Experimental Study to Improve the Machining Performance of EN-9 Material Using Carbon Dioxide

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Abstract-*The most widespread metal shaping process in industry is machining which includes boring, drilling, turning, shaping, milling etc. Most of the machining processes produce high temperature and stresses which effects very badly on tool life, form accuracy and surface integrity. To overcome it, various types of cutting fluids are used which are not user as well as environment friendly. Therefore, researchers are evaluating possible environment friendly alternatives which includes gases as cutting fluid which are pollution free, eco friendly as well as are good coolants. But still there is need to improve the machining performance with the applications of gases and increase the life of a cutting tool for which the cutting tools are cryogenically treated to enhance the performance . The cryogenic treatment improves the properties of the tool material.*

In the present experimental investigation, study the machining performance of cryogenic cubic boron nitride as a tool and EN-9 material as work piece using environment of carbon dioxide. The experimental study reveals that using cryogenic technology has effects on Cutting forces and Tool wear.

Keywords: Cutting speed, Feed, Depth of cut, Cutting forces, Tool wear.

I. INTRODUCTION

Cryogenic treatment is used on several types of materials to improve their performance in their various applications. Cryogenic treatment is the process of reducing the temperature of material over an extended period of time to extreme cold levels, usually slightly below −190 °C.

The cryogenic treatment has a wide range of applications. Some of the benefits of cryogenic treatment include longer part life, less failure due to cracking, improved thermal properties and better electrical properties including less electrical resistance, reduced coefficient of friction, less creep, improved flatness, and easier machining. It has been found and proved that cryogenic treatment improves wear resistance of many alloy steels and cubic boron nitride to a great extent. Cryogenic treatment has been widely adopted as a cost reduction and performance enhancing technology. Cryogenic treatment is also used as an enabling technology, when its stress relieving benefits are utilized to permit the fabrication or machining of critical tolerance parts. Generally, the cryogenic treatment improves the properties of the tool material. The cryogenic treatment improves tool wear resistance, surface finish of work piece material and reduces cutting forces.

The study of literature review states that life of the cutting tool plays a major role in increasing productivity and minimizing costs in machining processes. Researchers have performed a lot of work to study and improve the wear resistance of cutting tools and other machining output parameters of various materials by different approaches, which also includes modified cutting tool materials like cubic boron nitride and cryogenic cubic boron nitride. In the area of cutting tool technology, cryogenic treatment has been extensively studied on tool steels. But, a few researchers have studied the impact of cryogenic treatments on cubic boron nitride which is one of the most widespread tool materials in use today.

Arsecularatne J.A. et al. [1] investigated the wear mechanisms of cutting tools made of tungsten-carbide (WC), PCBN and PCD using the tool life and temperature criteria. For tool/work combinations WC/steel and PCBN/hardened-steel, under practical conditions, tool wear was found to be greatly influenced by the temperature. It was concluded that the most likely dominant tool wear mechanism for WC was diffusion and that for PCBN was chemical wear. For PCD, more experimental results and further research was required to determine the dominant wear mechanism as suggested by them.

Arner K.A. et al. [2] examined five different style cryogenic-treated tungsten carbide inserts in full production operations and confirmed very consistent changes in overall tool life; however, the amount of improvement was dependent on the tool style.

Cakir O. et al. [3]investigated the effects of cutting fluid, some gases applications and dry cutting on cutting forces, thrust forces, surface roughness, friction coefficient and shear angle in turning of AISI1040 steel material with P20 grade cutting insert. Nitrogen, oxygen and carbon dioxide gases instead of cutting fluid have been used and the results were compared to wet and dry machining processes. The carbon dioxide gas produced lower friction coefficient and higher cooling effect. These effects caused the lowest cutting force in carbon dioxide gas application as compared to other gases.

Dhar N.R. et al. [4] investigated experimentally the effect of minimum quantity lubrication on tool wear and surface roughness in turning AISI-4340 steel at industrial speed-feed combination by uncoated carbide inserts. The results have been compared with dry machining and machining with soluble oil as coolant. The selected cutting speed was 110 m/min, feed 0.16 mm/rev and depth of cut 1.5 mm. The pressure of the air-oil mixture was kept at 7 bar. The results indicated significant reduction in tool wear rate and surface roughness as compared with dry machining and machining with soluble oil as coolant. The reduction in tool wear rate and surface roughness was due to decrease in the cutting zone temperature and favorable change in the chip-tool and work-tool interaction.

Liu J. et al. [5] investigated the effects of carbon dioxide gas, oxygen gas, water vapor and mixture of vapor and gas on main cutting force, cutting temperature, chip deformation coefficient, rake face wear, and tool flank wear in turning ANSI 1045 steel material with cemented carbide tool. The cutting force was reduced about 20–40% with application of water vapor, gas and mixture of vapor and gas as coolant and lubricant than dry cutting and similar case with cutting temperature. The tool life was extended longer on applications of water vapor, and mixture of vapor and gas than dry cutting. The tool life extended about more than two times at high cutting speed and about two times at low cutting speeds with application of water vapor than dry cutting. The diffusion and adhesion was alleviated with application of water vapor because of chemical reaction between water vapor and metal surface and forming boundary lubrication layer. The tool wear can be reduced with application of carbon dioxide gas or water vapor in machining carbon steel.

Reddy T.V.S. et al. [6] carried out experiments on cryogenically treated P-30 tungsten carbide inserts to study the improvement in tool life. The work piece material selected was C45 steel, the cutting speeds chosen were 200, 250, 300 and 350 m/min. The cutting conditions and geometry were held constant throughout the test. From their results, they observed the improvement in life of untreated and deep cryogenically treated carbide inserts was by an amount of 9.58% and 21.8% respectively. The increase in tool life may be due to the structural changes in tool materials. The main cutting forces were also reduced when compared to untreated inserts. They concluded that precipitation and distributions of the phase after cryogenic treatment have improved the flank wear resistance.

Stewart H.A. [7] applied cryogenic treatment to tungsten carbide (6% Co) cutting tools and compared with untreated carbide cutting tools. The objective of the study was to determine whether tool wear could be reduced during turning tests with medium density fiberboard. Both the tool force data and observation of the cutting edges indicated that tool wear and cutting force were reduced. He believed that the cryogenic treatment appeared to have an effect upon the cobalt binder by changing phase or crystal structure so that more cobalt binder was retained during cutting.

Ramji B.R. [8] studied the effect of cryogenic treatment on the performance of coated carbide inserts in turning grey cast iron work piece. The used cutting speeds were 33.18, 21.10, 11.30, 5.94 m/min and the applied feed was 0.12 mm/rev. The selected depth of cuts were 1.5, 2, 2.5, 3 mm.The cryogenically cubic boron nitride showed lesser flank wear and reduced surface roughness as compared to non treated inserts.ANOVA indicated that cryogenic treatment on cbn was the only factor that influenced more, cutting velocity influenced tool tip temperature and cutting forces where as depth of cut affected mainly on flank wear and surface roughness. Cryogenic treatment significantly influenced cutting force, tool tip temperature, surface roughness and flank wear.

II. PROBLEM FORMULATON

The review of literature clearly indicated the machining of several engineering materials have been greatly improved by the new cutting tool materials like cubic boron nitride, cryogenically cubic boron nitride even in some case of difficult-to-cut metals. There are still some problems in machining processes which includes high temperature rise, dimensional accuracy and surface quality etc. The coolant effect reduces temperature in cutting zone and the lubrication action decreases cutting forces. However, as technology improves and cutting speeds in machining are increased, it was found that conventional cooling techniques, which include flood coolant techniques, tend to be detrimental to tool life. This is due to the inability for the coolant to reach the cutting edge at such high cutting speeds. Therefore, new methods of cooling are there out of which one is cryogenic treatment of cutting tools. It is on the whole is not a new process. The cryogenic treatment improves the properties of the tool material. The cryogenic treatment improves tool wear resistance, surface finish of work piece material and reduces cutting forces. Cryogenically treated tools perform better when the tool temperature is kept low. Their effectiveness can be extended if coolants or suitable methods of cooling are used to keep the tool temperatures low.

The review of literature also indicated that application of gases as a cutting fluid reduces the cutting zone temperature very effectively. Gases are pollution-free, eco-friendly and are good coolant and lubricant. The application of gases produced lower cutting force, improves the roughness of the finished surface, and reduces the tool wear. These effects caused the lowest cutting force in carbon dioxide gas application as compared to other gases.

The literature review also indicated that indicated that cryogenic treatment has been acknowledged as a means of extending the life of cubic boron nitride but no study has been reported in open literature regarding the effect of gases as a coolant on the performance of cryogenically treated cubic boron nitride in turning. So, the present work is based on some experimental investigation on the effect of carbon dioxide gas on the performance of cryogenically treated cubic boron nitride in turning. The experiments were performed at different input parameters i.e. cutting speed, feed and depth of cut and compared with dry machining. The effect of these parameters on cutting forces and tool wear were evaluated as per Taguchi design.

III. EXPERIMENTAL SET-UP

In the experimental investigation, the EN-9 material is used as the work piece material and Cubic Boron Nitride is used as the tool material. In Experimental investigation, Dry and carbon dioxide gas are used as varying parameters to evaluate the machining performance. The cutting force was measured by using a dynamometer for each machining condition and the flank wear was measured using metallurgical microscope as shown in fig.

the photographic view of metallurgical microscope

IV. WORK PIECE AND TOOL

The material selected for the experiments is EN9 steel having hardness of 33HRc. The EN9 steel is mostly used for the manufacture of crankshaft, screw, axes and shafts. The chemical composition of work piece material is C- 0.58%, Si- 0.28%, Mn- 0.72%, P- 0.004% and S- 0.004% where as tool material used is cubic boron nitride. These cutting tools were deep cryogenically treated. It has high hardness and high thermal conductivity. It has much higher tensile strength.

V. GASES

The carbon dioxide gas is used in this investigation. Nitrogen gas is used to compare its effectiveness with dry environment.

VI. SET-UP AND EXPERIMENTAL PROCEDURE

EN9 steel by cryogenically cubic boron nitride under both dry and gaseous cooling environments. For this experimentation a high power rigid lathe of HMT (LB-17 model) was used. The cutting tools were purchased from Mitsubishi, India.

For cooling and lubrication, carbon dioxide gas was used along with the dry environment. These gases were impinged from a mild steel nozzle having diameter 1.40mm. The pressure of nitrogen and carbon dioxide gases has been kept at 3 bars. The material selected for the experiment was EN9 steel having diameter 67mm and length 640mm.

The response parameters analyzed were cutting force and tool wear. The cutting force was measured by using a dynamometer for each machining condition. The tool was attached on dynamometer and static calibration of the system was completed before experiment. The flank wear was measured using metallurgical microscope (YUCON Japan). The effect of input parameters on cutting force and tool wear were evaluated as per Taguchi design, using L27 orthogonal array.

Input machining parameters at different levels

S. No.	Factor	Level-1	Level-2
1	A:Cutting Speed	28	63
2	B: Feed (mm/rev)	0.050	0.075
3	C: depth of cut (mm)	0.5	1.5
4	D: Environment	Dry	Carbon Dioxide Gas

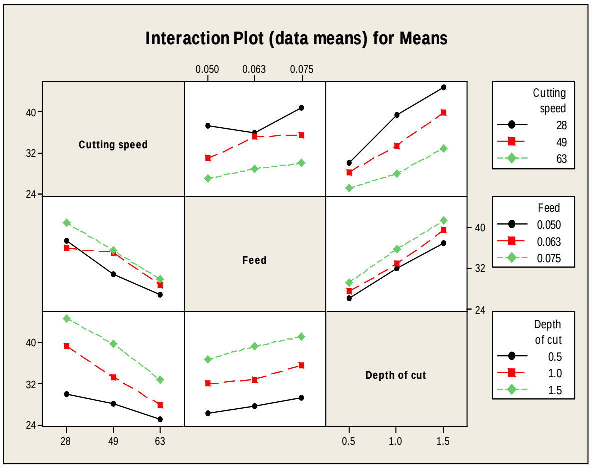
VII. EXPERIMENTAL OBSERVATIONS

Exp.	A: Cutting	B: Feed	C: Depth of	D:	Response-1 Cutting	Response-2 Tool

No.	Speed (m/min)	(mm/rev)	Cut (mm)	Environment	forces (kgf)	wear (mm)
1	28	0.05	0.5	Dry	32.7	0.319
2	28	0.05	1.5	Co_2	40.6	0.347
3	28	0.063	1	Co_2	34.2	0.312
4	28	0.063	1.5	Dry	46.7	0.357
5	28	0.075	0.5	Co_2	30.2	0.306
6	28	0.075	1	Dry	45.2	0.354
7	49	0.05	1	Co_2	29.1	0.335
8	49	0.05	1.5	Dry	36.5	0.399
9	49	0.063	0.5	Co_2	25.2	0.322
10	49	0.063	1	Dry	35.2	0.402
11	49	0.075	0.5	Dry	32.5	0.361
12	49	0.075	1.5	Co_2	38.2	0.391
13	63	0.05	0.5	Co_2	19.1	0.317
14	63	0.05	1	Dry	28.2	0.398
15	63	0.063	0.5	Dry	30.7	0.356
16	63	0.063	1.5	Co_2	26.5	0.407
17	63	0.075	1	Co_2	26.2	0.379
18	63	0.075	1.5	Dry	38.5	0.453

VIII. RESULTS

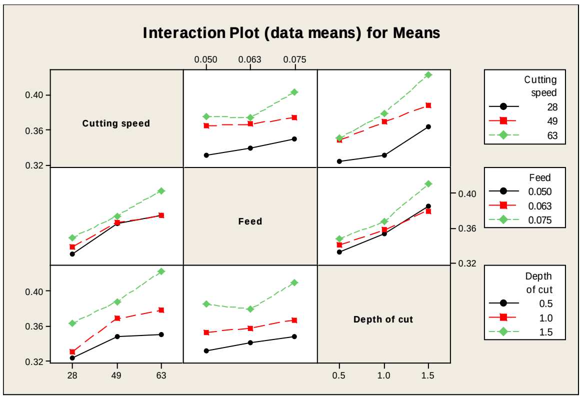
8.1 Effect of cutting forces



Interaction plot for means for cutting forces

The cutting force found decreased with the increase in speed. In case of gases application, the lowest cutting force was achieved by using carbon dioxide gas as a cutting fluid as compared to nitrogen gas and dry turning. This was due to more cooling and lubrication effect produced by the use of carbon dioxide gas which reduced the coefficient of friction at the interface of the tool and chip over the rake face. The cooling effect produced by the carbon dioxide gas appears to be more effective in reducing cutting force at comparatively higher cutting speeds.

8.2 Effect on Tool Wear



Interaction plot for means for tool wear

The lowest tool wear was achieved by using carbon dioxide gas as a cutting fluid. It was probably due to the reason that at lower cutting speeds, the temperature of the tool tip may never be high enough compared to ambient temperature to cause the noticeable positive effect of the coolant. It is apparent that the cooling effect produced by gases neutralized the adverse effect of possible higher tool chip interface temperatures during machining. This reduction in the temperature thus helped in restricting flank wear of the cutting inserts.

IX. CONCLUSIONS

In the present research work, an attempt has been made to study the effect of carbon dioxide gases on the performance of cryogenically Cubic boron nitride insert in turning EN9 steel. The results were compared with dry turning. The following conclusions are drawn.

1. Tool wear and cutting force have been reduced by the application of gases when compared with dry machining.

2. Depth of cut has the maximum influence under all machining conditions.
3. Cryogenically cubic boron nitride perform better by using carbon dioxide gas as compared with nitrogen and dry turning environments.
4. Maximum contribution using carbon dioxide was up to 14.35 % in improving tool life.

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