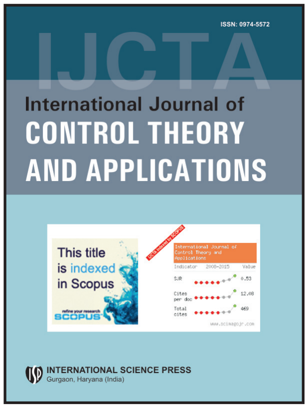

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Advanced Intelligence for Cryogenic Cooling in CO_2 and Performance Analysis of TiN Coated Insert in Conventional Milling of AISID$_2$ Steel

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Abstract:

Aim: Without coolant in machining it will affect the tool life, dimensional accuracy, cutting temperature, surface roughness and productivity of any product. So, the main aim of this study is to measured and analyze cutting temperature, cutting force, Surface roughness, tool wear and study of chip morphology by different cutting environment such as dry, wet, and cryogenic CO_2 by using conventional Milling machine, and compared with result. Finally SEM observation has to be done to analyses the tool wear and chip morphology.

Materials and methods: In this research work, the size of the work materials used was AISI D2 Steel of size is 150 mm × 50 mm × 50 m with SANDWIK make CVD TiN coated carbide cutting tool insert was used. The time taken for machining is 5 minute and depth of cut were maintain 0.6mm with different lower cutting speed and different feed rate.

Results: The use of cryogenic CO_2 cooling in the present work shown in deflation in cutting temperature in the range of 12.5-25% & 6.67-20% respectively as differ to dry and wet machining, and also application in the CO_2 reduces the cutting force 12-17% in dry and 8-13.5%in wet condition. Surface finish of the machined material is improved at an extraordinary level. Tool wear also was detected to be low on the application of CO_2.

Conclusion: Under this chosen cutting condition cryogenic CO_2 is the excellent choice for reducing the cutting force, tool wear, and cutting temperature and improved in surface roughness, since the higher cutting temperature requires the higher cooling effect.

Keywords: Cryogenic milling CO_2, Cutting temp, cutting force, surface roughness, Tool wear, chip morphology.

1. INTRODUCTION

The conventional machining leads a major role in the small scale industries, but small scale industries reinforcement the problems in machining are high cutting temperature affects tool wear, dimensional accuracy, surface roughness of the product, excessive tool wear cause cutting tools failure. And poor chip formation therefore the cooling tasks in machining operations plays main role and many operations cannot be worked out perfectly without cooling. So it is necessary to apply the cutting fluids to reduce the friction, and remove the heat as early as possible. Yakup yildz et. al., (2008), and Paul et. al., (2002) suggested that coolants cause various chemicals that may cause water pollution, soil contamination and health hazards if disposed without required treatments. Another way of minimize the cutting temperature is to use a cryogenic coolant,

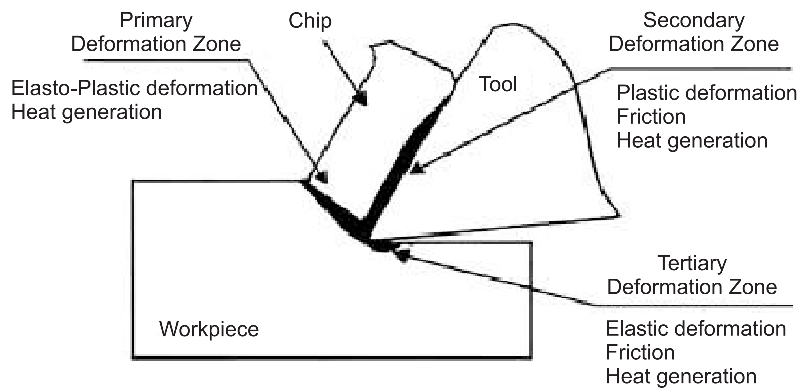


Figure 1: Chip formation and heat generation in metal cutting

Cryogenic machining is subjected to refer a machining operation which is examined at very low temperature at lower than 120°K. In cryogenic medium is an excellent cold medium liquefied gases is passed into the cutting zone and it mop up the heat on the cutting zone finally it evaporates into the atmosphere or influence. Many of the author's had used cryogenic process and have decribed that better tool life, reduced cutting temperature, better surface finish and reduced cutting focess were gained (De Chiffre et. al., 2007) The research paper suggest that cryogenic coolants provide a several benefit in machining as compared to other cooling process in machining. In the machining process both nitrogen and carbon dioxide are used as cryogenic coolant, because these CO_2 coolants are environmental-friendly clean tech for achieving recommendable control for cutting temperature and inflation of tool life.

In this study experimental work is carried out in conventional milling under dry wet and cryogenic CO_2 cooling with AISID_2 steel with CVD TiN coated insert tool at different speed, and feed combination

1. To study cutting temperature using K-type 6 channel thermocouple.
2. To study the cutting force using milling tool dynamometer
3. To study the surface roughness parameter by using surface roughness tester equipment
4. Scanning electron microscope (SEM) images are used to study the chip morphology
5. To study the tool wear using tool microscope and tool wear images in Scanning Electron Microscope (SEM)

This research paper ensure as follows: In section II explained about literature review. In section III explains about Material and experimental methodology. In section IV Results and discussion are segmented about cutting temperature, cutting force, surface roughness, tool wear, and chip morphology, and last section V conclusion of the paper.

2. LITERATURE REVIEW

The milling process compare to other machining process is very slow and having a low production rate and therefore various research scholar and engineers are try to overcome with effects of tool selection and try to control high cutting temperature using in place of different coolant. The key functions of cryogenic cooling in the metal cutting Process is to remove the heat excellently from the cutting zone, dropping the cutting forces and transforming the frictional characteristics at the chip-tool boundaries and finally this cryogens evaporate into the air

Sandeep Kumar et. al., (2016) differed to dry, wet & LN2 machining, total tool wear is decreased 0.75 times. The surface roughness improvement is 17.84%. Fx force records a decrease of 0.25 times and also he evidenced that the application of cryogenic coolant largely increases the machining performance as compared to dry & wet machining.

Bolewar A.B et. al., (2016) observed that cryogenic machining is an alternative technique to reduce cutting temperature arises through 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.

Munish Gupta et. al., (2015) conduct the Experimental Investigation of Machining AISI 1040 Medium Carbon Steel Under Cryogenic Machining and Compared with Dry Machining concluded that total tool wear were reduced to 55.45 and 65.53 %, surface roughness was reduced to 125.90 % and forces were reduced to 61.94 and 96.60 %.therefore The experimental results showed that the application of cryogenic coolant shows the complete growths in the machining performance as compared to dry machining.

Akshaya T Poojary et. al., (2014) “Investigation on machinability of AISI 1040 steel” observed that the cutting forces were less at high speed in cryogenic machining, and also concludes that a remarkable surface finish can be obtained adopting cryogenic cooling (dip method).

Sunil Magadum et. al., (2014) “Cryogenic Machining of SS304 Steel” Coated carbide CNMG 120404 Insert was used as a cutting tool. Tool wear, tool life and cutting forces were measured. The results have revealed that cryogenic machining has yielded better tool life as compared to conventional flood machining.

Ampara Aramcharoen et. al., (2014) “An Experimental Investigation on cryogenic milling of Inchonal 718 and its sustainability assessment” concluded that results demonstrated that the cryogenic cooling is promising for machinability and sustainability a compared to the oil based coolant and dry cutting in term of tool wear reduction, less friction at secondary deformation zone, lower energy consumption and contamination-free on machined part.

B. Dilip Jerold and M. Pradeep Kumar et. al., (2011) Investigated the performance of cryogenic coolant such as CO_2 and LN_2 in turning of AISI 1045 steel reported to cryogenic CO_2 reduces the cutting forces to about 2-12% and enhanced the surface roughness 2-14% of the machined part. Tool wear also be fewer on the application of CO_2 as compared to the wet and LN_2.

Ravi S. and Pradeep Kumar M. et. al., (2011) “Effects of liquid nitrogen on cryogenic machining of AISI D2 hardened steel” concluded that LN_2 as a coolant the cutting force and work piece surface roughness were minimized compared to dry & wet machining due to improved lubrication and cooling effect over a reduction of cutting zone temperature.

M. Dhananchezian, M.Preadeep Kumar, (2011) Study the Effect of Cryogenic Cooling With Modified Cutting Tool Insert in the Turning of Ti-6al-4v Alloy” proved that cryogenic cooling with a reformed cutting tool insert have shown well results on the cutting temperature, cutting force and surface roughness over wet machining.

Trausti stefansson et. al., (2011) “Application of cryogenic coolants in Machining process” SANDVIK coroment, [4] reported using a cryogenic cutting fluids for machining has a great technological and economical potential and it depends upon work piece material, cutting tool material, design of the tool & process parameter.

Dhananchezian et. al., (2009) conducted ”Experimental Investigation of Cryogenic Cooling by Liquid Nitrogen in the Orthogonal Machining Process” witnessed that in cryogenic cooling method, the temperature was reduced to 19–28% and the cutting force was improved to a maximum of 15% then dry machining of AISI 1045 steel. In machining of Aluminum 6061-T6 alloy.

3. MATERIALS AND EXPERIMENTAL METHODOLOGY

3.1. Work Piece Material

Harry Chandler et. al., (1995) Tool and die steels are high-carbon high-chromium steel and is having high hardness strength and wear resistant. AISI D2 steel is the most alloyed cold work tool steel. This steel is high in both element of carbon and chromium for the purpose of forming high volumes of secondary chromium carbides as a result of the convective process produce the carbides during the tempering procedure. This occurs rise to a high wear resistance steel. The work piece made for the work materials is Blanking & punching dies with excellent holding properties, abrasion resistance & dimensional stability. In this research work, the size of the work materials used was 150 mm × 50 mm × 50 mm. Mechanical properties and chemical composition of AISI D2 Steel are given bellow in the Table 1 and 2.

Table 1
AISI D2 Steel – Chemical composition

Element	*Amount (%)*
Carbon	1.50 – 1.70
Silicon	0.10 – 0.35
Manganese	0.25 – 0.50
Chromium	11.00 – 13.00
Molybdenum	0.80 max
Vanadium	0.80 max
Iron	Balance

Table 2
Mechanical properties of AISI D2 Steel

Mechanical Property	*Metric Value*
Hardness Rockwell C	62
Density	7.7 × 1000 kg/m^3
Poisson ratio	0.27 – 0.30
Elastic modulus	190 – 210 GPa
Thermal conductivity	20 (W/mK)

3.2. Cutting tool

Milling experiments has been worked out using index able cutting tool inserts, in this experiment inserts have been used in the research work are SANDWIK make CVD TiN coated carbide cutting tool insert of R390-11 T3 08M-PM-1025. Figure shows the cutting tool inserts are used in this experiment.

Figure 2: Photo graphic view-cutting tool insert

3.3. Tool Holder

A common tool holder was used for machining all the three work pieces, in all the cutting conditions. The complete specifications of the tool holder are given below and Figure shows the photographic view of the tool holder.

Tool Holder Specification

Shank diameter	: 16 mm
Overall length	: 50 mm
Head length	: 27 mm
Number of inserts	: 2

Figure 3: Tool holder Insert

3.4. Experimental Methodology

The experimental methodology for cryogenic machining is explain bellow in the line chart in Figure 4.

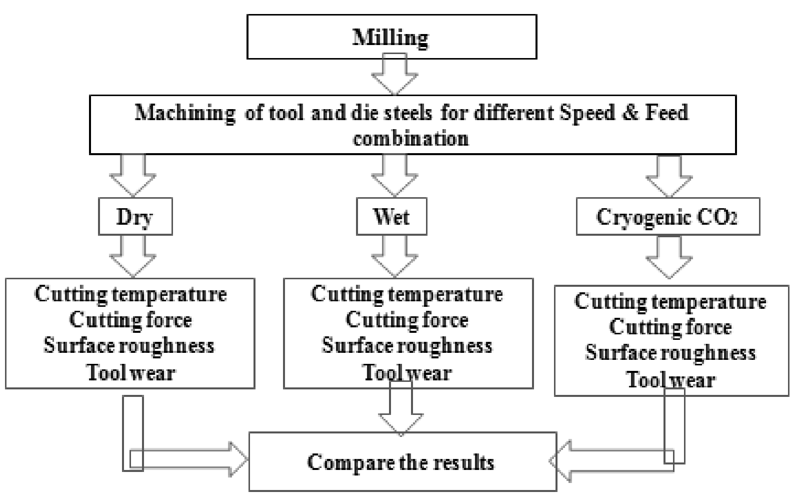


Figure 4: Line chart for Experiment Methodology

3.5. Experimental Condition

The experimental conditions for cryogenic machining is given bellow in the Table 3.

Table 3
Experimental Condition

Work piece material & size	AISI D2 steel 50 × 50 × 150 mm
Cutting tool insert	SANDVIK R390-11-T308-MPM 1030
Cutting velocity (m/min)	17.84 m/min, 45.24 m/min, 70.37 m/min
Feed rate (mm/rev)	0.034 mm/rev, 0.074 mm/rev, 0.150 mm/rev
Depth of cut (mm)	0.6 mm
Machining Time	5 min

3.6. Cryogenic Milling CO_2

The experimental setup for cryogenic milling CO_2 is as shown below. For measuring the cutting forces milling tool dynometer and tool-chip interface temperature was estimated by 6 channel K-type thermocouple are employed and Carbon dioxide cylinder connected with the accessories is as shown in bellow Figure 5. (Photographic view)

Figure 5: Cryogenic CO_2 Setup

In this method CO_2 Cylinder is attached with pressure regulator the regulator used for this purpose consists of two dial indicators, one indicating the cylinder pressure and the other indicating the supply pressure next to the regulator. Carbon dioxide flow meter is attached to measure the amount of flow of the carbon dioxide coolant. One end of a rubber hose is connected to the outlet of the flow meter, and the other end to valve for to stop the flow, from the valve nozzle is connected to point towards the cutting zone to supply the Cryogenic CO_2 while the machining operation is carried out.

4. RESULTS AND DISCUSSION

Milling experiments were carried out in four different work-tool combinations under dry, wet and CO_2 cooling for analyzing the tool wear. In the milling of AISI D2 Steel with a CVD TiN coated carbide tool of R390-11

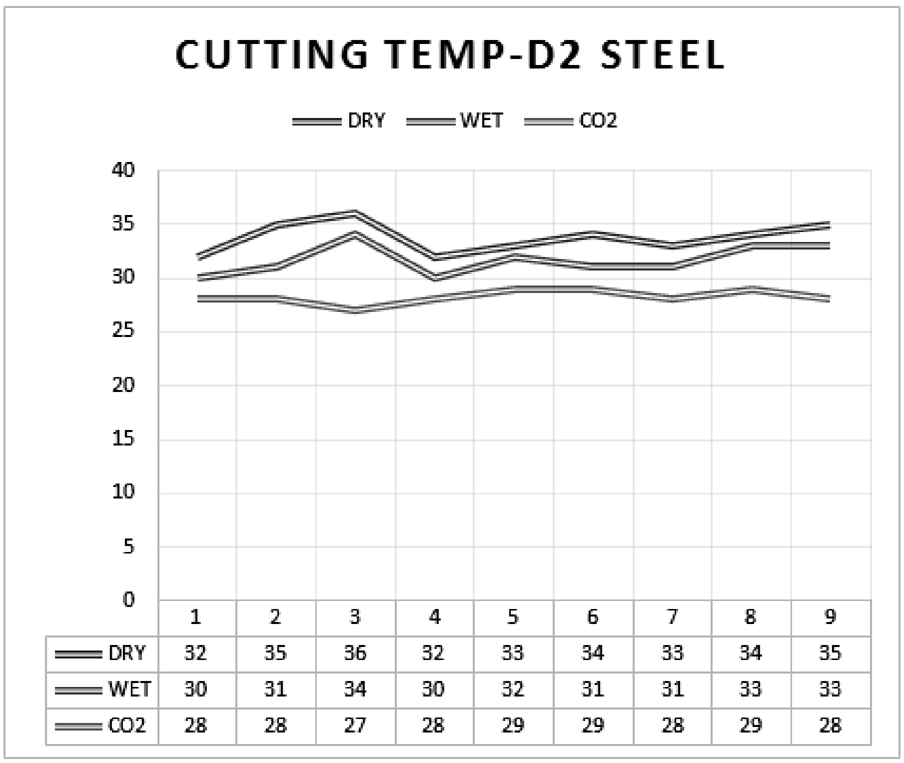
T3 08M-PM-1025 the cutting velocity employed were 17.84, 45.24 and 70.37 m/min, at a different feed rate of 0.034, 0.074, 0.150 mm/tooth and a constant depth of cut of 0.6 mm. The milling experiment has been worked out continuously for 5 minutes for each period of time to study the cutting temperature, cutting force, surface roughness, and tool wear, and the cutting tool inserts and chip are examined using a Scanning Electron Microscope (SEM).

4.1. Cutting Temperature

In metal cutting process, mechanical energy converted in to heat energy. There are three method of generating the heat during the cutting process.

1. Plastic deformation owing to a structural strain in the primary shear zone.
2. Plastic deformation by shear off and friction on the cutting face.
3. Friction be the chip and the tool on the flank face.

Figure 6 display the outcome of the tool chip interface cutting temperature (in °C) variations in different machining condition under dry, wet, and Cryogenic CO_2.



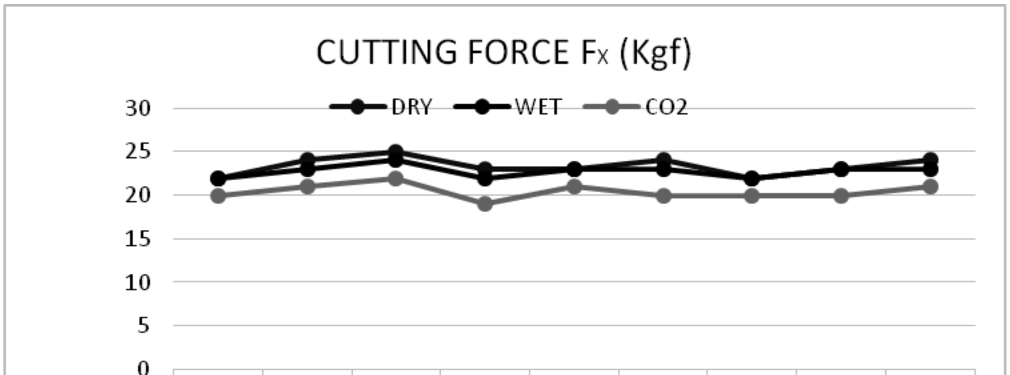
	1	2	3	4	5	6	7	8	9
DRY	32	35	36	32	33	34	33	34	35
WET	30	31	34	30	32	31	31	33	33
CO2	28	28	27	28	29	29	28	29	28

Figure 6: Variation of cutting temperature with different machining condition

In the conventional milling of AISI D_2 steel with a TiN coated carbide tool, when no coolant was supplied to the cutting zone (Dry), the cutting temperature at a cutting speed of 70.37 m/min and feed rate of 0.150 mm/tooth was 35°C.Similarly when cutting fluid was supplied to the cutting zone (Wet), the cutting temperature was 33°C at the similar cutting conditions. But the cryogenic CO_2 coolant was supplied into the tool – work interfaces, the cutting temperature was 28°C for the similar cutting conditions. It was identified that the mean diminution in the cutting temperature due to CO_2 cooling was 20% over dry machining and 15.15% over wet machining. The CO_2 cooling in the current work shown the reduction in the cutting temperature in the range of 12.5-25% and 6.67-20% respectively as compared to dry and wet machining. It was noticed that in all work-tool combinations, the increase in the cutting speed and feed rate decreased the effect of cryogenic cooling.

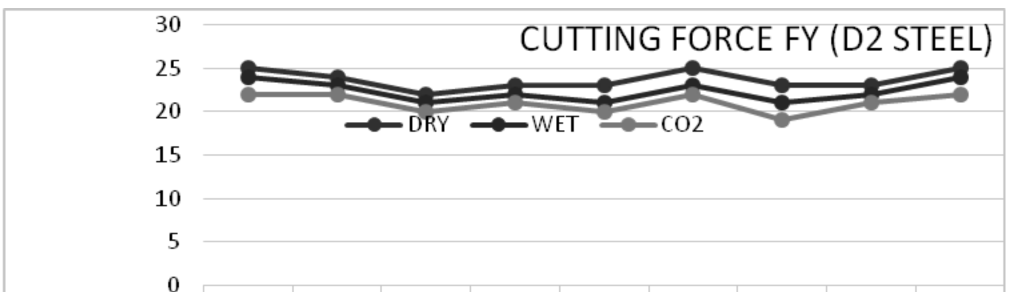
4.2. Cutting Force-F_X, F_Y and F_Z

Cutting force is the important parameter to ass's performance in the milling operations, which dominance to vibrations and low quality of the machining part. The results of the cutting force F_X, F_Y, and F_Z variations in different machining condition are shown in the Figure 7, 8, and 8. From the graph cutting force F_X, F_Y, F_Z clearly seen that cryogenic CO_2 reduced as compared to dry and wet machining in the milling of D2 steel. It means that cutting force reduced due to increase in speed and feed rates at all machining conditions in the range of 12-17% and 8-13.5% as compared to dry and wet machining.



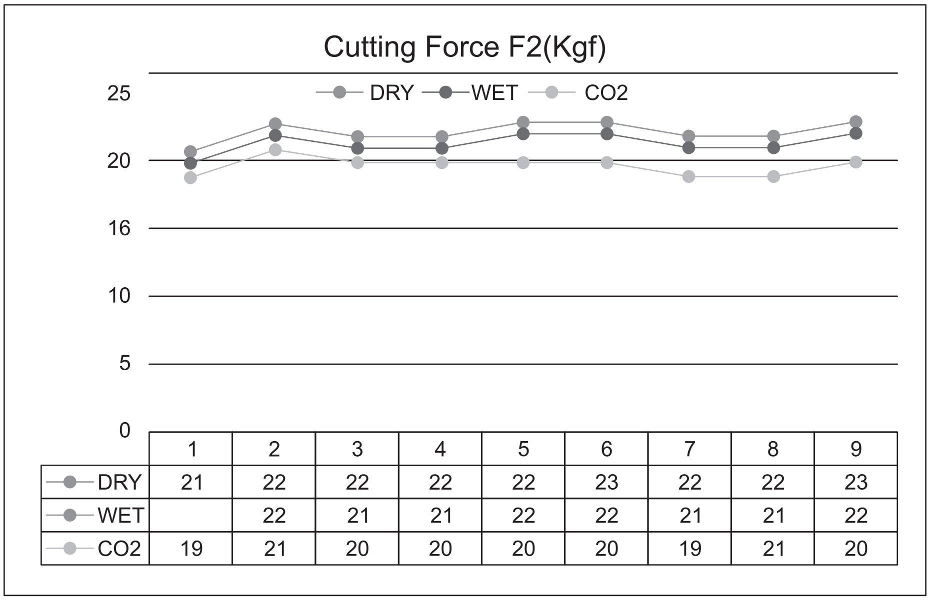
	1	2	3	4	5	6	7	8	9
DRY	22	24	25	23	23	24	22	23	24
WET	22	23	24	22	23	23	22	23	23
CO2	20	21	22	19	21	20	20	20	21

Figure 7: Difference of cutting Force (F_X) with different machining condition



	1	2	3	4	5	6	7	8	9
DRY	25	24	22	23	23	25	23	23	25
WET	24	23	21	22	21	23	21	22	24
CO2	22	22	20	21	20	22	19	21	22

Figure 8: Difference of cutting Force (F_Y) with different machining condition

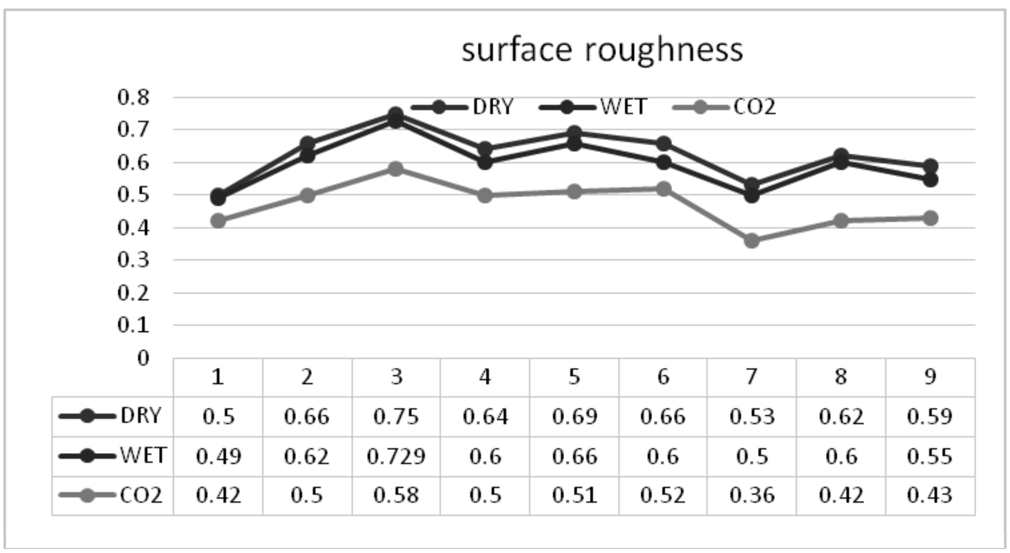


	1	2	3	4	5	6	7	8	9
DRY	21	22	22	22	22	23	22	22	23
WET		22	21	21	22	22	21	21	22
CO2	19	21	20	20	20	20	19	21	20

Figure 9: Difference of cutting Force (F_Z) with different machining condition

4.3. Surface Roughness

Surface roughness is also key characteristic parameter for evaluating the work piece quality of the finished work piece component. The results of machined surface roughness variations in different machining condition as shown in Figure 10 below:



	1	2	3	4	5	6	7	8	9
DRY	0.5	0.66	0.75	0.64	0.69	0.66	0.53	0.62	0.59
WET	0.49	0.62	0.729	0.6	0.66	0.6	0.5	0.6	0.55
CO2	0.42	0.5	0.58	0.5	0.51	0.52	0.36	0.42	0.43

Figure 10: Difference of Surface Roughness with different machining condition

From the graph shows that the surface roughness (R_A) at a cutting speed of 70.37 m/min and feed rate of 0.150 mm/tooth was 0.59 µm at dry condition. Similarly when cutting fluid was supplied to the cutting zone (Wet), the surface roughness (R_A) was 0.55 µm at the similar cutting conditions. But the cryogenic CO_2 coolant was supplied into the tool – work interfaces the Surface roughness (R_A) was 0.43 µM for the similar cutting conditions. For that reason cooling and lubrication effect will provide lower friction at the tool-chip and tool-wok interfaces therefore the surface roughness decreased by a rise in the cutting velocity, and increased with an increase in the feed rate.

4.4. Tool Wear

The average flank wear shown in Figure 11. Effect of cryogenic CO_2 as a cutting fluids on tool wear was studied with different speed and feed rate conditions of the cutting tool inserts were observed and average flank wear (VB) were measured by with the help of tool maker's microscope. Once average flank wear (VB) is reaches 0.3 mm. It should be considered as tool life was over.

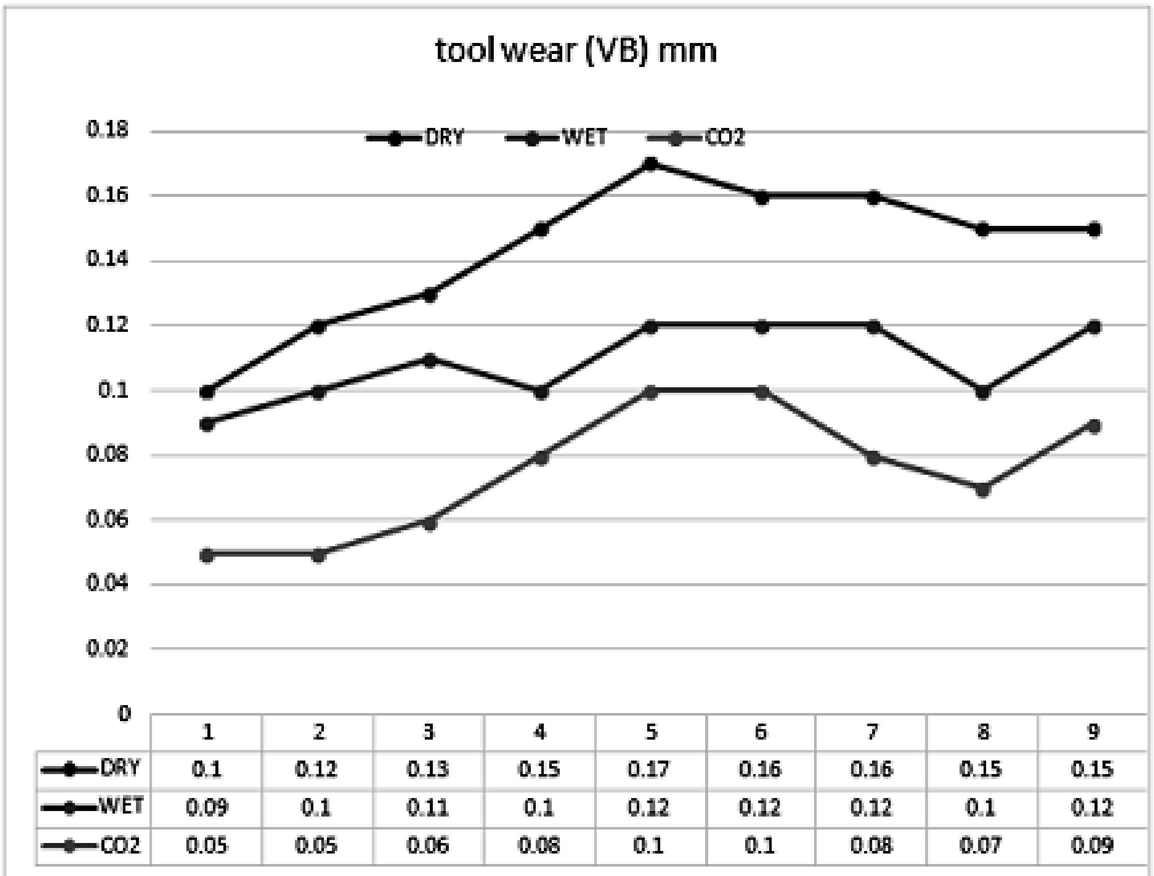


Figure 11: Difference of flank wear (VB) with different machining condition

The flank wear (VB) by a cutting speed of 70.37 m/min & feed rate of 0.150 mm/tooth was 0.15 mm, 0.12 mm and 0.09 mm for dry, wet & CO_2 machining correspondingly. Therefore flank wear (VB) is reduced due to cryogenic CO_2 40% and 25% as related to dry and wet machining. Figure displays the SEM views of cutting inserts after machining the cutting length of 90mm and machining duration of 5 min intervals.

From the shown Figure 12, 13 and 14 below SEM images clearly seen that cutting inserts are worn out more in the cutting edges and flank faces which were used for dry and wet machining then the cutting insert used in CO_2 machining condition. Therefore reducing the cutting temperature under cryogenic CO_2 cooling, the heat generated in the cutting zone will be detached successfully and hence the tool life will be upgraded.

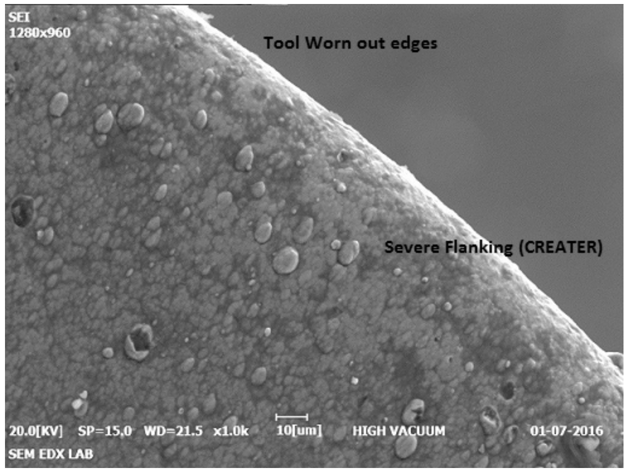


Figure 12: SEM Views of worn-out inserts under dry condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

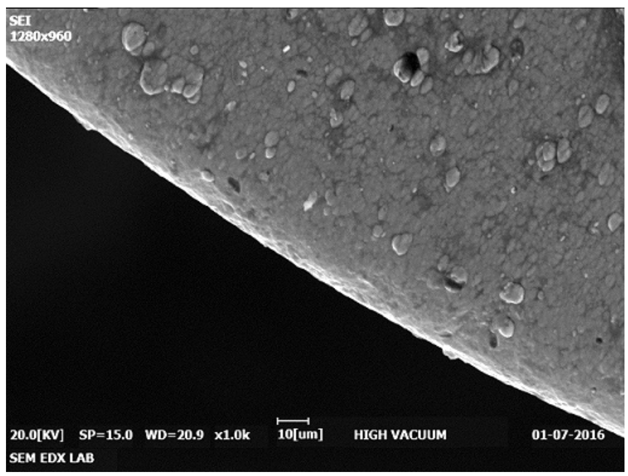


Figure 13: SEM Views of worn out inserts under wet condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

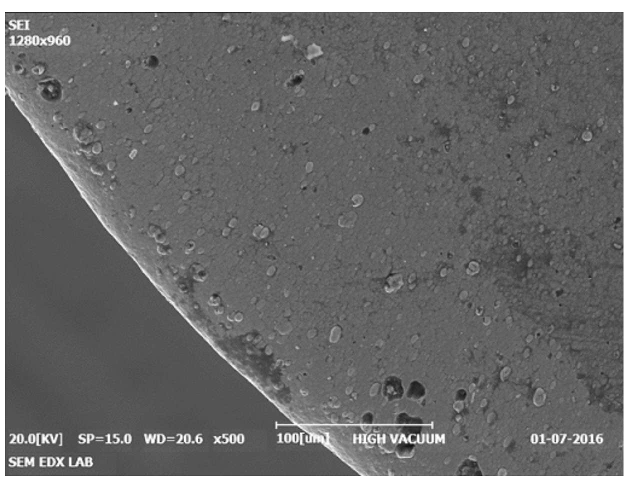


Figure 14: SEM Views of worn out inserts under cryogenic CO_2 condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

4.5. Chip Morphology

SEM images Figure 15, 16, and 17 shows the chips shapes during the conventional milling of AISI D2 Steel at a cutting speed of 70.37 m/min and feed rate of 0.150 mm/tooth and depth of cut 0.6 mm under dry and wet and cryogenic CO_2. From the Figure seen that longer curved chips with royal blue color chips are produced are produced in the dry machining it means extreme heat produced in the tool-chip interface resulting burnt chips. In the wet machining curved chips silver brown color chips are produced. It means that average heat is produced in the tool chip interface. Whereas the cryogenic CO_2 machining produces short forms of chips with silver color indicating that chips were less burnt .therefore when the cryogenic CO_2 were applied, the chip breakability was improved and better chip control and decreasing the friction between the work piece and tool chip interface.

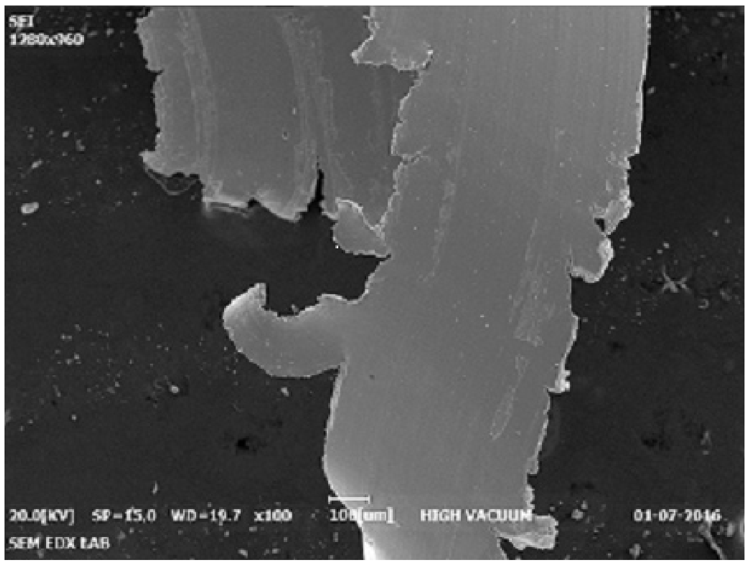


Figure 15: SEM Images of dry machining with cutting length of 90mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

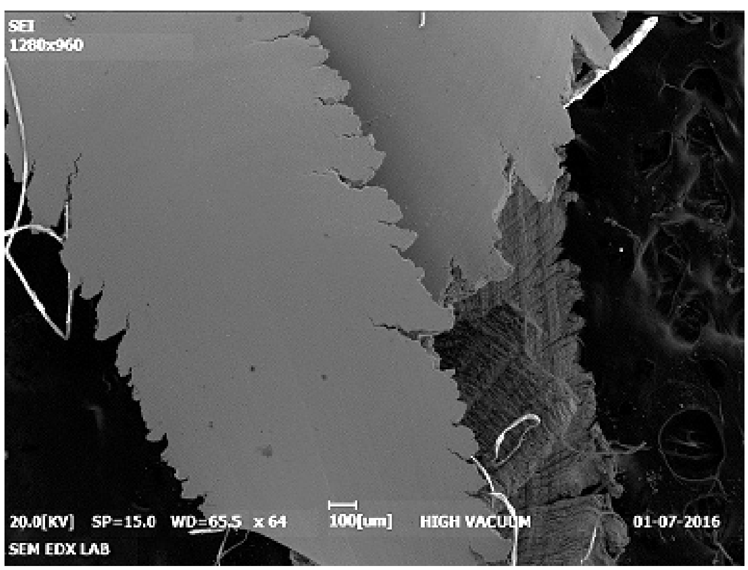


Figure 16: SEM Images of Wet machining with cutting length of 90mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

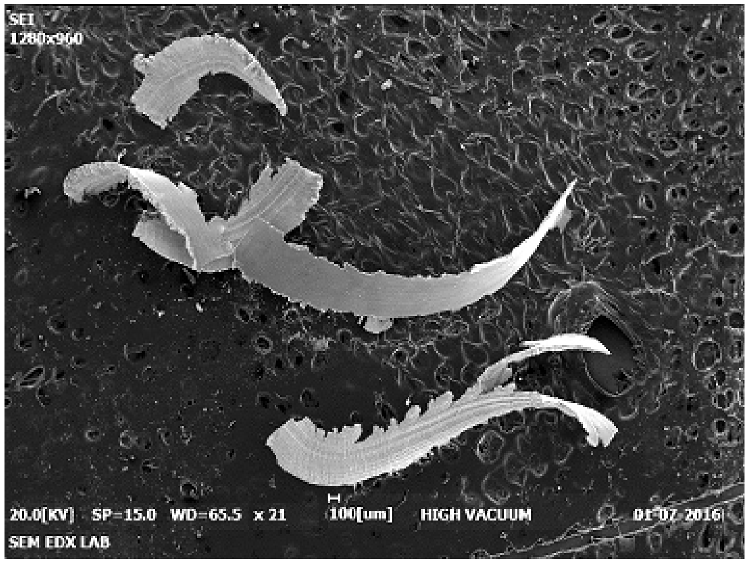


Figure 17: SEM Images of Cryogenic CO_2 machining with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

5. CONCLUSION

1. The CO_2 cooling in the present work shown the decrease in the cutting temperature in the range of 12.5-25% and 6.67-20% respectively as differed to dry and wet machining.
2. Cutting force are minimized due to increase in speed & feed rates at all machining conditions in the range of 12-17% and 8-13.5% as compared to dry and wet machining.
3. Using cryogenic CO_2 Surface finish of the machined work piece is enhanced to a superior extent as compared to dry & wet condition.
4. Tool life was improved in the range of up to 25% in wet & up to 40% in dry machining condition.
5. Cryogenic CO_2 provides better chip breakability and reduce the friction between work piece and tool-chip interface.
6. With the results obtained cryogenic CO_2 coolants are efficient and economical cost when compared to coolant oil is used.

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