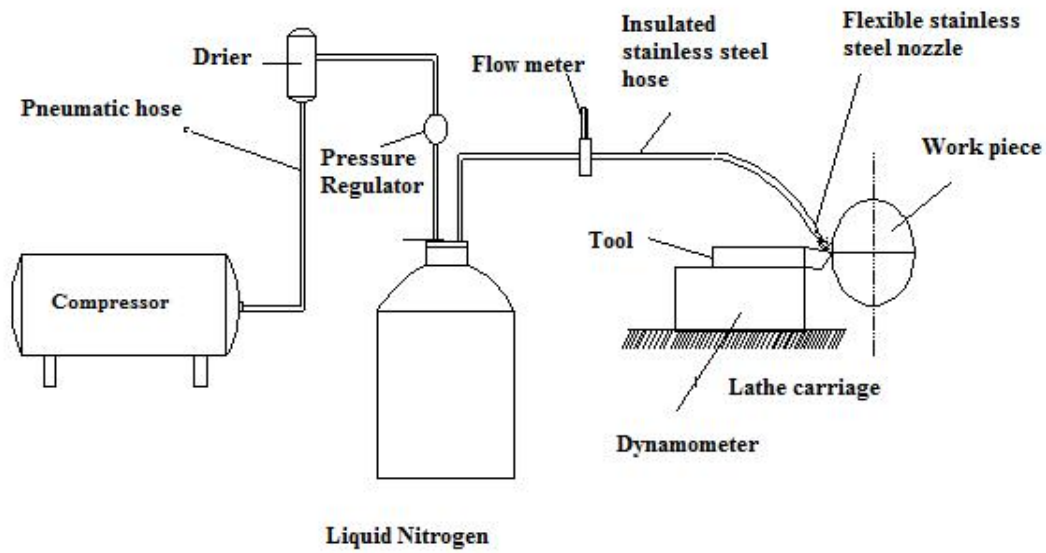


Figure 1. Schematic view of experimental set up for cryogenic LN₂ machining

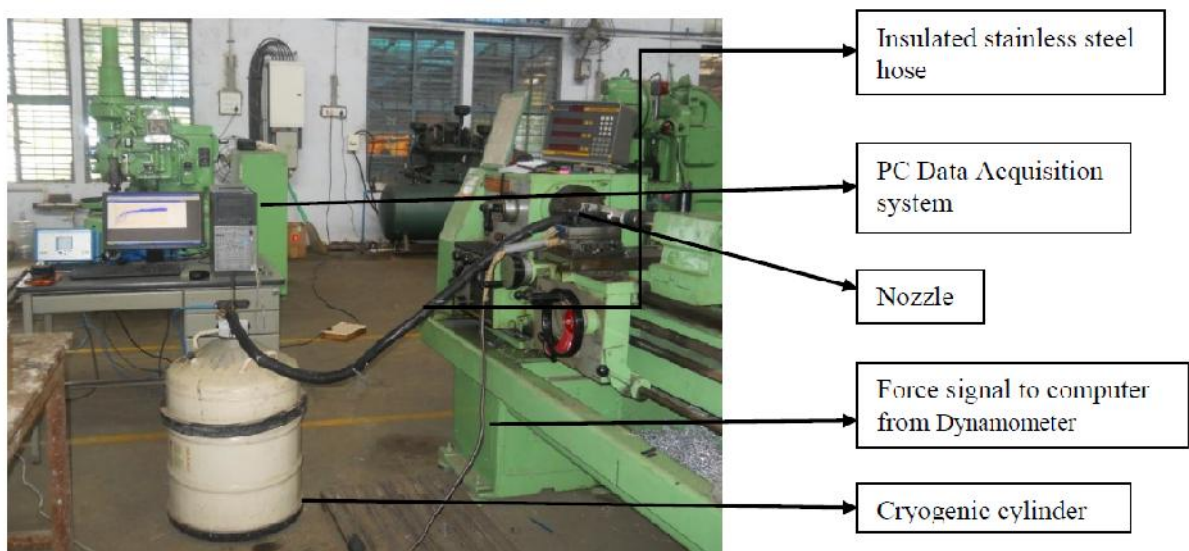


Figure 2. Photographic view of Experimental setup

3. Results and Discussion

3.1. Cutting temperature

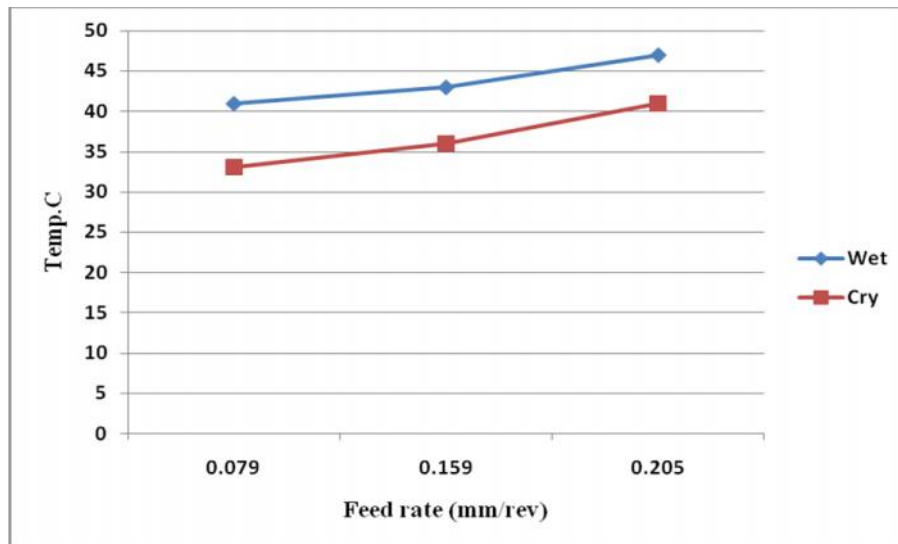


Figure 3a. Cutting temperature at cutting velocity of 181m/min with different feed rate

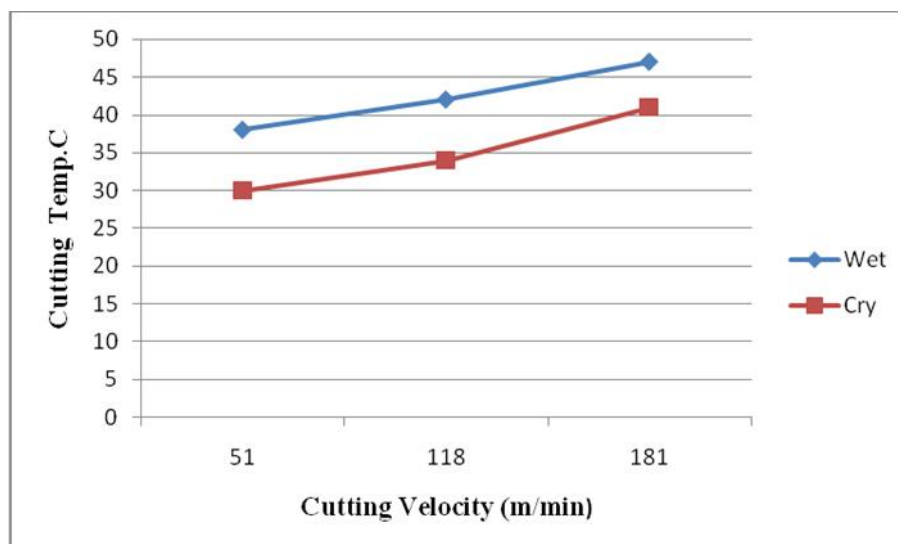


Figure 3b. Cutting temperature at feed rate of 0.205 mm/rev with different cutting velocity

The cutting tool temperature was measured using a non contact type thermometer for different cutting velocity and feed rate conditions. Figure 3a and 3b shows the variation of the cutting temperature under cryogenic and conventional coolant conditions at a constant cutting velocity of 181 m/min. and constant feed rate of 0.205 mm/rev respectively. The result showed that the cutting tool temperature was increased proportionally with the increase in the feed rate and cutting velocity. This was due to more plastic deformation and contact friction between the workpiece and tool. The LN₂ applied

between the workpiece and cutting tool absorbs the high heat energy generated in the cutting zone area. Due to its low boiling point (-196°C), the LN_2 gets evaporated by absorbing the high heat energy generated between the workpiece and tool insert used, since the LN_2 was impinging in liquid and gaseous forms between the workpiece and the tool, the friction at the chip tool contact surface and temperature is reduced. This reduction of temperature is about 17-29 % compared to wet machining conditions.

3.2. Cutting force:

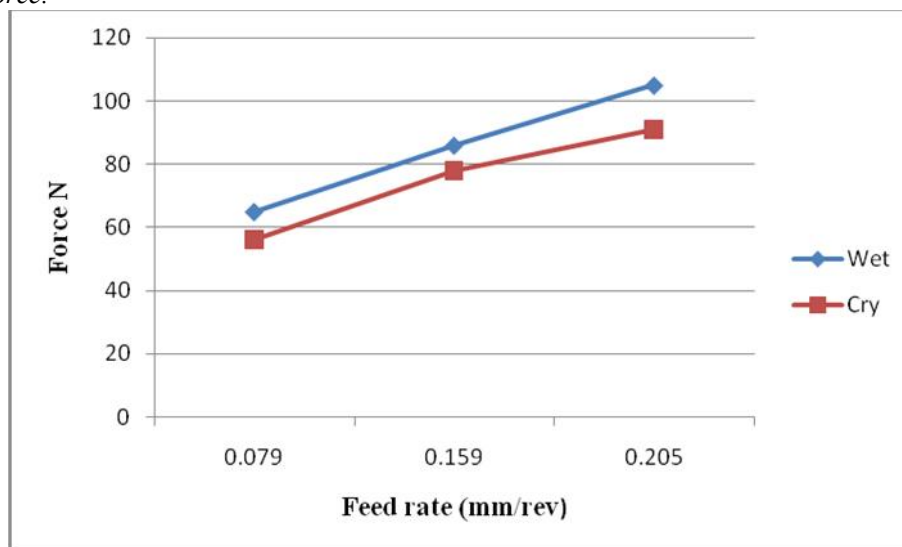


Figure 4a. Cutting force at cutting velocity of 51m/min with different feed rate

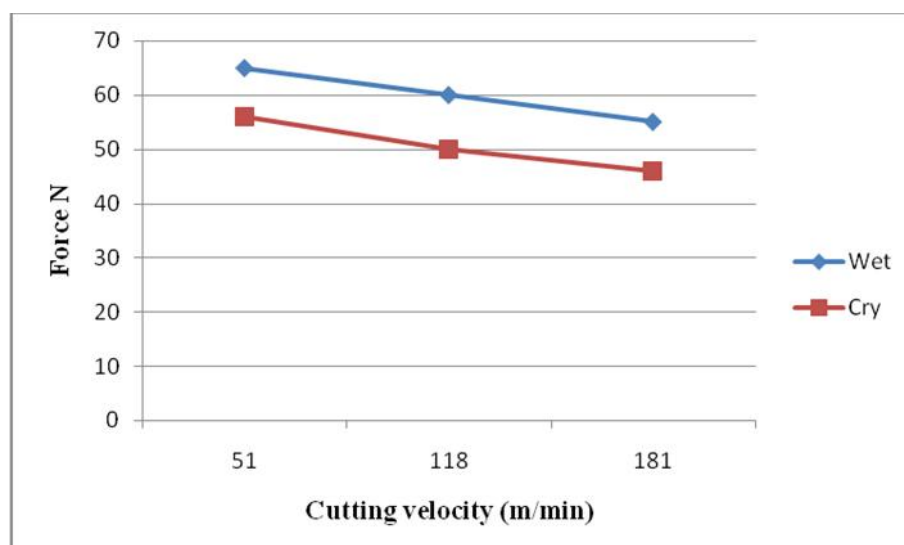


Figure 4b. Cutting force at feed rate of 0.079 mm/rev with different velocity

The main cutting force for various cutting velocity and feed rate conditions was measured. The variation of the cutting force under cryogenic and conventional coolant conditions at a constant velocity of 51 m/min and constant feed rate of 0.079 mm/rev, is shown in Figure 4a. and Figure 4b. respectively.

It is observed from Figure 4a that with the increase in feed rate cutting force is increased. This is due to the increase in the material removal rate and work done per unit time. It is also observed that when cryogenic LN₂ was used as the coolant the cutting force was reduced

The Figure 4b shows the variation of the cutting force at a constant feed rate of 0.079 mm/rev. It is observed that the cutting force decreased with the increase in the cutting velocity. This is due to less duration of the contact between the material and the tool. When the cutting temperature is increased at higher velocity, the material plasticity also increases, which reduces the cutting force. The formation of BUE at high temperature vanished, resulting in a reduction in the cutting force. It can be observed that the application of LN₂ reduces the cutting force more than wet machining conditions. This is due to the adhesion produced by the penetration of LN₂ in liquid and gaseous forms between the workpiece and the tool. The reduction of temperature and reduced friction at the chip tool interface, reduced the cutting force to a great extent. This reduction of the cutting force is about 11-20 % compared to wet machining conditions.

3.3. Surface roughness

The surface roughness value of the machined workpiece was measured at a constant feed rate of 0.079 mm/rev and constant velocity of 51 m/min, by varying the other parameters of cutting velocity and feed rate respectively. The mean surface roughness values (R_a) were taken for both the conditions for evaluation. The surface roughness values at a constant feed rate of 0.079 mm/rev are shown in Figure 5. The surface roughness values at a constant velocity of 51 m/min are shown in Figure 5.

It is clearly seen from figure 6. that the surface roughness decreased with the increase in the cutting velocity. This was due to less duration of contact of the workpiece material tool. The lower material removal rate and reduction of BUE due to increase in temperature, also caused a reduction in the surface roughness value.

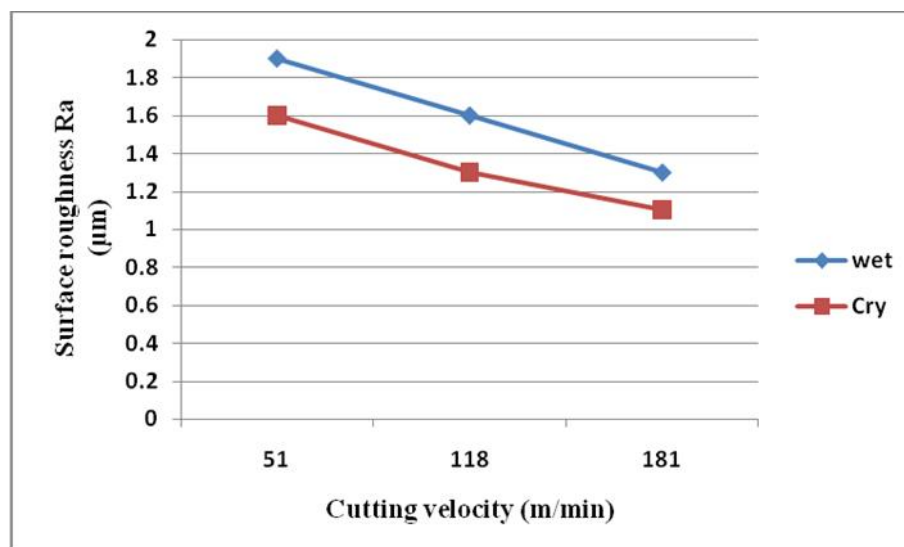


Figure 5. Surface roughness at the feed rate of 0.079 mm/rev with different cutting velocity

It is clear from the above illustration that the use of LN₂ coolant reduced the surface roughness values compared to the conventional wet machining conditions. This is because of the reduction of the cutting temperature and cutting force compared to wet machining conditions. It is also noted that the lesser adhesion of the material over the tool, reduced friction at the chip tool interface due to a better cushioning effect, and higher tool hardness improved the surface finish values. The use of low temperature LN₂ produced better surface finish values by about 15–23% when compared with conventional wet machining conditions.

4. Conclusion

The following conclusions can be drawn based on turning the Al 7075 alloy by using cryogenic LN₂ as a coolant :

1. The use of cryogenic liquid nitrogen coolant reduced cutting temperature 17–29% less compared to conventional wet machining.
2. The application of cryogenic LN₂ reduced cutting forces at about 11–20% less compared to conventional wet machining..
3. Surface roughness was reduced on use of the cryogenic LN₂ coolants. The application of the LN₂ coolant reduced the surface roughness value by about 15-23 % compared to wet machining conditions.

5. References

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