EFFECT OF CRYOGENIC COOLING ENVIRONMENT USING CO2 ON CUTTING TEMPERATURE IN TURNING PROCESS

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ABSTRACT

In this study, the turning process is carried out by machining AISI 1045 steel with the CNMG 120412 multi-coated carbide insert. The machining operations were carried out in different machining environments. The effect of cryogenic cooling with CO2 as the cutting coolants is studied and compared, with dry and conventional wet machining in terms of the cutting temperature. It was observed that cryogenic machining is an effective alternative method, to reduce the cutting temperature arises during the machining process. Reduction of cutting temperature in the range of 9 – 19% was observed at high speed (145 m/min) compared to wet machining. The outcome of the study can be useful for the industry and practitioners to improve productivity and reduce environmental impact due to use of coolant.

INTRODUCTION

High production machining is having high strength and heat resistant materials, is associated with the generation of a large amount of heat and cutting temperature. Such high temperature rise causes dimensional deviation in the work piece and premature failure of the cutting tools. It also impairs the surface integrity of the product. Generally, these problems are controlled by using flood cooling by a conventional coolant. Conventional cooling methods are not only ineffective, but also spoil the working environment by producing harmful gases and smoke.
Many researchers had used cryogenic machining process, and have reported that better tool life, reduced cutting temperature, better surface finish and reduced cutting forces were obtained (De Chiffre et al 2007, Liu et al 2007). Cryogenic machining was carried out earlier in machining steels (Dhar et al 2002), by using liquid nitrogen as the cutting fluid. A review of the above literature suggests that by cryogenic machining the life of the cutting tool gets enhanced with better surface finish, reduced cutting temperature and cutting forces.

LITERATURE REVIEW

Cryogenic machining was first investigated at 1953 by Bartley who used Liquid carbon dioxide as the coolant. Cryogenic machining is a term referred as machining operations conducted at very low temperatures typically lower than 120˚K. Although there are some references in which the cryogenic term is used for higher temperatures. In cryogenic machining a super cold medium, usually liquefied gases, was directed into the cutting zone in order to reduce the cutting zone temperature and cool down the tool and/or work piece. Among potential alternative solutions, the use of cryogenic gases as cutting and grinding fluids, e.g., carbon dioxide and liquid nitrogen, has been known since the early 1950s (Dhar et al 2002). The cryogenic approach is different in that the temperature at the cutting zone is reduced to a very low range. The unsuitability of the conventional cutting fluids led researchers to use cryogenic coolants (cryogen) for machining purposes, and this was successful in exploring favourable cutting conditions.

In the cryogenic pre-cooling method, the work-piece or the chip produced is cooled by using the liquid nitrogen cryogen. The aim of this method is to change the nature of the chip produced during the metal cutting process, i.e., from ductile to brittle, on application of the cryogenic coolant (Hong and Ding 2001). Wang and Rajurkar (1997) investigated the tool wear mechanism in the turning reaction bonded silicon nitride with CBN inserts. It was found that tool life increased due to cooling by liquid nitrogen.

Reddy et al (2008) studied the performance of deep cryogenic treated tungsten carbide cutting tool inserts, in machining C45 steel. The machinability of the work piece is evaluated in terms of flank wear, surface roughness and cutting forces. The cryogenically treated cutting inserts performed better than the untreated cutting inserts. Yakup and Muammer (2008) studied the use of liquid nitrogen and investigated in detail its application methods in material removal operations, and its effects on the cutting tool and work piece material properties, cutting temperature, surface roughness, tool wear/tool life and dimensional deviation, and friction and cutting forces. Ahsan and Mirghani (2008) also said, that the tool life of the cutting inserts was used, improved up to 4 times with the cryogenic cooling approach. In this work, modified cutting inserts used for the supply of liquid nitrogen.

The tool life and tool wear of uncoated carbide cutting tool inserts in machining of Ti-6Al-4V alloy was studied under dry, wet and cryogenic cooling environments by Venugopal et al, (2007). A substantial improvement in tool life was noticed under cryogenic cooling compared to dry and wet machining. Pusavec et al (2010) presented a case-study that highlight the importance of sustainable machining technologies in achieving sustainable development objectives. a sustainability estimation of cryogenic and high pressure jet-assisted machining in comparison to conventional machining was examined. It was observed that sustainable machining alternatives offer a cost- effective route to improving economic, environmental, and social performance in contrast to conventional machining. Liu et al (2010) also used carbon dioxide as one of the cutting coolants, and examined its performance in terms of surface roughness and tool wear. The use of CO_2 as the cutting coolant produced a lower friction coefficient, improved surface finish and reduced tool wear. Shokrani et al (2012) studied CNC end milling of the Inconel 718 nickel based alloy using TiAlN coated solid carbide tools. The experimental investigations told that cryogenic cooling has a significant potential to improve surface roughness of machined parts as compared to dry machining.

Thus the review of the literature suggests that cryogenic machining is the most favourable alternative process for conventional cooling, in terms of reducing the cutting temperature, cutting forces, and tool wear, and improving the surface roughness. Cryogenic cooling is an environment-friendly clean technology for achieving desirable control of cutting temperature and enhancement of tool life. However, more work is needed to explore the potential advantage of cryogenic cooling. Hence, in this study, experimental work is carried out to investigate the performance of cryogenic CO_2 as coolant in reducing the cutting temperature. The results obtained with the use of cryogenic carbon dioxide coolants are compared with those of dry and wet machining.

EXPERIMENTAL SET-UP AND PROCEDURE

In this research work, experimental work has been carried out by turning AISI 1045 steel work-pieces at different speed-feed combinations. All the work-piece materials were machined under different machining environments, like dry machining, conventional wet machining, and machining using cryogenic CO2 as coolant. Cutting temperature parameter was analysed in cryogenic machining conditions, using carbon dioxide as the cutting coolants, and are compared with those of conventional and dry machining. In this study solid AISI 1045 steel of 60 mm external diameter and 300 mm length were used in the turning operation. The experimental conditions used for carrying out the machining are shown in Table1

Table 1 Experimental conditions used for carrying out the machining

Work piece material	Cutting tool Insert	Cutting Velocity (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutting Environment
AISI 1045	CNMG 120412-MP K10 (Taegutec)	41, 94 and 145	0.051, 0.096, 0.143 and 0.191	1 mm	Dry, Wet, cryogenic CO_2 as coolant

Turning experiments was carried out using tungsten carbide cutting tool inserts on Nagmati - 175 centre lathe having 8 spindle speeds and 32 table feeds with a maximum of 1200 rpm. Multi-coated carbide cutting tool insert was used due to its use in turning AISI 1045 steel. The schematic diagram of the cryogenic cooling setup for supplying carbon dioxide as shown in fig.1.

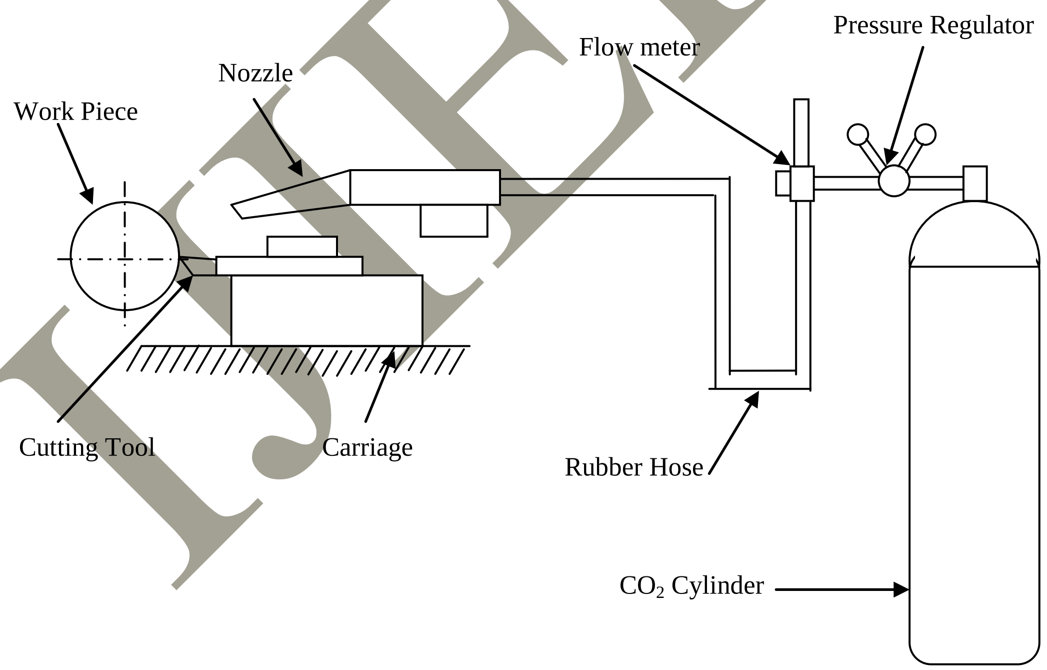

Figure1 Schematic diagram of the cryogenic cooling setup

The cutting temperature at the chip-tool interface measured by using a calibrated non-contact type infrared thermometer. The accuracy of the instrument is ± 1.0% of the reading.

MATHEMATICAL MODEL

The dependent variables cutting temperature (CT) can be considered as a linear combination of the independent variables, namely feed rate (f), cutting speed (Vc) and cooling conditions (Cc). To determine the coefficients of equation, least square method is taken in multiple linear regression analysis. Thus, general equation can be obtained:

$$Y = A + B_1 V_c + B_2 f + B_3 C_c \quad \text{......................................} (1)$$

where Y is the corresponding response or dependent variable i.e., CT, A is constant called the intercept of the plane, B1, B2 and B3 are the regression coefficients depends upon main parameters. The given equation is called multiple linear regression model. Above studies shown that the cutting speed is the most dominate factor influencing cutting force and surface finish, followed by feed and depth of cut, in that order (Neseli et al, 2011). Hence the cutting speed and feed rate were varied keeping the depth of cut constant. The Taguchi parametric approach is applied to find out the optimum results. Experiments were carried out under the constraint of processing parameters and their levels (as shown in Table 2) by following Taguchi orthogonal array.

Table 2 Three level and three parameters for Taguchi Orthogonal array

Sr. No.	Cutting speed (mm/min)	Feed (mm/rev)	Cooling conditions
1	141	0.179	Dry
2	91	0.205	Wet
3	57	0.248	Cryo

Table 3 Observation table for the response variables

Expt No	Input Variable			Out put
	F	V	Cc	CT
1	41	0.051	1	58.6
2	41	0.096	2	39.7
3	41	0.143	3	40.2
4	41	0.191	2	65.3
5	94	0.051	3	45.7
6	94	0.096	1	99.4
7	94	0.143	3	71.9
8	94	0.191	1	128.7
9	145	0.051	2	79.2
10	145	0.096	1	115.8
11	145	0.143	2	117.2
12	145	0.191	3	112.8

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By using the least square method to the observed data (Table 3), following regression equations 1 is obtained between input parameters and cutting temperature. The equations are developed using MINITAB 16 statistical analysis software. The outcome of the Minitab regression is as followers

$$CT = 35.1 + 0.533\ Vc + 303\ f - 20.0\ C_c \qquad (2)$$

The validation of the model formulated for cutting temperature is shown in figure 2. The model regression coefficient calculated using Microsoft excel is 0.9835 with R Square value of 96.7 %. This validates the model formulated.

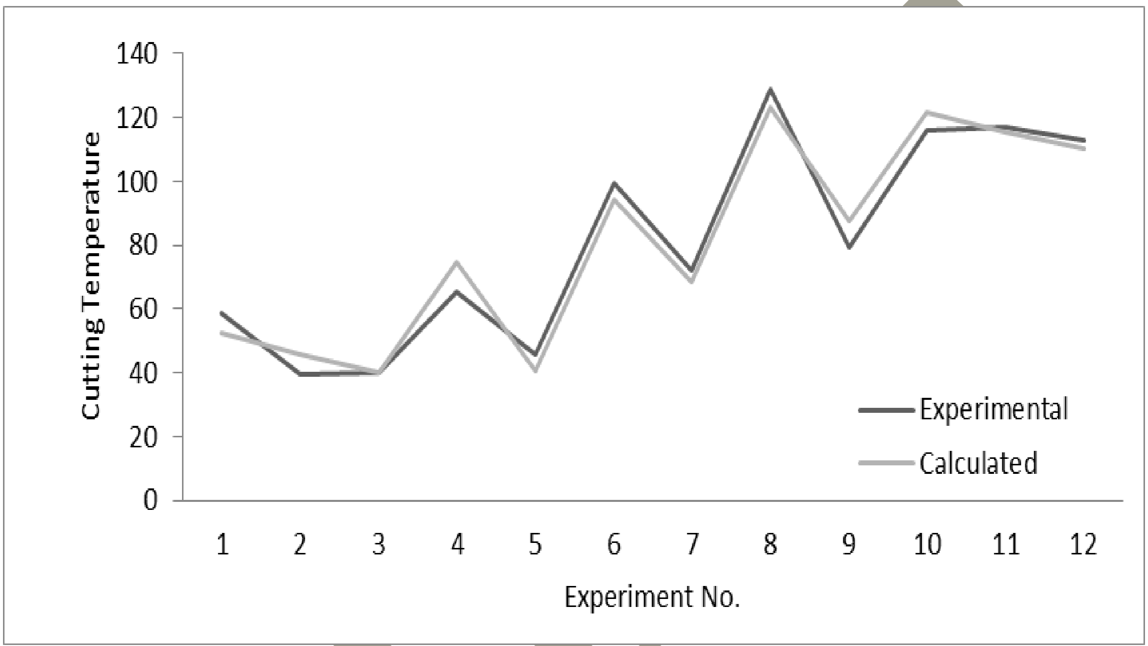

Figure 2 Validation of cutting temperature model

RESULTS AND DISCUSSIONS

The result obtained in cryogenic machining is compared with that of dry and conventional wet machining, and is discussed below. The effect of the cutting temperature with feed rate, and cutting velocity in machining AISI 1045 steel under different machining environments is shown in Figures 3

It is viewed that the cutting temperature increases with the increase in feed and speed. The results indicate that there is a reduction in the cutting temperature at cryogenic CO2 machining in the range of about 9 to 25%, when compared to wet cutting, depending on the other machining parameters, like cutting speed and feed rate. . It is also observed that the percentage of reduction in the cutting temperature is in the range of about 10 – 25% at low speed (41 m/min) when cryogenic CO2was used as the coolant, whereas a reduction of cutting temperature in the range of 9 – 19% was observed at high speed (145 m/min) compared to wet machining.

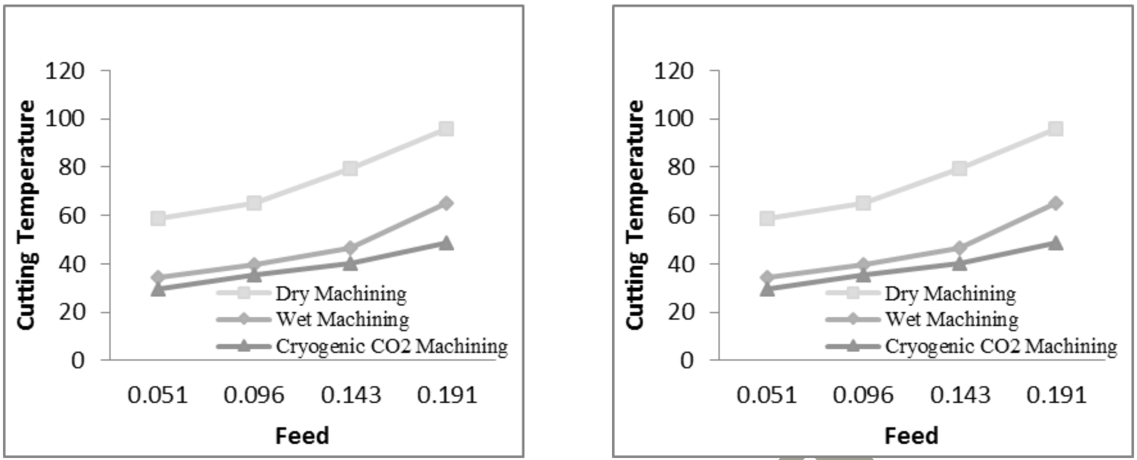

Figure 3 Variation of the cutting temperature while machining AISI 1045 steel with different feed rates under different machining conditions (a) 41 m/min (b) 94 m/min

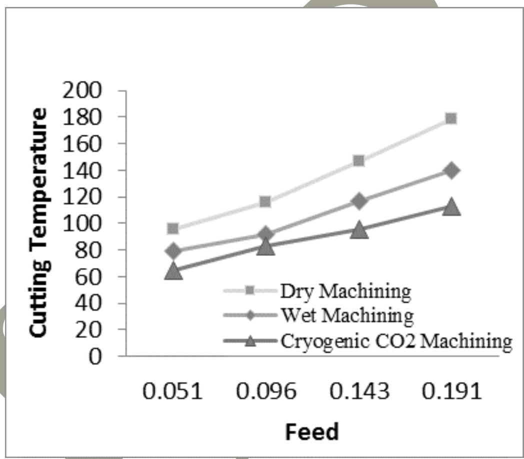

Figure 3 Variation of the cutting temperature while machining AISI 1045 steel with feed rates145 m/min under different machining conditions

CONCLUSION

On the basis of various experiments carried out and the analysis of results, the following conclusions can be drawn

1) Cryogenic machining is an effective another method, to reduce the cutting temperature arising during the machining process.

2) Cutting temperature in cryogenic CO2 machining in the range of about 9 to 25%, when compared to wet cutting, depending on the other machining parameters, as cutting speed and feed rate. When cryogenic CO2 was used as the coolant, whereas a reduction of cutting temperature in the range of 9 – 19% was observed at high speed (145 m/min) compared to wet machining.

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