

Machinability Study of Austenitic Stainless Steel under Wet and Cryogenic Treatment in Face Milling

Karthik Rao M C¹ . Arun Kumar Shettigar¹ . Rashmi L Malghan² . Shrikantha S Rao² .
Mervin A Herbert²

¹Manipal Institute of Technology, Department of Mechatronics Engineering, Manipal, India.

²National Institute of Technology Karnataka, Department of Mechanical Engineering, Surathkal, India.

ABSTRACT

In manufacturing industries, the rise in cutting temperature during machining operations influences the surface finish of the product. Since in metal cutting the usage of coolant is less efficient compared to cryogenic machining in reducing the rise in temperature in tool-workpiece interface. The paper shows the impact of cryogenic fluid nitrogen (LN₂ at -196 °C) on surface integrity and cutting temperature in processing of AISI 316 and the outcomes were contrasted over the wet machining. The outcomes have revealed that cryogenic machining has yielded better surface finish when contrasted with traditional wet machining.

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Introduction

Austenitic stainless steel is a standout amongst the most engineering materials with a wide assortment of utilizations. Better resistance than erosion and similarity in high temperature and high vacuum has especially settled on it an appealing decision. Stainless steel is otherwise called corrosion resistant steel, since it is an iron-based steel combination, which contains least 11% chromium. Chromium exhibit in it keeps it from getting corrode. At the point when conventional carbon steel is presented to rain water, it erodes effectively because of the development of a dark coloured iron oxide at first glance, which is regularly called as rust. In any case, when more than around 10% chromium is added to standard steel, the oxide at first glance is changed. Stainless Steel for the most part has high malleability and weldability properties.

Machining industries are utilizing ordinary liquid cooling at the metal cutting area to defeat the temperature raises [1]. Nonetheless, it was discovered that flood cooling strategy not bunch to diminish the cutting temperature at device chip interface at higher cutting liquids [2,3] and regular cutting liquids is concoction contaminants causes a few health, environmental issues and extra transfer cost [4]. Likewise, it is determined that the related costs identified with cutting liquids are 30% of aggregate assembling costs [5]. Albeit a few ecologically cognizant controls limited the enterprises as far as utilization and transfer of customary slicing liquids because of wellbeing risky and natural contamination affect [6]. In this way, there is a need to focus on green assembling to defeat natural contamination, cutting liquid transfer, support, upkeep and lower profitability issues. Cryogenic machining is one of the alternative approaches. Subsequently, in this study cryogenic splash cooling system is utilized, i.e. streaming of the Liquid nitrogen (LN₂) at - 196°C at the tool-workpiece interface. LN₂ generously decreases the temperatures at

the tool-chip interface and creates much lower friction coefficient [7]. A. Bordin et al. illustrated low tool wear and low surface roughness in cryogenic machining contrasted with dry machining amid machining of titanium amalgam [8]. B.D. Jerold et al. demonstrated that CO₂ yielded better instrument wear contrasted with the wet machining for AISI 1045 steel [9]. D. Umbrello illustrated better surface finish in cryogenic machining contrasted with the dry machining amid machining of AISI 52100 steel [10,11]. F. Klocke et al. observed lower tool wear and reduced surface roughness in cryogenic condition compared to minimum quantity lubrication (MQL) machining conditions because of the considerable decrease of the cutting temperatures [12]. Thus, cryogenic machining expands the efficiency and quality of the item in the machining of gamma titanium aluminides contrasted with the other wet, MQL machining. S. Y. Hong et al. completed monetary and natural investigation in the turning of AISI 304 and inferred that cryogenic approach is more beneficial and help to achieve more prominent profitability contrasted with emulsion cooling, without wellbeing and ecological concerns [6].

To the author's knowledge very less report is accessible on machining of AISI 316 under cryogenic condition. From the literature, it can be observed that cryogenic cooling increases the tool life, attains better surface finish with amid machining of hard to cut material, regardless of many points of interest it over cools the surface, increases the hardness of the machined surface. Thus, the point of the current investigation is to consider the impact of LN₂ as the coolant on cutting temperature and surface integrity in the processing of AISI 316 over the wet machining.

Experimental

Materials and Methods

Table 1 depicts the experimental conditions utilized in the current work. CNC Spark DTC-12 was utilized to carry out

Face milling experiments on AISI 316 stainless steel. LN₂ cryogenic machining setup is delineated in Figure 1 and metal cutting region is shown in Figure 2. Experiments were carried out in 650, 750 and 850 rpm, constant feed rate of 250 mm/min and depth of cut 0.8 mm. The boundary limit of parameters depended on the preliminary experiments conducted.

Table 1: Experimental conditions

Workpiece Material & Size	AISI 316 (100mm x 40mm x 30)
Face Milling Process	Spindle Speed:
Parameters	650,700,750,800,850 rpm
	Feed Rate: 250 mm/min
	Depth of Cut: 0.8mm
Environments	Wet (Flood Coolant). Cryogenic (LN ₂)



Figure 1: Cryogenic machining setup



Figure 2: Cryogenic machining region

Cryogenic Cooling Method

A minimal cost setup of cryogenic cooling was utilized to encroach the LN₂ at the tool-workpiece interface. The setup includes TA55 cryocan, it is utilized to stock up the LN₂ via

the air compressor. Later on, the pressurized LN₂ is provided through the spout to the tool-workpiece interface with the pressure of 3 bar and flow rate of 0.36 l/min.

Measurement of Performance Characteristics

The surface roughness of each cryogenically machined surface was measured using the Mitutoyo surface roughness analyser. Three readings at different locations were measured on each machined surface and the average of it was considered as the conclusive estimation of surface roughness estimation. Infrared thermometer was utilized to quantify the cutting temperatures at the tool-workpiece interface.

Results and Discussion

Effect of cryogenic LN₂ on cutting temperature

From the Figure 3, it is observed that the cutting temperature increases linearly with the spindle speed in both cryogenic and wet machining. The prominent cutting temperatures at a spindle speed of 650 rpm and feed rate of 250 mm/min was 112.8 °C for wet and 43.6 °C for cryogenic machining. It is noticed that 69.4% of cutting temperature decreased by using LN₂ over wet conditions. This is because of the low temperature of LN₂ which was influenced at the tool-workpiece interface as it retains the cutting temperatures at the cutting region.

The cutting temperatures raised from 43.6 °C to 103.5 °C and 112.8 °C to 335.9 °C in cryogenic and wet machining respectively, when the spindle speed raised from 650 to 850 rpm at a constant feed rate of 250 mm/min. In the study using LN₂, reduced the cutting temperature from 69.2% to 81.4% over the wet machining. From the Figure 3 it can be seen that, the rise in temperature diminished for cryogenic condition compared to wet machining. It is also observed that there is a decrement in the cryogenic effect with increase in spindle speed this is because of the accumulation of chips at tool face, so it hinders the entrance of LN₂ in-turn reducing the cryogenic effect [13].

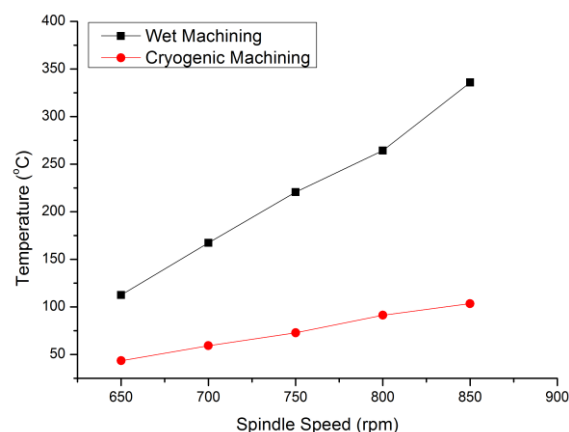


Figure 3: Cutting Temperature Variation

Effect of cryogenic LN₂ on surface finish

The surface roughness estimation of machined surface of various spindle speed under the cryogenic and wet machining conditions is shown in Figure 4 and observed that surface roughness diminishes with increment in spindle speed. This effect is because of increment of cutting temperatures with an increase in spindle speed, as this

causes to thermal softening of workpiece material and more expulsion of surface discontinuities and blemishes at the higher spindle speed resulting in a better surface finish. The surface roughness value is $0.84\mu\text{m}$ and $1.96\mu\text{m}$ for cryogenic and wet machining respectively at the spindle speed of 650 rpm, feed rate of 250 mm/min and depth of cut of 0.8 mm. By using LN_2 , 37.62% of surface finish was enhanced over the wet machining. This is because of the concurrent use of LN_2 at the tool-workpiece interface lessens the cutting temperatures in the metal cutting region, thus leading to less adhesion at the tool-workpiece interface and creating less tool mark on the machined surface, in this manner better surface finish was accomplished.

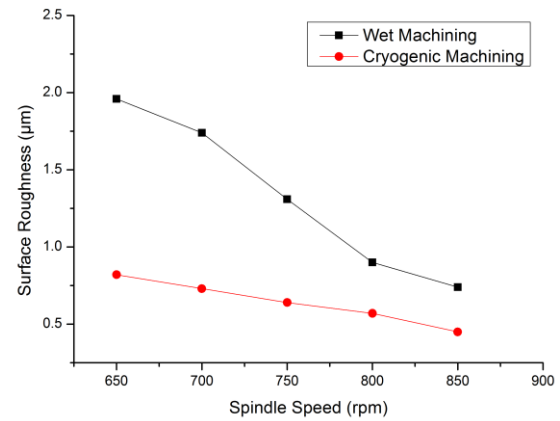


Figure 4: Surface Roughness (Ra) Variation

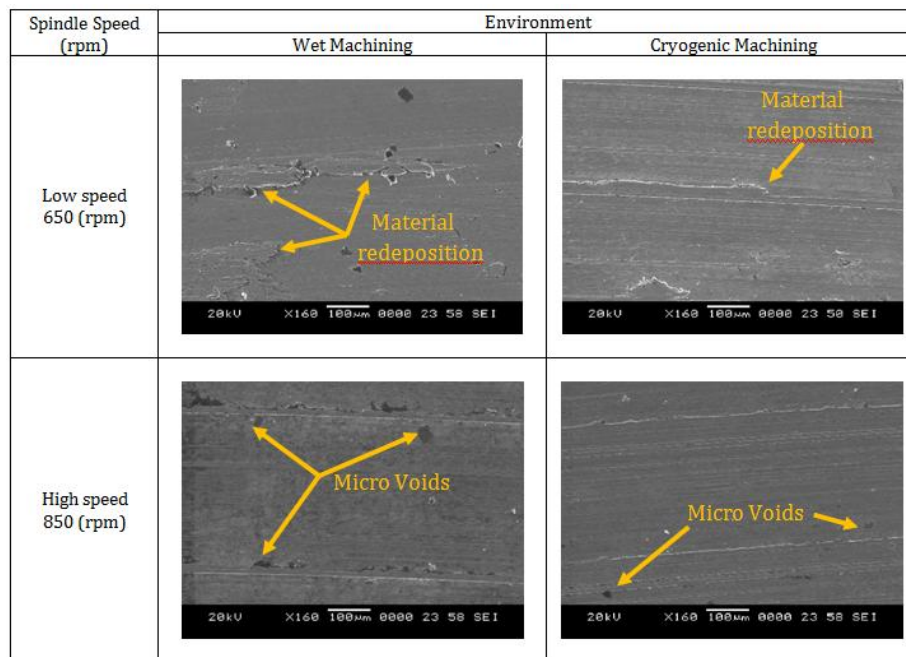


Figure 5: Machined surface SEM images at different environment

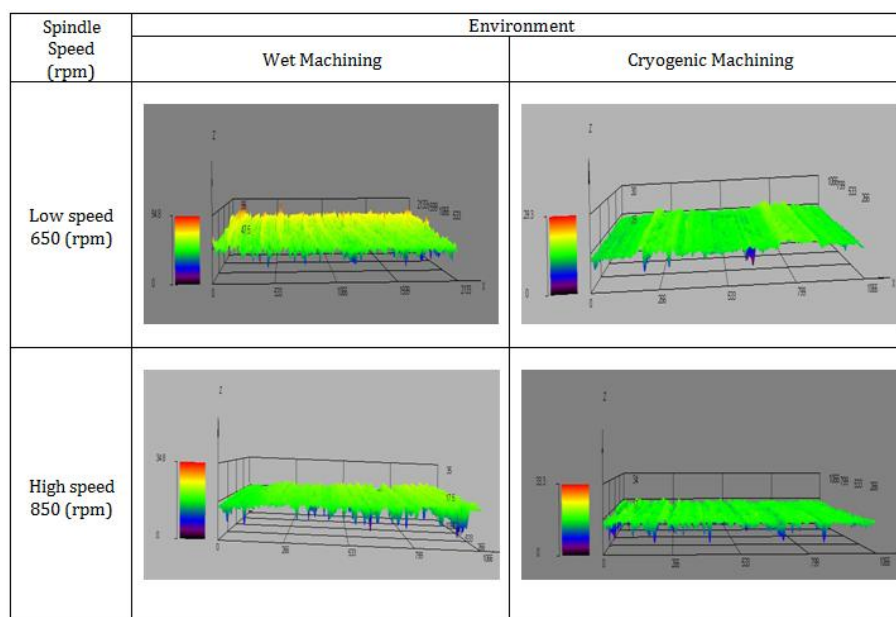


Figure 6: Machined surface 3D confocal images at different environment

From the Fig. 5 and Fig. 6, it can be observed that micro voids, less depositions of material and surface peaks of lower intensity have been located in cryogenic machining. The surface roughness value reduction in cryogenic machining was observed to be 39.18 % to 58.16 % compared to wet machining at varying spindle speed from 650 rpm to 850 m/min, constant feed rate of 250 mm/min and constant depth of cut of 0.8 mm.

Conclusions

The major conclusions that can be drawn from the experimental study are:

1. LN2 viably controlled the metal cutting region temperature, thus facilitated better surface finish over wet machining.
2. By using cryogenic conditions 69.4% of the cutting temperature was reduced over wet machining.
3. Experimentally it was substantiated that cryogenic machining essentially enhanced the performance of face milling even at higher spindle speed during machining of AISI 316. In this manner, cryogenic machining expands the efficiency with better quality.

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