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Experimental Investigation of Machining EN 31 Steel under Cryogenic Machining: A Comparison with Dry Machining

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ABSTRACT: This experimental work was carried out by turning EN31 steel in which the effect of cryogenic cooling (LN2) used as a cutting fluid is compared to that of dry machining with respect to tool wear i.e. crater, surface roughness and cutting forces (feed forces). Experiments were performed using uncoated tungsten carbide insert tool. Application of conventional cutting fluid often cannot control the high cutting temperature in high production machining. Besides, they are the major source of pollution from machining industries. Cryogenic cooling is an environment friendly clean technology for desirable control of cutting temperature. The present work investigates the role of cryogenic cooling by liquid nitrogen jet on average chip tool interface temperature, tool wear, dimensional accuracy and surface having constant feed rate and constant rpm speed. Compared to dry & wet machining, in LN2 machining, overall the tool wear is decreased 0.75 times. The surface roughness improvement is 17.84%. Fx force records a decrease of 0.25 times The experimental results proved that the application of cryogenic coolant overall increases the machining performance as compared to dry machining.

Keywords: Cryogenic cooling Tool wear Surface roughness Cutting forces

I. INTRODUCTION

High production machining particularly of high strength and heat resistance materials is associated with generation of large amount of heat and cutting temperature. Such high temperature causes dimensional deviation in the work piece and premature failure of cutting tools by Dhar *et.al.* [1].

Generally such problems are tried to be controlled by profuse cooling with soluble oil. But conventional cooling is not that effective as the bulk chip tool contact under high cutting velocity and feed prevents the fluid from entering the chip tool interface where temperature is maximum. But application of conventional cutting fluids creates several techno-environmental problems by Paul *et.al*, 2002 [3]. Therefore, the extensive heat generated developed from the tool chip interface evaporates the coolant before it reaches the cutting area. Hence heat generated during machining is not re-moved and is one of the main causes of the reduction in tool life [4]. The tool failure, poor surface finish and less dimensional accuracy are associated due to this high cut-ting temperature in cutting zone [5]. The tools have to withstand high temperature and stress during turning; they have to be shock resistant during milling, corrosion resistant and chemically inert towards the work piece material [6-8]. Further, conventional fluid also creates environmental and disposal problems. Therefore to overcome these problems, a new cooling approach is investigated i.e. cryogenic cooling, in which the liquid nitrogen (LN2) is used as a cutting fluid in the machining operation. This work especially, focuses on the effect of cryogenic coolants on machining characteristics. Earlier, much work is investigated using LN2 as the coolant to reduce the cutting temperature, tool wear, surface roughness and cutting forces [9, 10]. Paul et al. [11-14] described the beneficial effect of LN2 used as a coolant in terms of tool life, surface roughness and tool wear. Hong et al. [15] investigated that, the use of cryogenic coolant in machining. Cryogenic cooling provided less cutting forces, reduced cutting temperature, better surface finish and improved tool life compared to dry machining Dhar *et.al*. The favorable role of cryogenic cooling in chip breaking and reducing cutting temperature in turning Ding and Hong. [16].

In this present work, a new type of cooling approach is used i.e. cryogenic machining in which the liquid nitrogen is used as a coolant. Dhar and Kamruzzaman [18] discussed the beneficial effects of cryogenic cooling in machining. They conduct an experiment on cryogenic cooling and proved that the cryogenic cooling helps to reduce the cutting temperature in tool work interface and maintain the cutting edge sharp, which results in better tool life, surface finish and higher dimensional accuracy as compared to dry and wet ma-chining. The major disadvantage of using LN2 is that it increases the overall machining cost and it pre cools the work piece, which increases the hardness of material during machining. This results into increases the cutting forces and abrasion to the tool [15]. To eliminate this problem, the LN2 is prevent from the work piece and only directly applied on the tool rake face. LN2 have a property that it rapidly evaporates when it comes to contact with air. So in this present study, a special set up is prepared; therefore it cannot effects on the work piece material.

II. OBJECTIVE

As seen from the literature, the cryogenic cooling suggests many advantages and disadvantages in machining processes. In order to achieve minimum tool wear, good surface quality and minimum cutting forces the cutting conditions should be carefully selected with and appropriate conditions. So that during machining a new tool material is to be developed with lower coefficient of friction and high heat resistance. The main objective of the current work is to study the effect of LN2 as the coolant in machining EN 34 steel and to compare the tool wear i.e. crater and flank wear, surface roughness, cutting forces (feed and cutting forces) and cutting temperature with dry machining and wet machining.

III. EXPERIMENTAL PROCEDURE

In this experimentation, the effect of cryogenic coolant such as LN2 on tool wear, surface roughness, temperature and forces i.e. feed and cutting forces in machining of EN 31 steel compared to dry machining. The number of experiments and parameter chosen for this study are based upon preliminary experiments which are given below:

(1) Selection of Experimental conditions.

a) Material Selection- for the En 31 steel (0.16% C, 0.18% Si, 0.53% Mn, 0.011% S, 0.022% P, 1.56% Ni, 0.26% Cr, 0.25% Mo) 60mm diameter and 150mm length.

b) Machine for work- High-power rigid lathe machine, 6.5-feet bed, 3-phase 2 HP motor

c) Cooling Environments -(i) Dry (ii) Wet (conventional flood cooling with 1:20 soluble oil) (iii Liquid N_2.

Cutting tool inserts - Standard uncoated carbide insert (0.4.0.8,1.2).

(2) Parameters selections (N.Dhar,2006)-

a) Constant parameters-1200 RPM & 0.205 feed.

b) Input parameters-Nose radius (0.4,0.8,1.2mm), Depth of cut(0.6,1.0,1.2mm)

c) Cooling conditions (Dry, Wet, Liquid N2)

d) Output parameters-Tool wear, surface roughness, cutting forces

A. Dry Machining

To make a basis for comparing the tool wear, surface roughness, tool forces and cutting temperature for cryogenic machining, dry machining was performed. In dry machining, the experiments were performed without uses of any coolant

B. Wet Machining Process

In wet machining process involves use of cutting fluid. High cutting zone temperature is conventionally tried to be controlled by employing flood cooling by soluble oil. In high speed-feed machining conventionally applied cutting fluids fail to penetrate the chip tool interface and thus cannot remove heat effectively. But application of conventional cutting fluids creates several techno-environmental problems like environmental pollution, water pollution and soil contamination during disposal requirement of extra floor space and additional system for pumping, storage, filtration, recycling, chilling, etc.

C. Cryogenic Cooling

In the cryogenic machining, external cooling method is used having a pipe with an internal diameter of 1.5 mm. This method was opted because; the less heat is generated as compared to internal cooling system, which overall improves the machining behavior of product. The cryogenic cooling setup is shown in Fig. 1. The cryogenic fluid is used which is supplied by the nozzle. The flow of LN2 from the nozzle was targeted at the rake face along the main cutting edge of the tool. The flow was controlled using flow meter. The LN2 jet coming along the main cutting edge is provided mainly to protect the rake face and the principal flank surface. To avoiding the possibility of excessive cooling, LN2 was used in the jet form flowing from a nozzle at a predetermined rate of flow 0.36 l/min and pressure 5 bar.

Table 1: Final observations.

Sr. No.	Nose Radius	D.O.C	Cooling Conditions	Wear (mm)	Surface Roughness (um)	Forces (Fx)
1	0.4	0.6	Dry	.76	3.86	30
2	0.4	1.0	Wet	0.40	3.20	25
3	0.4	1.2	Cryo	0.19	2.17	13
4	0.8	0.6	Wet	0.28	3.14	26
5	0.8	1.0	Cryo	0.14	2.50	16
6	0.8	1.2	Dry	0.48	4.18	22
7	1.2	0.6	Cryo	0.07	2.62	10
8	1.2	1.0	Dry	0.32	4.30	26
9	1.2	1.2	Wet	0.21	3.68	23

Fig. 1 (a) Photographic view of the experimental set-up.

Fig. 1(b) Tool holder and coolant delivery nozzles.

RESULTS AND DISCUSSIONS

The present experimental study involving the turning of anEn34 steel was carried out under dry, wet and cryogenic environments. The experimental results of the cryogenic tool wear, surface finish and tool force have been compared with those of dry machining.

The observation of Nose radius, Dept of Cut, Cutting Conditions on Tool wear

Fig. 2 as seen from the trend the crater wear is decreased with increasing the Nose Radius. This is because small nose radius has less strength and large nose radius has strong edge (Paul. *et.al*, 2001). As seen from the trend the crater wear is decreased from dry to cryogenic and it was least during cryogenic machining. This is because in cryogenic cooling reducing cutting temperature in turning (Dhar *et.al*, 2001). As seen from the trend the crater wear is decreased from dry to cryogenic and it was least during cryogenic machining. This is because in cryogenic cooling reducing cutting temperature in turning (Dhar *et.al*, 2001).

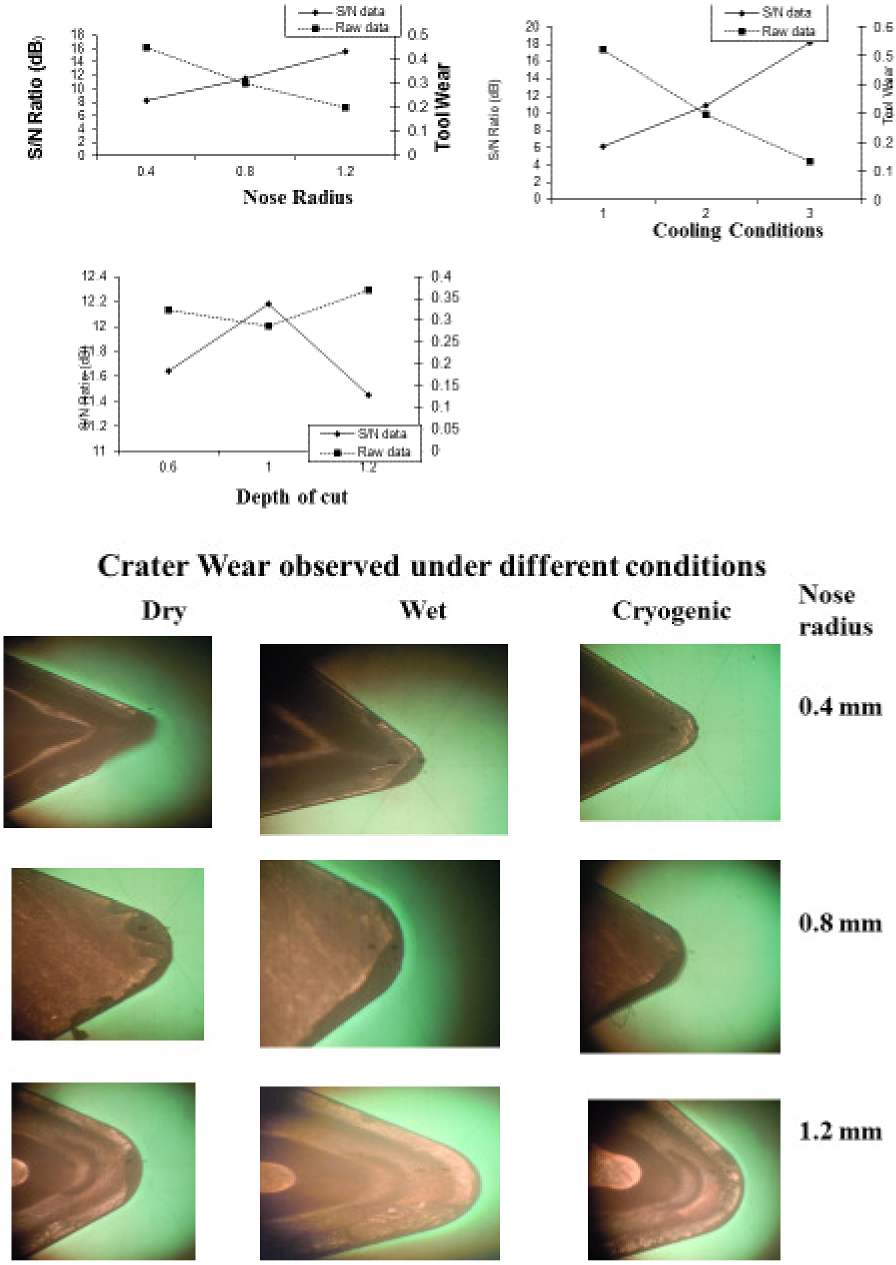

Fig. 2. Effect of Crater wear w.r.t. Nose radius, depth of cut and cooling conditions.

The observation of Nose radius, Dept of Cut, Cutting Conditions on Surface Roughness

Fig. 3 As seen from the trend the surface roughness is increased with increasing the Nose Radius. It is because by increasing the nose radius, area of contact increases which in increases the friction and thus surface roughness increases (Singh *et.al*, 2010). The variation of S/N ratio and surface roughness w.r.t depth of cut and gives the best setting at the largest S/N ratio. As seen from the trend the surface roughness is increased with increasing the depth of cut. The variation of S/N ratio and surface roughness w.r.t cooling condition gives the best setting at the largest S/N ratio. As seen from the trend the surface roughness is decreased from dry to cryogenic and it was minimum at cryogenic machining.

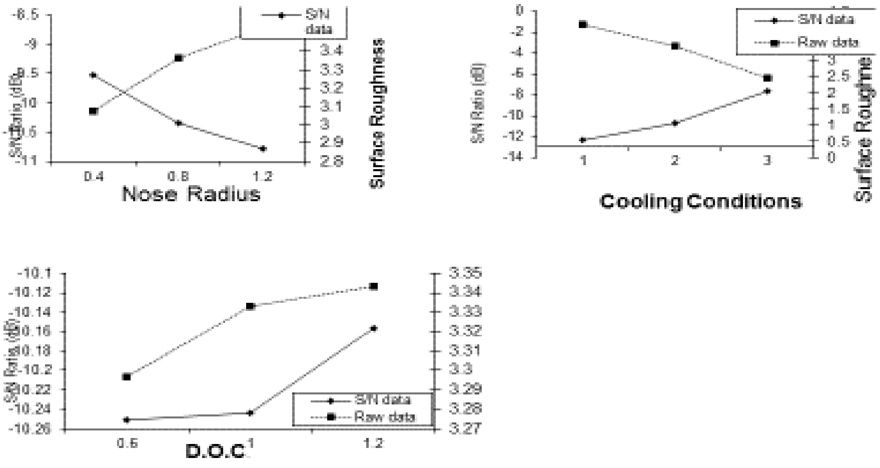

Fig. 3. Effect of surface roughness w.r.t. Nose radius, depth of cut and cooling conditions.

The observation of Nose radius, Dept of Cut, Cutting Conditions on Feed Forces

Fig. 4 shows the variation of S/N ratio and Feed force w.r.t nose radius and gives the best setting at the largest S/N ratio. As seen from the trend the feed force is decreasing with increasing the Nose Radius (Mengliu *et.al*, 2004).The variation of S/N ratio and feed force w.r.t cooling condition gives the best setting at the largest S/N ratio. As seen from the trend the feed force is decreased from dry to cryogenic and it was minimum at cryogenic machining.

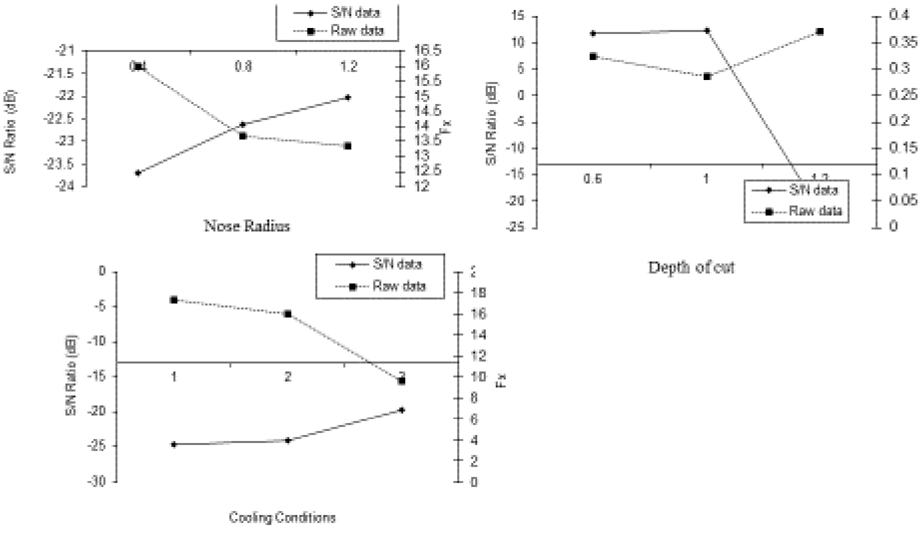

Fig. 4. Variation of S/N ratio and Fx w.r.t. Nose radius, depth of cut and cooling conditions.

CONCLUSION

This present work investigates the effect of cryogenic cooling (LN2) as a cutting fluid in turning En 34 steel material on tool wear i.e. crater wear, surface roughness and cutting forces (feed cutting forces) to dry& wet machining. This resulted in lesser amount of crater wear by producing better surface finishing. LN2 found to be more advantageous for increase in surface finishing. Compared to dry and wet machining, overall the tool wear were based on the confirmation run, the tool wear is decreased 0.75 times.

The surface roughness improvement is 17.84%. Fx force records a decrease of 0.25 times. The experimental results proved that the application of cryogenic coolant overall increases the machining performance of En34 steel using uncoated carbide insert as compared to dry and wet machining.

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