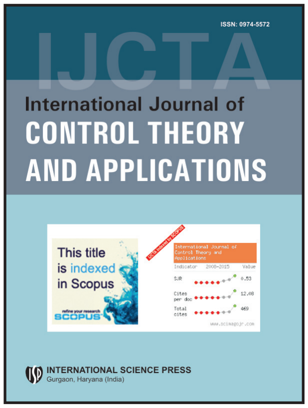

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Effect of Cryogenic CO_2 on Conventional Milling Machining of AISI P20 Tool Steel using Multi Coated Carbide Insert

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Abstract:

Purpose: With the increasing demand for high quality, highly reliable, and economical machined components, the manufacturing industry must find innovative methods for producing precision components. To meet such demand, manufacturers are seeking ways to improve the process planning methodologies. One such method is Cryogenic CO_2 machining. 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

Design/methodology/approach: cryogenic CO_2 machining can be absorbs the heat from the cutting zone and evaporates into the atmosphere. In this paper Experimental work is carried out in conventional Milling machine AISI P20 tool steel by dry, wet, and cryogenic CO_2 condition with different lowering speed, lowering feed, under choosing such condition discussed in the results of cutting temperature, surface roughness, cutting force, Tool Wear of multi coated carbide insert, chip morphology, and also in the surface roughness parameter which is debugged into MINITAB-17 software for taguchi Analysis. In this research work, the size of the work materials used was AISI P20 Steel of size is 150 mm × 50 mm × 50 m with MITSUBISHI make multi coated carbide cutting tool insert was used. The time taken for machining is 5 minute and depth of cut were maintain 0.6 mm with different lower cutting speed and different feed rate.

Findings: The use of cryogenic CO_2 cooling in the present work shown in deflation in cutting temperature in the range of 6.1 – 14.28% & 3.1 – 11.76% respectively as differ to dry and wet machining, and also application in the CO_2 reduces the cutting force 15.38 – 50% in dry and 7.69 – 33.33%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.

Originality/value: At the end of the result discussion observed that cryogenic CO_2 is the best choice for improve the metal cutting process because this cryogenic methods provides a realistic alternative to conventional coolant for milling process requisition and also it is environmentally friendly, but also succeeded in reducing the surface roughness, provides better chip formation and increases tool life.

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

1. INTRODUCTION

Machining is a spell that is associated to removal of unwanted material, normally in the form of chips in the work piece. This Process is used to convert preformed blocks of metal into desired shape, size and finished specified, often to great precision in order to fulfill design requirements. Hence, machining processes are often the most expensive. Although the theoretical analysis of metal cutting process is complex, but the application of these processes in the industrial world is widespread. The study of metal cutting focuses on the behavior of tool and work piece material that influence the efficiency and quality of cutting operations performed. The metal cutting process involves pressing of a cutting tool against the work piece, with certain degree of force, resulting in removal of material from the work piece, in the form of chips. This results in enormous heat generation at the tool chip interface. Hence, continuous use of cutting tool for machining, results in tool wear eventually leading to its failure.

With the advancement in metal machining operations, it is necessary to apply the cutting fluids to reduce the friction and remove the heat as early as possible but conventional coolants are soil contamination and health problem So that researchers shifted towards the concept of sub-zero treatments and this was introduced to check the effect on industrial field, another way of reducing the cutting temperature is to use a cryogenic coolant, because this cryogenic medium absorbs the heat from the cutting zone and evaporates into the atmosphere. The word 'cryogenic' pertains to something at or causing the creation of very low temperatures, typically <193K (–80°C to –90°C) and has a wide variety of uses in electrical and mechaical components as well as superconductors used in fields such as quantum physics. Additionally 'cryogenic' is associated with cooling fluids in high-output industrial machining processes, and can also be found referring to materials engineering and heat treatment technologies. While low temperatures are indeed involved in both instances.

Ampara Aramcharoen, Shaw Kah Chuan et. al., (2014) says in the "An experimental investigation on cryogenic milling of Inconel 718 and its sustainability assessment" suggested that Cryogenic cooling system applicable in heat reduction, temperature distribution and leads to enhance more efficient and more economical in machining especially for advanced and difficult-to-cut materials.

Mon *et. al.,* [27] conducted tests turning titanium alloys with Ti-Al-N coated carbide. The trials were done at three different cutting speeds for cryogenic cooling and one test of conventional cutting fluid for comparison and concluded that When compared to conventional machining the flank wear and crater on the insert was reduced dramatically and surface roughness improved from 0,43 μm to 0,13 μm.

Shokrani et. al., [3] evaluated the cryogenic milling of Inconel 718 compared to dry machining. The surface finish was improved and tool life minimized.

In the present investigation, used Multi Coated Carbide inserts were subjected to cryogenic machining (–80°C to –90°C) and machining studies were conducted on P20 Steel at lowering speed, lowering feed, and constant depth of cut using dry, wet and cryogenic CO_2 Machining.

2. MATERIALS AND METHODS

2.1. Work Piece Material

Tool steels for plastic injection molding and die casting applications. The work piece materials used in the experimental work were AISI P20 Steel. The work piece made for the work materials is medium and large size moulds, injection moulds, extrusion dies, press brake dioes, aluminium die casting, forming tools, home equipment and other large daily goods e.g. containers etc 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 P20 Steel are given bellow in the table.

Table 1
Chemical Composition of AISI P20 Steel

Element	*Amount (%)*
Carbon	0.40
Silicon	0.30
Manganese	1.50
Chromium	1.90
Molybdenum	0.20
Iron	Balance

Table 2
Mechanical properties of AISI D2 Steel

Mechanical Property	*Metric Value*
Hardness Rockwell C	32
Density	7.8 × 1000 kg/m^3
Poisson ratio	0.28 – 0.30
Elastic modulus	205 GPa
Thermal conductivity	20.2(W/mK)

2.2. Cutting Tool

Milling experiments were carried out MITSUBISHI make using index able multi coated cutting tool inserts. Figure shows the cutting tool inserts are used in this experiment

Figure 1: Photo graphic view-cutting tool insert

2.3. Tool Holder

A common tool holder APMT-1125-MT was used for machining all the three work pieces in all the cutting conditions. Figure shows below the photographic view of the tool holder.

Specification:

Shank diameter : 20 mm

Overall length : 50 mm

Head length : 25 mm

Number of inserts : 2

Figure 2: Tool holder Insert

3. CRYOGENIC MILLING CO_2 METHOD

The experimental condition for cryogenic milling CO_2 as shown in table below:

Table 3
Experimental Condition

Work piece material & size	AISI P20 steel 50 × 50 × 150 mm
Cutting tool insert	MITSUBISHI-APMT1135PDER-M2VP15TF
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

Figure 3: Cryogenic CO_2 Machining Setup

A HMT-MTR make conventional Milling machine was used to perform the milling operations. Cutting inserts were fixed in tool hoder to carryout the machining process. The experimental setup used for cryogenic CO_2 machining as shown in photographic view below. A K-type 6 channel thermocouple was used for measuring the cutting temperature on the cutting zone of the insert during maching process. Cutting forcess were measured by using milling tool dynometer. The finished work-pieces were examined for measuring the surface roughness tester. Tool wear test were conducted with machining time of 5min. Inserts and chips was viewed under SEM analysis.

4. RESULTS AND DISCUSSION

4.1. Cutting Temperature

The result will be expressed in graphs to provide the reader with a clearer view of the tool chip interface cutting temperature (in °C) variations in different machining condition under dry, wet, and Cryogenic CO_2.

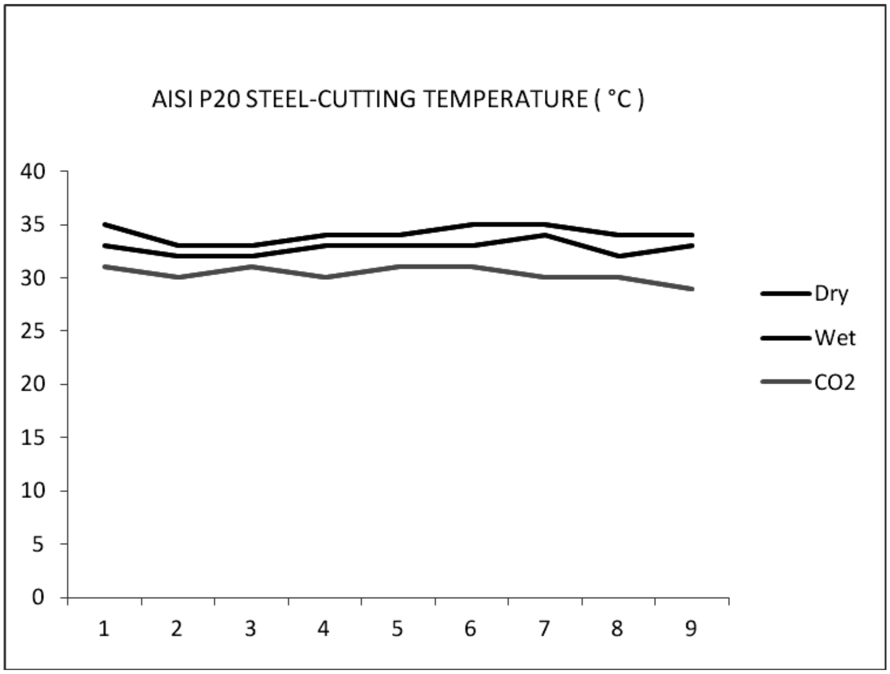

Figure 4: Graphical representation of cutting temperature with different machining condition (Dry, Wet, & Cryogenic CO_2)

The result show that when no coolant was applied to the cutting zone, the cutting temperature was 35°C .in the same way when coolant was applied in the cutting zone the cutting temperature was 34°C ,but the cryogenic CO_2 coolant was applied in the cutting zone interfaces, the temperature was identified Maximum of 31°C, therfore it was observed that the CO_2 cooling reduction in the cutting temperature range of 6.1-14.28% and 3.1-11.76% respectively as compared to dry and wet machining.

4.2. Cutting Force F_X, $F_{Y,}$ and F_Z

The forces acting on a tool are an important aspect of machining for studying the machinability condition. knowledge of the cutting forces is needed to estimate the power requirements and undesirable vibrations, resulting poor surface finish of the machined part, therefore in order to find the comparison of the Feed force, Normal force and axial force i.e., (F_X, F_Y, F_Z) with different Speed, Feed combinations in the milling of AISI P20 Steel under dry, wet and cryogenic CO_2 Machining condition as shown in graph *a*, *b*, *c*.

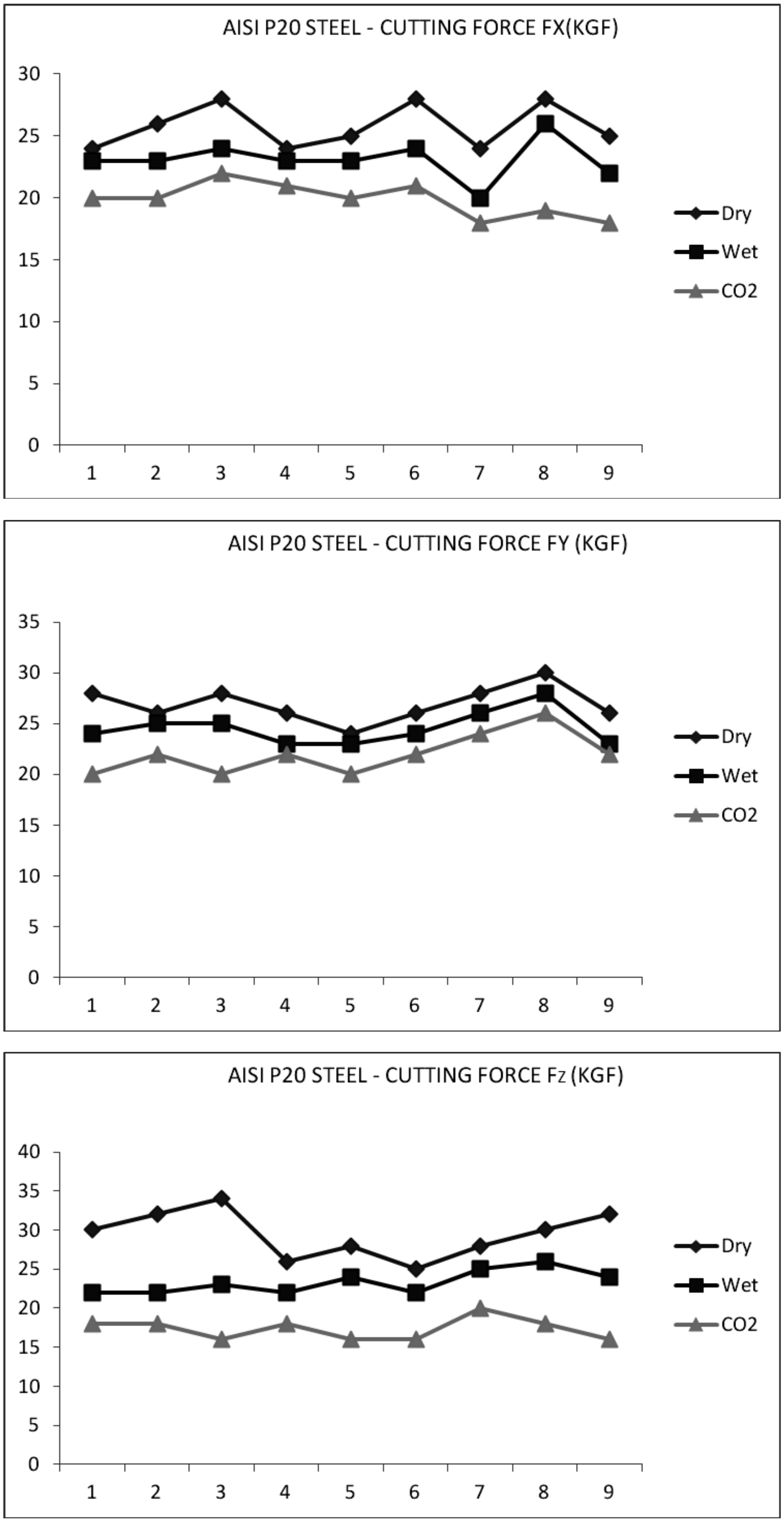

Figure 5, 6, 7: Graphical representation of cutting Force (F_X, F_Y, F_Z) with different machining condition

From the graph F_X, F_Y, F_Z clearly seen that cryogenic CO_2 minimized as differed to dry and wet machining in the milling of AISI P20 Steel. It means that cutting force reduced it depends upon increase in speed and feed rates at all machining conditions in the range of 15.38-50% and 7.69-33.33% as compared to dry and wet machining.

4.3. Surface Roughness

From the graph seen that in dry environment surface finish (R_A) value was 0.68 µm in the cutting velocity of 70.37 m/min and feed rate of 0.150 mm/tooth in the same way in wet environment surface finish value was 0.65 µm, but the cryogenic CO_2 coolant was supplied in the work-tool interface the surface finish was obtained at 0.53 µm correspondingly. It means that, the surface roughness decreases as cutting velocity increases. With increase in cutting velocity, the cutting force decreases which tends to minimum vibration and less power consumption during the machining operation.

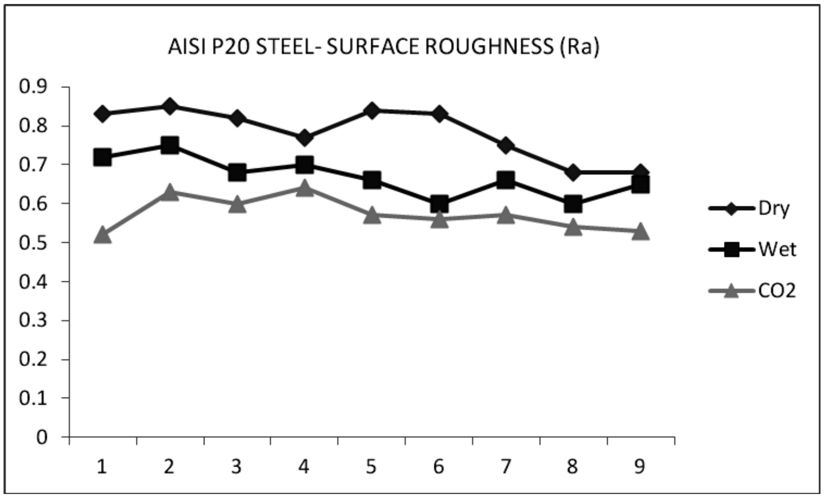

Figure 8: Graphical representation of Surface Roughness with different machining condition

4.3.1. Taguchi Technique

MINITAB-17 is used for Taguchi design which is employed for response variable selected to achive better machining performance in surface roughness. In this design process three level parameter are used such as speed, feed and depth of cut has been selected to achive the optimize the value of surface roughness. Signal to noise ratio (S/N) analysis can be done to find optimum cutting parameters using this software. S/N ratio is to be find the performance of a characteristic in largest value of S/N ratio desired

Table 4
Taguchi L9 Experimental Method

Model No	*Cutting Velocity m/min*	*Feed (mm/Tooth)*	*Depth of Cut (mm)*
1	17.84	0.034	0.2
2	17.84	0.074	0.4
3	17.84	0.150	0.6
4	45.24	0.034	0.4
5	45.24	0.074	0.6
6	45.24	0.150	0.2
7	70.37	0.034	0.6
8	70.37	0.074	0.2
9	70.37	0.150	0.4

$$\begin{aligned}\text{Number of Experiment} &= [(L-1)\times p]+1\\ &= [(3-1)\times 3]+1 = 7\\ &\approx L9\end{aligned}$$

Table 5
Response table – Dry, Wet and Cryogenic CO_2

Test No	*Dry R_a*	*Wet R_a*	*Cryogenic CO_2 R_a*
1	0.83	0.72	0.52
2	0.85	0.75	0.63
3	0.82	0.68	0.60
4	0.77	0.70	0.64
5	0.84	0.66	0.57
6	0.83	0.60	0.56
7	0.75	0.66	0.42
8	0.68	0.60	0.54
9	0.68	0.65	0.52

Table 6
S/N Ratio – Dry Environment (Smaller is Better)

Model No	*Cutting Velocity m/min*	*Feed (mm/Tooth)*	*Depth of Cut (mm)*
1	0.833	0.7833	0.7800
2	0.8133	0.7900	0.7667
3	0.7033	0.7767	0.8033
Delta	0.1300	0.0133	0.0367
Rank	1	3	2

Figure 9: Main Effect plot for SN ratios-Dry Environment

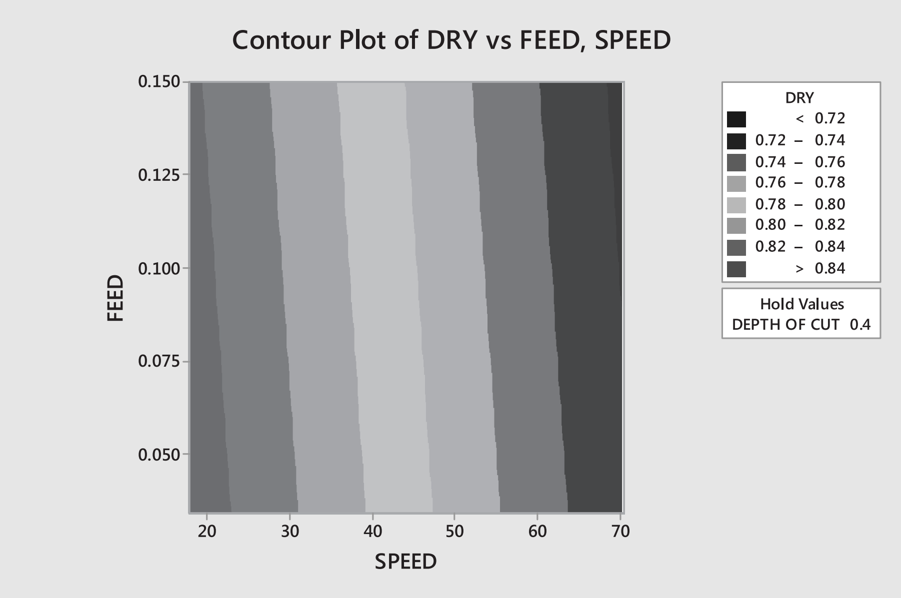

Figure 10: Contour plot for dry environment

Table 7
Signal to Noise Ratios – Wet Environment (Smaller is Better)

Model No	*Cutting Velocity m/min*	*Feed (mm/Tooth)*	*Depth of Cut (mm)*
1	0.7167	0.6933	0.6400
2	0.6533	0.6700	0.7000
3	0.6367	0.6433	0.6667
Delta	0.0800	0.0500	0.0600
Rank	1	3	2

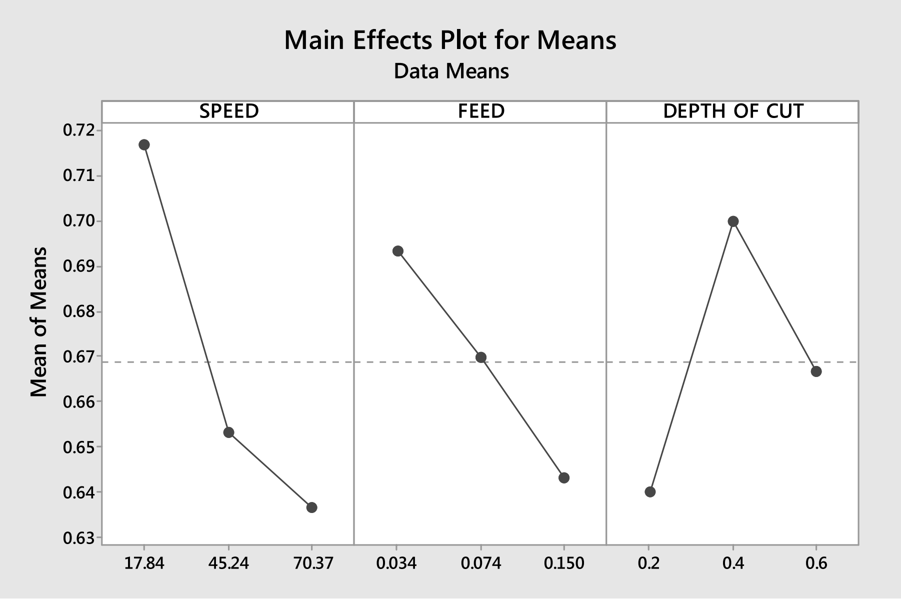

Figure 11: Main Effect plot for SN ratios-Wet Environment

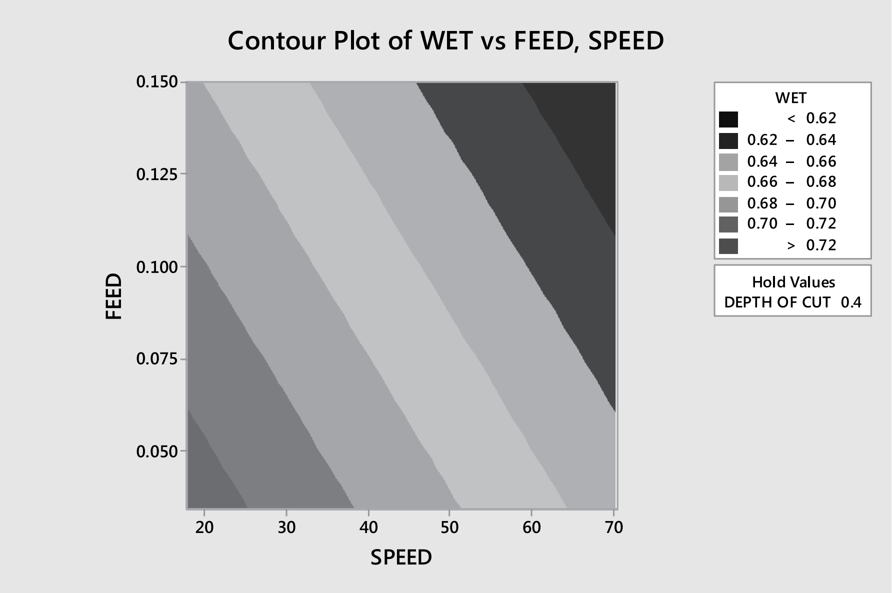

Figure 12: Contour plot for dry environment

Table 8

Signal to Noise Ratios – Cryogenic CO_2 Environment (Smaller is Better)

Test No	*Cutting Velocity m/min*	*Feed (mm/Tooth)*	*Depth of Cut (mm)*
1	0.5833	0.5267	0.5400
2	0.5900	0.5800	0.6000
3	0.4967	0.5633	0.5300
Delta	0.0933	0.0533	0.0700
Rank	1	3	2

Figure 13: Main Effect plot for SN ratios-Cryogenic CO_2 Environment

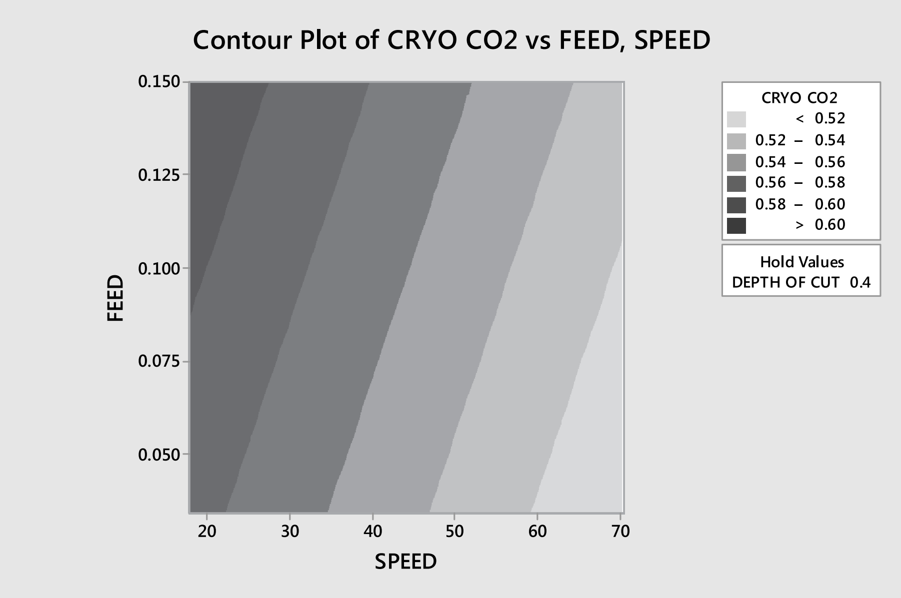

Figure 14: Contour plot for cryogenic CO_2 environment

After conducting Taguchi analysis in AISI P20 Steel of surface roughness values are examined and optimized parameters are gained. Speed is a control parameter of AISI P20 Steel in machining. Higher Signal – Noise – Ratio (S/N) value is obtained with cutting velocity of 70.37 feed rate of 0.150 and depth of cut 0.4 mm are optimum cutting parameter for minimum surface roughness. In this discussion to Dry, Wet and cryogenic CO_2 surrounding, the surface roughness value is less than other combinations so high cutting velocity and high feed of cryogenic CO2 machining process produces extraordinary surface finish as compared to dry and wet coolant.

4.4. Tool Wear

Figure shows the average flank wear. This flank wear (VB) is measured by using Tool maker's microscope. Once the average flank wear reaches 0.3 mm it is considered as a tool life was over.

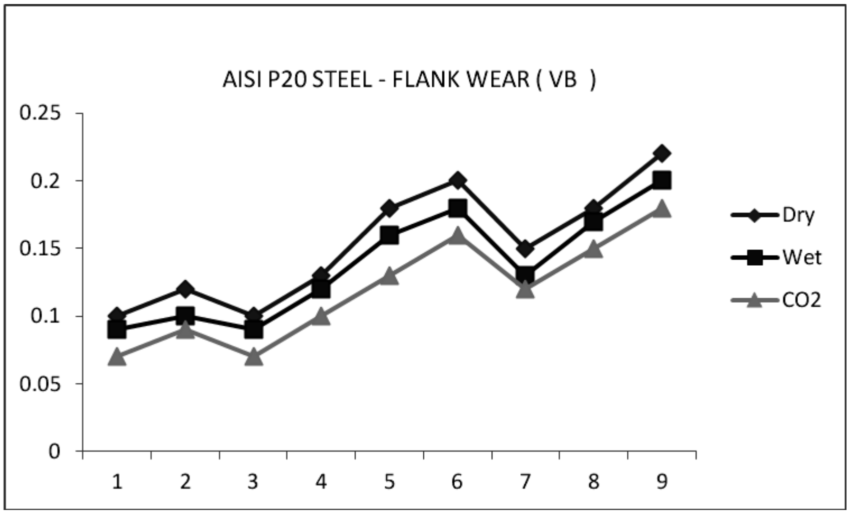

Figure 15: Variation of flank wear (VB) with different machining condition

The flank wear (VB) at a cutting speed of 70.37 m/min and feed rate of 0.150 mm/tooth was 0.15 mm, 0.13 mm and 0.12 mm for dry, wet and CO_2 machining, respectively. Therefore flank wear (VB) is reduced due to cryogenic CO_2 20% and 10% as compared to dry and wet machining.

Figure shows the SEM views of cutting inserts which is used for conventional machining purpose after cutting length 90 mm and machining duration of 5 min intervals.

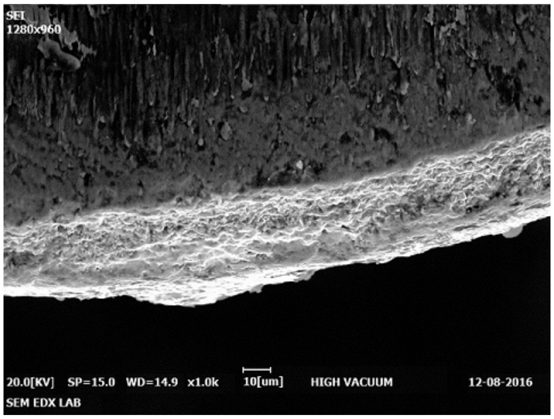

Figure 16: SEM Views of worn-out inserts under dry condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

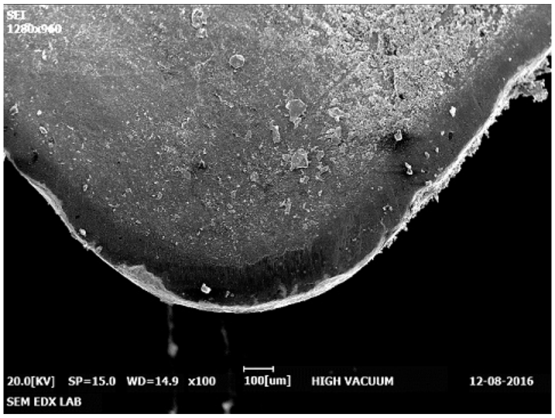

Figure 17: SEM Views of worn out inserts under wet condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

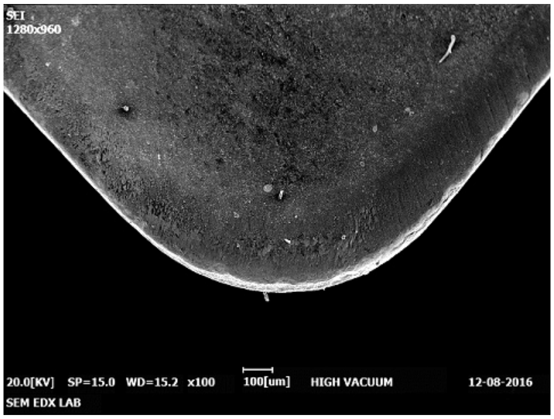

Figure 18: SEM Views of worn out inserts under cryogenic CO_2 condition with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

Figure shows the SEM images of cutting inserts. There was a clear improvement concerning tool wear between dry, wet, and cryogenic cooling. The CO_2 has a little edge over dry and wet cooling and the flank wear forms at very slow rate while milling with CO_2. The flank wear in cryogenic milling is predictable and uniform compared to conventional machining. This happened because of reduced cutting temperature under cryogenic CO_2 cooling, the heat generated in the cutting zone will be removed effectively and hence the tool life will be increased.

4.5. Chip Morphology

SEM images shows the chips shapes during the conventional milling of AISI P20 Steel at a cutting speed of 70.37 m/min and feed rate of 0.150 mm/tooth and depth of cut 0.6mm under dry and wet and cryogenic CO_2.

From the Figure seen that longer curved chips with dark blue color chips are produced are produced in the dry machining it means extreme heat produced in the tool-chip interface resulting burnt chips and also high friction between tool chip interface. In the wet machining small curved with black 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 better and effective chip control and reducing the friction between the work piece and cushion at tool – chip interface.

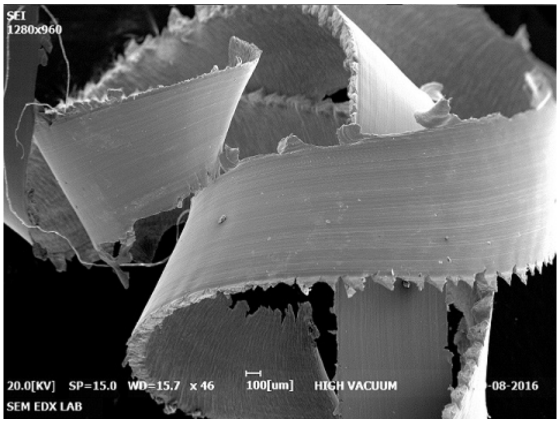

Figure 19: SEM Images of dry machining with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

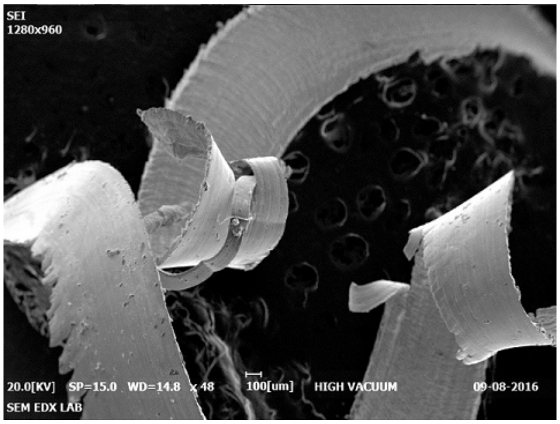

Figure 20: SEM Images of Wet machining with cutting length of 90 mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

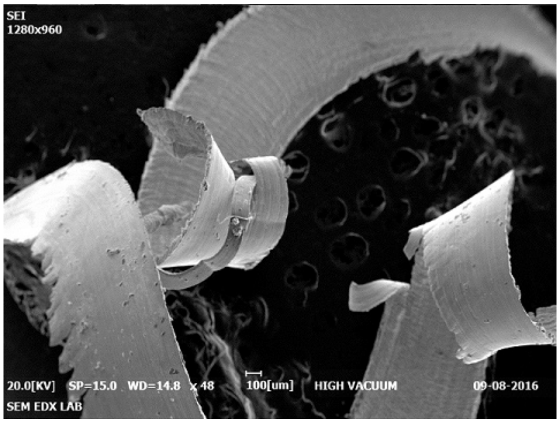

Figure 21: SEM Images of Cryogenic CO_2 machining with cutting length of 90mm and machining duration 5 min (cutting speed-70.37 m/min and feed-0.150 mm/tooth)

5. CONCLUSION

Therefore from the analyzed discussion

1. It is confirmed that CO_2 cooling in the present work shown the reduction in the cutting temperature in the range of 6.1-14.28% and 3.1-11.76% respectively as compared to dry and wet machining.
2. It is confirmed that cutting force are reduced due to increase in speed and feed rates at all machining conditions in the range of 15.38-50% and 7.69-33.33% as compared to dry and wet machining
3. It is confirmed that using cryogenic CO_2 Surface finish of the machined work piece is improved to a greater extent as compared to dry and wet condition. And also by taguchi technique optimized parameters are gained. Speed is a control parameter of AISI P20 Steel in machining with higher S/N ratio value cutting velocity of 70.37 feed rate of 0.150 and depth of cut 0.4mm are optimum cutting parameter for minimum surface roughness.
4. It is confirmed that Tool life was improved in the range of up to 10% in wet & up to 20% in dry machining condition
5. It is confirmed that 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 economical cost and efficient coolant when compared to coolant oil is used. And also it gives the cushion effect in the tool – chip interface,

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