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An Experimental Investigation on Machinability of Titanium (Grade -2) using Cryogenic Machining

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***Abstract:* -- Among the group of super hard alloys, titanium is one of the fastest growing materials used in aerospace applications. The prime rationale for designers to choose titanium in their designs is its relative low mass for a given strength level and its relative resistance to high temperature. One drawback of these titanium material is their poor machinability. Many researches are going on to develop a machining technique that improves the machinability of hard materials. One such method that is under research for is cryogenic machining. In this type of machining the traditional coolant is replaced by the Liquid Nitrogen. Only the Liquid nitrogen is more preferable in machining because it is cost effective, safe, nonflammable and environmental friendly gas, in addition to that it cannot contaminate work piece, no separate mechanism for disposal .In this paper a machining test is conducted on the titanium Grade -2 material and the machining parameters temperature at the cutting area, cutting forces , power consumption , surface roughness are found by varying the speed, feed , depth of cut for the both normal machining and cryogenic machining.**

***Index Terms*—titanium grade-2 , cryogenic machining, cutting forces, surface roughness.**

I.INTRODUCTION

Titanium is a metal showing a high strength-weight ratio which is maintained at elevated temperatures and it has exceptional corrosion resistance. These characteristics were the main cause of the rapid growth of the titanium industry over the last 40 years. The [1] major application of the material in the aerospace industry, both in air frames and engine components. Non aerospace applications take advantage mainly of their excellent strength properties, for example steam turbine blades, superconductors, missiles etc. ; or corrosion resistance ,for example marine- services ,chemical petro-chemical ,electronics industry ,bio- medical instruments etc. However, despite the increased usage and production of titanium, they are expensive when compared to many other metals, because of the complexity of the extraction process, difficulty of melting and problems during fabrication. The problems in machining titanium originate from three basic sources: high cutting, temperatures, chemical reactions with tools, and a relatively low modulus of elasticity. Unlike steel, titanium does not form a built-up edge on tools, and this behavior accounts for the characteristically good surface finishes obtained even at low cutting speeds. Unfortunately, the lack of a built-up edge also increases the abrading and alloying action of the thin chip which literally races over a small tool-chip contact area under high pressures.[2] This combination of characteristics and the relatively poor thermal conductivity of titanium results in unusually high tool-tip temperatures. Titanium's strong chemical reactivity with tool materials at high cutting temperatures and pressures promotes galling and tool wear. Mechanical problems result from titanium's relatively low modulus of elasticity, half that of steel.[3] The low modulus coupled with high thrust forces required at the cutting edge can cause deflections in slender parts. Distortion of that kind creates additional heat, because of friction between the tool and workpiece, and problems in meeting dimensional tolerances.[4]

To overcome all the above problems in the machining titanium the cryogenic machining is preferred. It is a machining process where the traditional lubro -cooling liquid (an emulsion of oil into water) is replaced by a jet of liquid nitrogen.[5] Cryogenic machining is useful in rough machining operations, in order to increase the tool life. It can also be useful to preserve the integrity and quality of the machined surfaces in finish machining operations. Cryogenic machining tests have been performed by researchers since several decades, but the actual commercial applications are still limited to very few companies Both cryogenic machining by turning and milling are possible.[6,7] In this paper machinability study has been carried out under cryogenic coolant as well as water based coolant on Lathe Machine where Power consumption, cutting forces and surface roughness values were studied in machining of Titanium Grade-2 material.[8]

II. APPLICATIONS

Grade 2 titanium is called the “workhorse” of the commercially pure titanium industry, thanks to its varied usability and wide availability. It shares many of the same qualities as Grade 1 titanium, but it is slightly stronger. Both are equally corrosion resistant[9,10]

Titanium Grade 2 may be considered in any application where formability and corrosion resistance are important, and

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strength requirements are moderate. Some examples of aerospace applications have included airframe skins in "warm" areas, ductwork, brackets, and galley equipment. Ti Grade 2 has also been widely used in marine and chemical applications such as condensers, evaporators, reaction vessels for chemical processing, tubing and tube headers in desalinization plants, and cryogenic vessels. Other uses have included items such as jigs, baskets, cathodes and starter-sheet blanks for the electroplating industry, and a variety of medical applications.[11,12]

III. EXPERIMENTAL PROCEDURE

In this experiment, the machinability parameters of the titanium are found out for the both normal machining and the cryogenic machining. The following order is followed to obtain the different machinability parameters

- Material Selection and chemical composition Test
- Vickers Hardness and UTM Testing
- Machining Test

A. *Material Selection and chemical composition test*

Titanium Grade-2 in the round bar form is selected for the machining test. The dimensions that chosen are given below

- Dia 25 mm X 200 mm length – Normal Machining
- Dia 25 mm X 200 mm length – Cryogenic Machining

The optical Emission Spectrometer is used to find out the chemical composition of the above selected material. The following is the result of the test shown in Table 1

Table 1 Chemical Composition of Titanium

V %	0.17
Al %	0.61
Ti %	99.10

B. Vickers Hardness and UTM Testing

For the selected material titanium grade-2 the Vickers hardness and UTM testing is performed to determine the hardness and strength of the material. The obtained result is shown below Table 2

Location (Surface)	Impression 1	Impression 1	Impression 1	Average (HV)
Titanium Grade -2	207	209	207	207.67

Table 2 Vickers Hardness Testing Results

The UTM Testing is performed on a FIE Universal Testing Machine 40KN and the input data is shown in the Table 3

Specimen Type	Round
Initial Diameter	12.82 mm
Final Diameter	9.1 mm
C/S Area	129.082 mm^2
Original Gauge Length	50 mm
Final Gauge Length	56.32
Extensometer Gauge Length	25 mm

Table 3 Input data to the specimens

The following table 4 shows the test results for the titanium Grade-2

	Values
Ultimate Load	72.00 KN
Ultimate tensile Strength	547.487 N/mm^2
Elongation	18.200 %
Reduction in Area	44.960 %
Yield Stress	452.700 N/mm^2
Yield Strength	59.535 KN

Table 4 UTM Testing Result

C. Machining Test

The orthogonal cutting trials were carried out on HMT make High precision Lathe NH 22 (Figure 1) , which has a 7 kW motor power and the spindle rotation speed ranges from 40-

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2040 rpm in forward and 60-1430 rpm in reverse. Carabid Tipped Tool is used for entire experiment. In this Investigation the parameters depth of cut , Speed and feed are varied .In this experiment when one parameter is varied the other are kept constant. The other parameters like feed, coolant discharge rate , length of cut are kept constant .For each and every experiment the following are found out

- Determination of Cutting Forces
- Temperature at the cutting Area
- Surface roughness after machining

Figure 1 HMT Lathe NH 22

Figure 2 Machining operation on Lathe

- **Determination of cutting forces**

In this experiment cutting forces which are generated while machining the material are first determined by the lathe tool dynamometer and later using the PC interfacing device the values are transferred to the computer. Using the values a graph showing the different cutting forces is generated by the computer. Using this graphs the cutting forces are noted by taking highest peak for the respective force . The sample graph are shown below in Figure 3

Figure 3 Sample graph generated by PC interfacing Dynamometer

The Lathe tool dynamometer is shown in Figure 4 and the PC interfacing unit is shown in the Figure 5

Figure 4 Lathe Tool Dynamometer

Figure 5 PC Interfacing Unit

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The cutting forces which are determined by using the PC - Interfacing dynomometer for every experiment are tabluted below Table 5 for normal machining and Table 6 for Cryogenic machining with their respective machining inputs

- Normal Machining

Variation	Values	Cutting Force (F_c) Kgf	Axial Force(F_f) Kgf	Feed Force(F_t) Kgf
Depth Of Cut	0.3	17	11	9
	0.6	18	14	10
	0.9	23	12	6.2
Speed	88	17	12	10
	192	31.2	6.2	6.1
	325	16	9	6
Feed	0.03	20	13	10
	0.06	27	18	8
	0.09	35.7	17	14

Table 5 Cutting Forces for Normal Machining

- Cryogenic Machining

Variation	Values	Cutting Force (F_c) Kgf	Axial Force(F_f) Kgf	Feed Force(F_t) Kgf
Depth Of Cut	0.3	15.2	6.1	13
	0.6	22	11	18
	0.9	28	21	14
Speed	88	16	9	9
	192	16	11	12
	325	17	8	9
Feed	0.03	6.1	13	6
	0.06	13.1	12	12
	0.09	7	11	8

Table 6 Cutting Forces for Cryogenic Machining

- **Determination of Temperature at cutting Area**

The temperature at the cutting area is measured using the MT-4 Infrared thermometer (Figure 6) for every specimen machining. The temperatures obtained for each experiment are tabluted in the Table 7

Figure 6 MT 4 Infrared thermometer

- Surface Roughness after machining

- Normal Machining

Variation	Values	Temperature at the cutting area (˚C)	Surface Roughness R_a(µm)
Depth Of Cut	0.3	9.5	30.8
	0.6	3.2	30.3
	0.9	11.9	30.7
Speed	88	7.9	28.4
	192	5.1	28.6
	325	3.2	28.7
Feed	0.03	6.5	32.4
	0.06	4.2	30.5
	0.09	18	30.6

Table 7 Temperature at cutting area and surface roughness for Normal Machining

- Cryogenic machining

Variation	Values	Temperature at the cutting area (˚C)	Surface Roughness R_a(µm)
Depth Of Cut	0.3	34.7	23.1
	0.6	15.9	26.3
	0.9	5.2	28.6
Speed	88	12.9	21.4
	192	13.2	18.8
	325	17.7	28.4
Feed	0.03	14.9	18.6
	0.06	14.3	23.1
	0.09	11	21

Table 8 Temperature at cutting area and surface roughness for Cryogenic Machining

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IV. RESULTS AND DISCUSSION

A. Calculations

Using the data acquired in the machining test power consumption is calculated for all the experiments for the both normal and cryogenic machining and tabulated in the Table 9

Power consumption :

P = F * V (watts or kilo watts)

where F = cutting force
V = cutting velocity

Cutting velocity :

$$V = \pi DN \quad \text{(mm/min)}$$

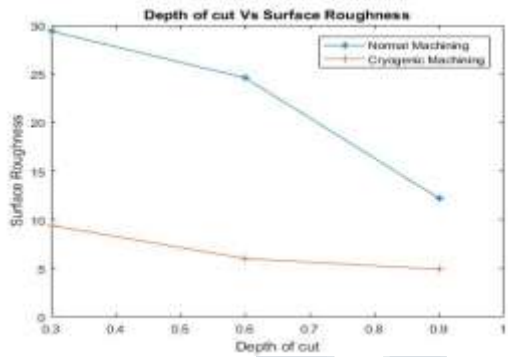
Where D = Diameter of work piece
N = Speed in rpm

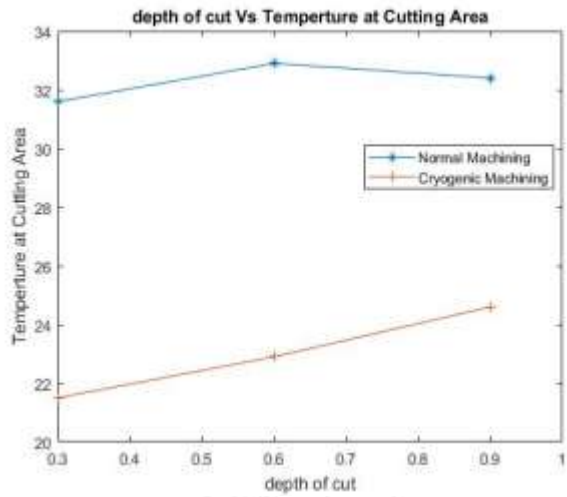
Variation	Values	Power Consumption (watts)	
		Normal Machining	Cryogenic Machining
Depth Of Cut	0.3	23.66	38.46
	0.6	26.03	38.46
	0.9	23.65	39.44
Speed	88	20.79	15.82
	192	12.03	23.66
	325	73.45	36.72
Feed	0.03	12.03	19.72
	0.06	33.53	43.39
	0.09	42.40	8.28

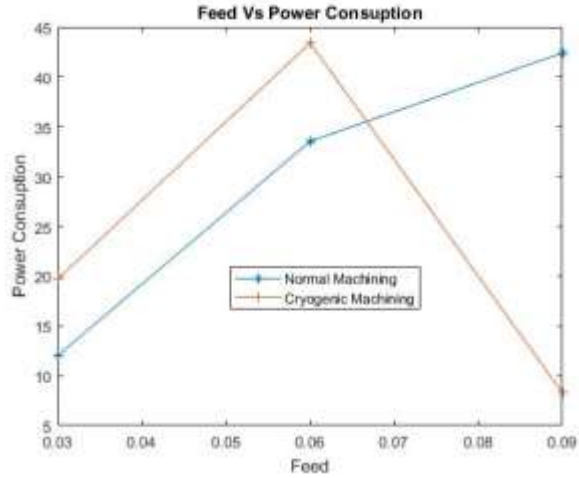
Table 9 Power consumption for both normal and Cryogenic machining

B. Graphs

The graphs are plotted for surface roughness, Temperatures and power consumption using the MAT LAB Software and are shown in Figure 8







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V. CONCLUSION

- Tthe detailed study of the results of the experiment conducted it is clear that the machinability of the Titanium is improved when liquid nitrogen is replaced by the traditional coolant

- The machining of the titanium is one of the major issue in the production sector , this project helps to suggest the correct machinability parameters to machine titanium and helps to study the variation of different machinability parameters while machining titanium

- Good surface Roughness , Low temperatures at the cutting area , Reduced cutting forces are observed when replacing the coolant with the liquid nitrogen (Cryogenic Machining)

- Replacing the LN2 with the traditional coolant will not be a good idea if the production is less as the handling and dispensing costs may be higher if the production is in small scale. Installing of LN2 plant will make the LN2 handling and dispensing Costs

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