A PROJECT REPORT

ON

"Machinability Study Of Titanium Alloy Using Cryogenic Cooling."

Submitted to

UNIVERSITY OF MUMBAI

In Partial Fulfilment of the Requirement for the Award of

BACHELOR'S DEGREE IN
MECHANICAL ENGINEERING

BY

KHAN ABDUL MUJAMMIL AZIZ	**15ME14**
MALIM DANISH SALIM	**16ME40**
SAYYED MOHD ABUZAR MOHD ATHAR	**14ME44**
SHAIKH VAKAS AHMED MUKHTAR AHMED	**15ME53**

UNDER THE GUIDANCE OF
PROF. AFAQAHMED M JAMADAR

DEPARTMENT OF MECHANICAL ENGINEERING
Anjuman-I-Islam's Kalsekar Technical Campus
SCHOOL OF ENGINEERING & TECHNOLOGY
Plot No. 2 3, Sector - 16, Near Thana Naka,
Khandagaon, New Panvel - 410206

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CERTIFICATE

This is certify that the project entitled

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submitted by

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is a record of bonafide work carried out by them, in the partial fulfilment of the requirement for the award of Degree of Bachelor of Engineering (Mechanical Engineering) at ***Anjuman-I-Islam's Kalsekar Technical Campus, Navi Mumbai*** under the University of MUMBAI. This work is done during year 2018-2019, under our guidance. **Date: / /**

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Project I Approval for Bachelor of Engineering

This project entitled "Machinability Study Of Titanium Alloy Using Cryogenic Cooling"

by ***KHAN ABDUL MUJAMMIL AZIZ, MALIM DANISH SALIM, SAYYED MOHD ABUZAR MOHD ATHAR and SHAIKH VAKAS AHMED MUKHTAR AHMED is approved for the degree of*** Bachelor of Engineering in Department of Mechanical Engineering.

Examiners

1. .... 2. ....

Supervisors

1. .... 2. ....

Chairman

....

Declaration

I declare that this written submission represents my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or fal- sified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Student Name
Roll Number:

Contents

ABSTRACT

The challenge of modern machining industries, according to this study, is to attain high quality in terms of dimensional precision, surface finish, high production rate, and cost savings while reducing environmental effect. Several factors influence these objectives, one of which is the cooling lubricant. Many authors have studied machinability with coolant in machining using flood coolant, MQL, and cryogenic cooling, and it has been discovered that the kind of coolant, cutting speed, feed rate, and depth of cut all effect surface finish, cutting forces, chip formation, and tool wear. Because there is very little research on water vapour as a coolant in the literature, it was chosen to investigate the machinability of titanium alloy with the introduction of this environmentally friendly coolant.

Keywords – Flood coolant, Cryogenic cooling, and
Environmental friendly coolant.

INTRODUCTION

• Titanium alloys are metals that contain titanium and other chemical components in varying proportions. (See Table 1) The tensile strength and toughness of such alloys are extremely high (even at extreme temperatures). They are low in weight, have excellent corrosion resistance, and can sustain high temperatures. Because of their high strength-to-weight ratio, outstanding corrosion resistance, and high temperature adaptability, they are key engineering materials for industrial applications. Titanium alloys have long been popular in the aerospace and aircraft industries due to their ability to maintain high strength and corrosion resistance at high temperatures. They're also becoming more common in the chemical, automotive, medicinal, and nuclear industries.

Material	Content
C	< 0.08 %
Fe	< 0.25 %
N2	< 0.05 %
O2	< 0.2 %
Al	5.5 – 6.76 %
V	3.5 – 4.5 %
H2 (Sheet)	< 0.015 %
H2 (Bar)	< 0.0125 %
Ti	Balance

Table 1 : Composition of Titanium alloy In S.I unit

• In terms of machining, titanium and its alloys are the most difficult materials to work with. Many difficult-to-machine materials can now be machined at higher metal removal rates because to advancements in cutting tool materials. Because of their chemical affinities with titanium, none of these tool materials appear to be useful in machining titanium. Titanium machining isn't helped by new developments in tool coating.

• The coating has a poorer thermal conductivity than the tungsten carbide insert, preventing heat dissipation at the cutting spot due to excessively concentrated high stress and high temperature. Because of their chemical affinities, titanium carbide and titanium nitride coatings are not appropriate for machining titanium alloys. As a result of the lower cutting temperature and improved chemical stability of the work piece and tool, cryogenic machining is projected to considerably increase productivity in the machining of titanium and its alloys. The majority of cryogenic machining experiments [5–14] on titanium and its alloys have shown that freezing the work piece or cooling the tool with a cryogenic coolant improves machinability.

• Cryogenic machining is a machining method in which a jet of liquid nitrogen replaces the typical lubro-cooling liquid (an emulsion of oil in water). Cryogenic machining is advantageous in harsh machining operations because it extends tool life. In finish machining procedures, it can also be useful to maintain the integrity and quality of the machined surfaces. Researchers have been conducting cryogenic machining studies for several decades, but commercial uses are currently limited to a few companies. Both turning and milling cryogenic machining are feasible. The machinability of Titanium alloy (Ti-6Al-4V) was investigated using both cryogenic and water-based coolants. MRR, cutting forces, and surface roughness values were measured in both environments. The results obtained using cryogenic coolant are superior than those obtained with water-based coolant.

PROPERTIES OF TITANIUM ALLOY

• Titanium is so highly valued due to its interesting properties. The key properties of titanium are:

Property	Typical value
Density	4.42
Melting Range	1649±15˚C
Specific Heat	560
Thermal Conductivity	7.2
Tensile Strength	897
Compressive Strength	848
0.2% Proof Stress	828
Elastic Modulus	114
Hardness	3730
Charpy, V-Notch Impact	24
Welded Bend Radius x Thickness	6

Table 2 : Properties of Titanium alloy

• **Strength** - When titanium is alloyed with other metals and elements, it becomes extremely strong. This can result in the desired level of ductility or strength. Titanium has the same tensile strength as steel.

• **Lightweight** - Titanium is also lighter than steel and has comparable strength. This is an excellent quality for medical and construction applications. Builders like titanium's excellent strength-to-weight ratio because they're always looking for ways to make stronger buildings using lighter materials.

• **Corrosion-resistant** - Most types of corrosion are resistant to titanium. In the presence of salt water, acids, and other chemical solutions, most metals will corrode; however, titanium is surprisingly resistant to them. Unlike steel, titanium is also resistant to stress corrosion cracking.

• **Biological Compatibility** - Because of its bio-inert properties, titanium can be employed inside the human body. This means titanium is non-toxic to humans and will not be rejected as readily when used in procedures like Osseo integration, which involves fusing a foreign object to human bone to give structural support for prosthesis or implants.

APPLICATION OF TITANIUM ALLOY

Titanium is a fantastic metal to deal with because of the wide range of qualities it contains. Titanium can be used for a variety of purposes, including the following:

• **Medical** - Titanium has become one of the most extensively used metals in the medical profession. It's bio-inert, meaning it won't react with anything within the body, making it an excellent choice for dental implants, orthopaedic rods, bone plates, and other prosthesis. It can also be used to make scalpels and drills, among other medical devices.

• **Aircraft** - Titanium is most commonly used in aircraft construction. Titanium is the most commonly utilised metal in the manufacture of jet engines and airframes. Because of its small weight, it is particularly useful for improving jet efficiency.

• **Automotive** - Titanium is a common material in the automobile and motorbike industries. Because these machines have so many moving components, they require a lot of tough material. Titanium alloys are great for parts like rods, valves, and camshafts in automobiles and motorcycles. These kind of titanium parts are essential in the racing sector.

• **Industrial** - Titanium is also used in a variety of industrial applications. New applications for titanium in building are constantly being explored. Because it is lightweight and corrosion resistant, it is a good building material for outdoor applications.

• **Chemical Processing** - Titanium is useful in the chemical and pharmaceutical industries, where equipment is frequently exposed to caustic and toxic compounds.

• **Other** - Titanium is used in a wide range of sectors, including jewellery, clocks and watches, eyeglasses, and golf. These consumer goods are more durable and appealing. Titanium has also piqued the interest of the marine industry, as materials in constant contact with salt water require greater corrosion resistance.

DEVELOPMENT OF CRYOGENIC COOLING

• Low-temperature method has been studied since the mid-nineteenth century. The principles of thermodynamics advanced during that time period, while the earliest contributions to cryogenic research worked between 1850 and 1900. (See Figure 1). There was essentially no practical use of the applications at first, and the subject was solely of intense curiosity to scientists. [2] The initial challenge was to figure out how to get low enough temperatures to liquefy gases like oxygen, nitrogen, hydrogen, and helium. The liquefaction technology was transferred in the first half of the twentieth century. The production of oxygen for the welding industry was the initial use in the manufacturing sector. The first cryogenic machining was described in 1953. W.S. Hollis claimed in 1961 that utilising water as a coolant for machining titanium alloys might extend the life of carbide tools. [3] Increased material removal rates in machining titanium using and were reported by researchers at Grumman Aircraft Manufacturing in the 1960s. In 1970, Uehara and Kumagai tried machining titanium alloys, carbon steels, and stainless steels. Their findings revealed that different metals behave differently, with variable effects on tool life, surface roughness, and flank wear. Several cryogenic liquids are available, but they are nearly solely used in machining operations. To tell the difference between liquid and. Low temperatures are caused by a mechanism that has to be understood. [4]

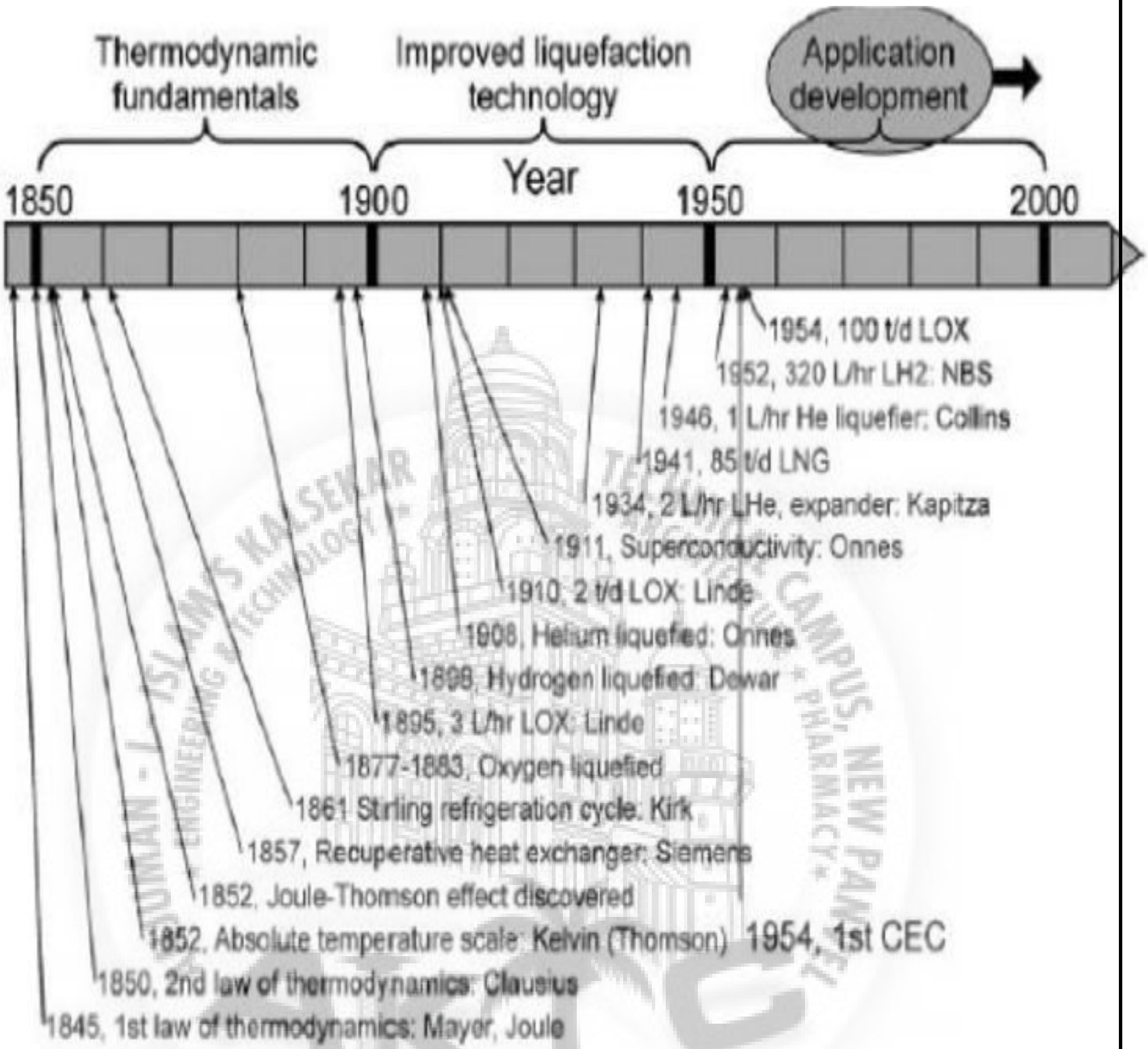

Figure 1 : A timeline for early milestones in cryogenic technology

SUPPLY OF CRYOGENIC COOLING

• Machinability of titanium alloys under cryogenic coolants (Liquid Nitrogen) has been determined to be excellent. Friction generates heat between the cutting tool and the workpiece while cutting. The heat generated will be transported away by chips, with the remainder dispersing into the work piece and cutting tool. The absorbed heat softens the cutting tool (poor performance), resulting in deformation, production of a built-up edge, or cutting tool failure, resulting in surface defects on machined samples [5]. To combat this, cryogenic liquid is delivered to the cutting zone by a variety of methods and equipment. The liquid is held in tanks that are cylindrical or spherical in shape, with pressure control and a vaporizer. The pressure in the tank forces the coolant to the cutting zone during the spraying operation, and no additional energy is required for the application.

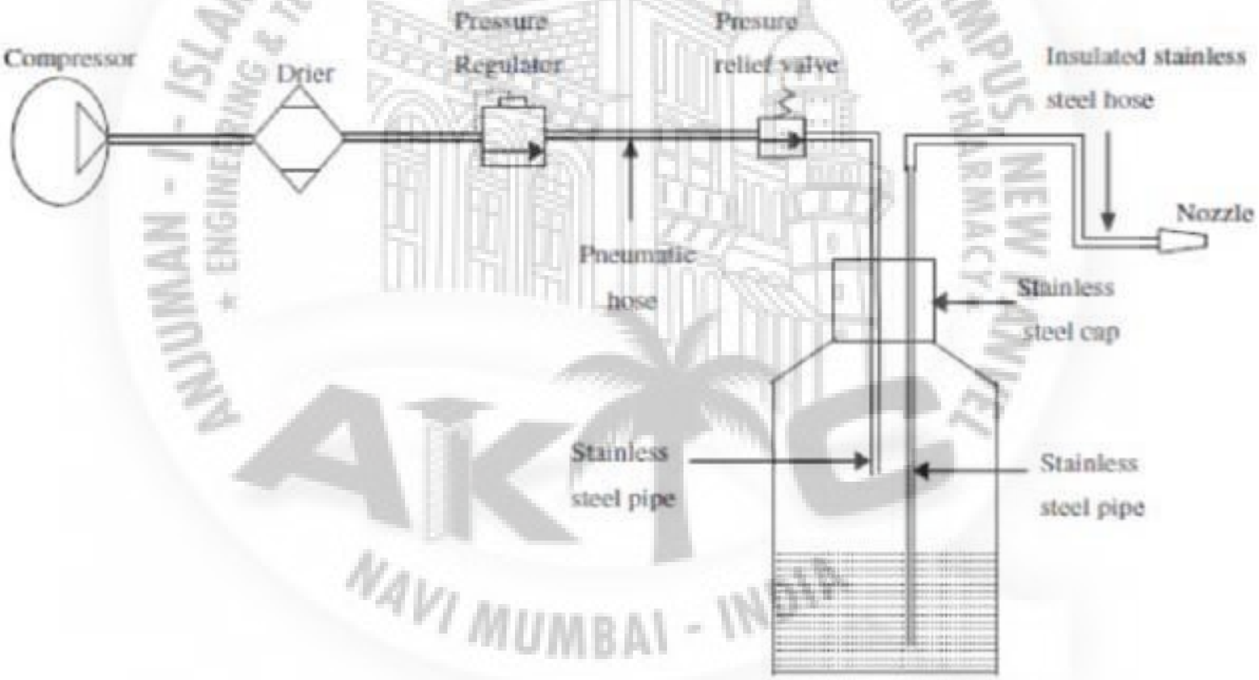

FIGURE 2 : Schematic diagram of cryogenic cooling setup

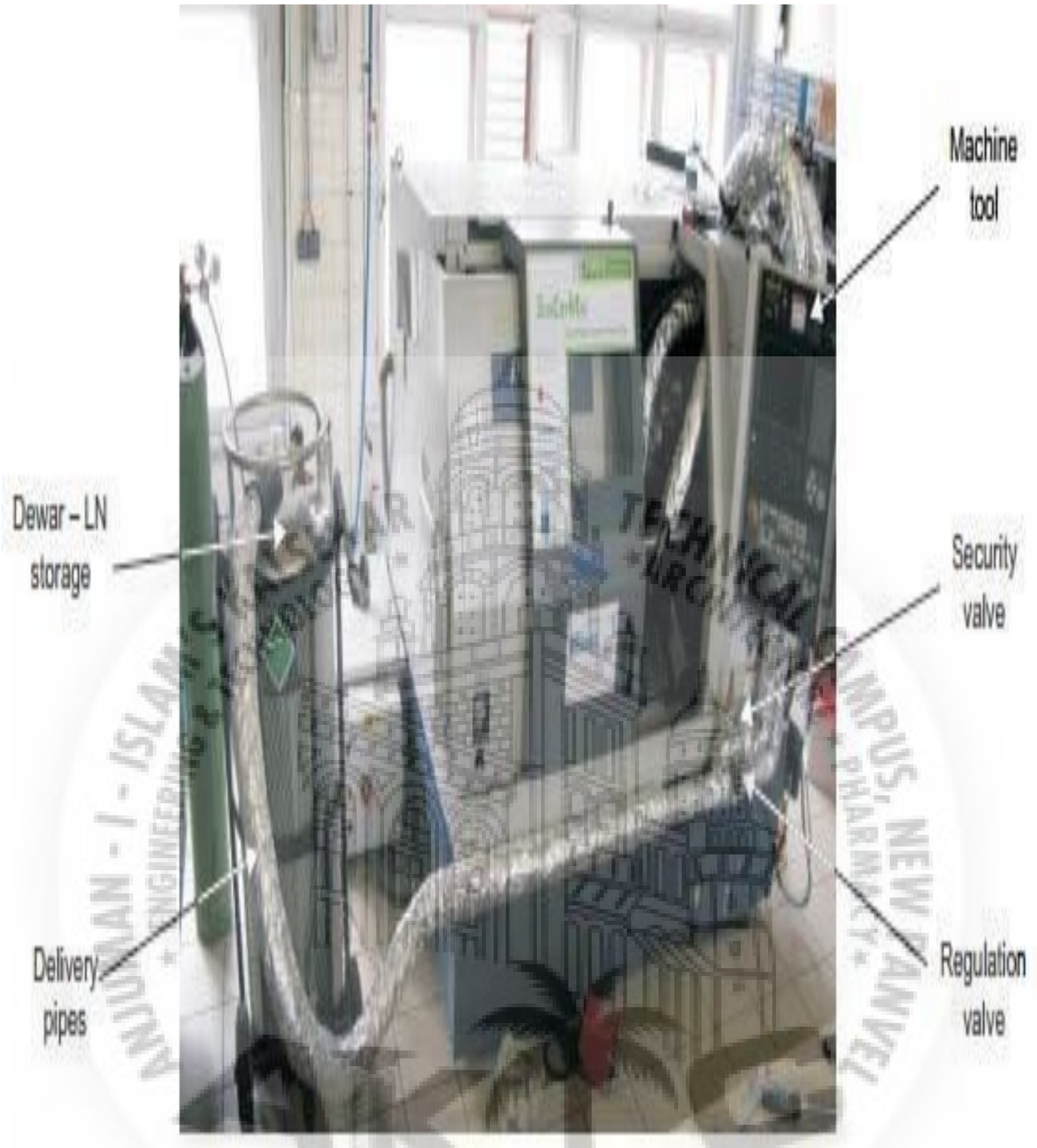

Figure 3 : Cryogenic Machining Setup

POTENTIAL BENEFITS OF CRYOGENIC COOLING

Machining of Titanium alloy in cryogenic conditions is better than cutting under aqueous coolants (Table 2).Various Advantages reported by the investigators are as follows:

(¡)sustainable machining methods (cleaner, safer, environment friendly) to eliminate numerous costs associated with conventional cutting fluids and clean-up operations (ii) increase of material removal rate without increases in worn tool and tool change over costs (iii) increase of productiofvity (iv) increasing cutting speeds without increases in worn tool and tool change over costs (v) increasing of tool life due to lower abrasion and chemical wear (vi) machining of hard parts and hard to machine alloys, which in the past, could have been produced only via expensive grinding operations (vii) surface roughness of machined workpiece improvement (viii) produced parts quality improvement by preventing mechanical and chemical degradation of machined surface (ix) potentially lower investment costs due to reduction in number of machine tools required (x) improvement of manufacturing flexibility due to reduced production times and high output, etc

Category	Unites	Mineral oil	Anionic surfactant	Nonionic surfactant	Liquid nitrogen
Energy use	MJ	5.94	60.20	51.50	1.80
Global warming potential (GWP)	kg CO_2eq	3.56	3.00	5.60	0.00
Water use	kg	0.00	6.00	0.00	*50.00
Acidification	g SO_2eq	3.83	25.00	15.80	0.00
Solid waste	g	5.19	64.20	27.10	0.00
Land use	m²	0.00	0.00	0.00	0.00

* cooling water at 15 °C

Table 3 : Comparison with other coolants

PROCESS PARAMETERS FOR MACHINING TITANIUM ALLOY

Process parameters are important in every machining operation. In order to get the highest efficiency of the selected combination of cutting tool and material, the process parameters have to be optimized. That can be a highly complex process but necessary to stay competitive. Whether it's the flow rate of the coolant, the shape of the tool the cutting parameters, the slightest deviation can have massive impact on the process. [7]

1. Flow Rate and Pressure of Cryogenic Supply

The flow rate of external supply of LN_2 has mostly been reported in combination with turning operations. The range is from 0.5 kg/min to 3.36 kg/min at pressure of 1.4-24 bars with the most common combination with flow rate less than 1 kg/min with pressure from 7.5-15 bars [8, 9, 10]. Dhananchezian is the only one to report about pressure from internal application of LN_2 at pressure of 3 bar. The only occasion, the flow rate was mentioned in an article concerning milling operation with LN_2 the flow rate was 4.2 kg/min. For the flow rate of CO_2 the flow rate was rarely mentioned. Schaarschmidt and Machai performed tests with internal application of CO_2, where Schaarschmidt milled with a flow rate of 0.48 kg/min and Machai et al. used a flow rate at 2.72 kg/min in a turning operation.[11] Bermingham. And Klocke used external CO_2 in turning operations at 8.2 and 6 bar pressure respectively. [12]

1. To minimize the time and to get the maximum output work with the help of 3 in 1 draw out panel.
2. To increase the efficiency of the panel.

2. Cutting Parameters

Titanium-based alloys have greater cutting parameters on average than nickel-based alloys. The cutting speed was usually evaluated between 70 and 150 m/min, with a feed rate of 0.10 to 0.25 mm/rev]. 13 and 14 The two outliers were Venkatesh and Dhananchezian, who tested at cutting speeds of 300 m/min and 27 m/min, respectively, with depths of cut ranging from 0.30 to 2.00mm. (15)

COMPONENTS

Titanium Alloy (Ti6Al4V)

- Taking Titanium Alloy of 13mm diameter and 1300mm length.
- Cutting this titanium alloy into 70mm length each.
- We will have 18 pieces of 13mm diameter and 70mm length.
- We are going to test only on 9 pieces in case any error occurs for that reason we have kept 9 extra pieces of Titanium Alloy.

Vortex Tube

- The Vortex Tube, also known as the Raque-Hilsch Vortex tube,is a mechanical device that separates a compressed gas into hot and cold streams.
- The gas emerging from the hot end can reach temperatures of 200°C and the gas emerging from cold end can reach -50°C
- It has no moving parts

VORTEX TUBE WORKING/OPERATIONS .

- Compressed air enters the chamber.
- Stationary Generator generates a Vortex @ 1,000,000 rpm.
- Outer Vortex gains energy due to friction .
- This hot outer Vortex is exhausted or vented through an adjustable valve .
- Ramming air flows back to the generator in the opposite direction of the outer Vortex .
- Due to the reverse Vortex flow, the energy level of the molecules reduces so it gets cooled.
- This cooled air is expanded through a nozzle and air becomes Super cooled.

VORTEX TUBE WORKING/OPERATIONS.

- Vortex Tube can generate refrigeration up to 1800 watts by using filtered air compressed to 7 bar.

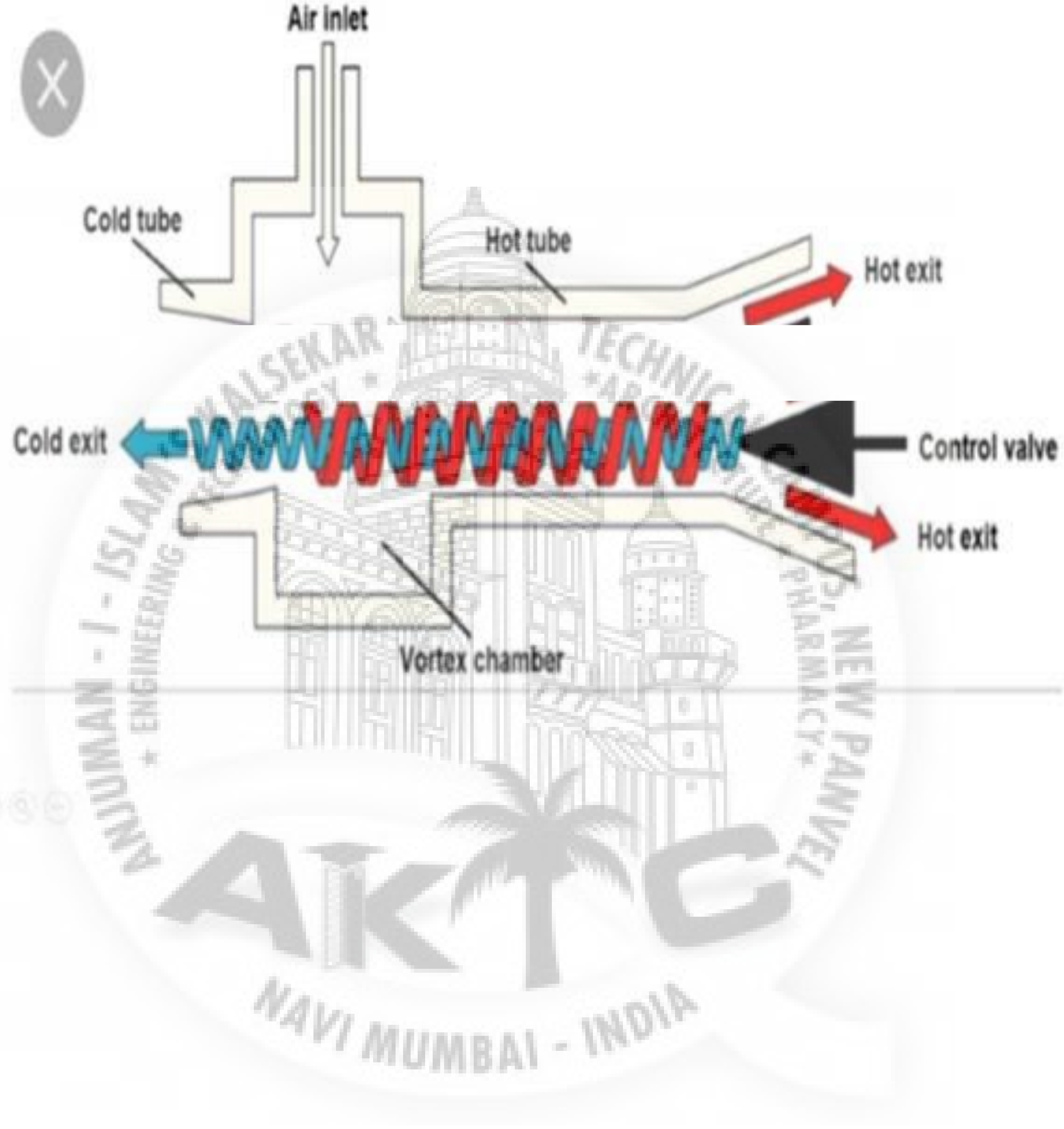

FIGURE 4 :- WORKING OF VORTEX TUBE

ADVANTAGES OF VORTEX TUBE

- No leakage problem as air is used as refrigerant.
- Low initial cost.
- Less space.
- Simple in design.
- Light in weight.
- No moving parts.
- Simple maintenance and no skilled labour's required.

DISADVANTAGES OF VORTEX TUBE

- Limited Capacity.
- Low COP.
- Small portion of air is appearing as chilled and major portion is heated.

APPLICATIONS OF VORTEX TUBE

- Commonly used in inexpensive spot cooling of cutting tools in lathes and Milling machines , when compressed air is available
- It can be used for removal of chips produced by tools.

PROCEDURE

Performing turning operation on a samples of Titanium (Ti-Al-4V) alloy which are of 13 mm diameter and 90 mm length respectively. The turning operation performed on this 9 samples is upto 40 mm length. While performing the turning operation the speed and feed are varying for each samples and the depth of cut is kept constant. The different speed used are 60 m/min, 70 m/min & 80 m/min. And the different feeds are 0.08 mm/rev, 0.16 mm/rev & 0.32 mm/rev respectively. The different speed and feed used for each sample is shown in Table.1. The compressed air which is used as coolant while performing the turning operation is made to pass through a vortex tube. The vortex tube also known as Raque-H, ISICH vortex tube, is a mechanical device that separate's a compressed gas into hot and cold streams. The gas emerging from hot end can reach temperature of 200°c and the gas emerging from cold end can reach upto 50°c. It has no moving parts. In our case the compressed air which we are getting from the compressor is at a temperature of 32°and a pressure of 6 bar. When this compressed air is allowed to pass through vortex tube the temperature of compressed air obtained is -3°c and a pressure of 5 bar is obtained.

Sample	1	2	3	4	5	6	7	8	9
Speed (m/min)	60	60	60	70	70	70	80	80	80
Feed (mm/rev)	0.08	0.16	0.32	0.08	0.16	0.32	0.08	0.16	0.32
Depth of cut (mm)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 4

After Performing the turning operation on all 9 samples with the respective speed, feed & depth of cut. The chip for each sample is collected to measure the chip thickness. The chip is always greater than uncut chip thickness. This is because during cutting, the cutting edge of the tool is positioned at a certain distance below the original work surface. This corresponds to the thickness of the chip prior to the chip formation. As the chip is formed along the shear plane, its thickness increased to tc. The chip thickness is measured with the help of digital vernier caliper. The chip thickness is obtained for each sample is shown in Table.5

Sample	1	2	3	4	5	6	7	8	9
Speed (m/min)	60	60	60	70	70	70	80	80	80
Feed (mm/rev)	0.08	0.16	0.32	0.08	0.16	0.32	0.08	0.16	0.32
Depth of cut (mm)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Chip thickness (mm)	0.38	0.34	0.32	0.36	0.31	0.29	0.37	0.3	0.27

Table 5

The chip thickness ratio is then measured, once the chip thickness is measured. In the metal cutting process, the chip flow of the metal is shorter & thicker than the metal prior to the cutting because of plastic deformation. The extent of the variance in dimension is denoted by the chip thickness ratio or cutting ratio is defined as the ratio of thickness before cutting to the thickness after cutting. It is denoted by γ. Whenever there is high cutting ratio it means the cutting action is good. But cutting ratio will always be less than unity. The chip thickness ratio obtained for different samples is known in Table.6

Sample	1	2	3	4	5	6	7	8	9
Speed (m/min)	60	60	60	70	70	70	80	80	80
Feed (mm/rev)	0.08	0.16	0.32	0.08	0.16	0.32	0.08	0.16	0.32
Depth of cut (mm)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Chip thickness (mm)	0.38	0.34	0.32	0.36	0.31	0.29	0.37	0.3	0.27
Chip thickness ratio (mm)	0.5263	0.5882	0.625	0.555	0.645	0.689	0.5405	0.666	0.7407

Table 6

[A] EFFECT OF CUTTING SPEED ON CHIP THICKNESS RATIO.

It is observed from the plot that cutting speed is a linear relationship with chip thickness ratio.AS the cutting speed increases from 60m/min to 70 m/min the chip thickness ratio also increases. Further as the cutting speed increases from 70 m/min to 80 m/min, the chip thickness ratio also increases. The chip thickness ratio is minimum at 60 m/min cutting speed and maximum at 80 m/min cutting speed Fig.1 shows the effect cutting speed on chip thickness ratio.

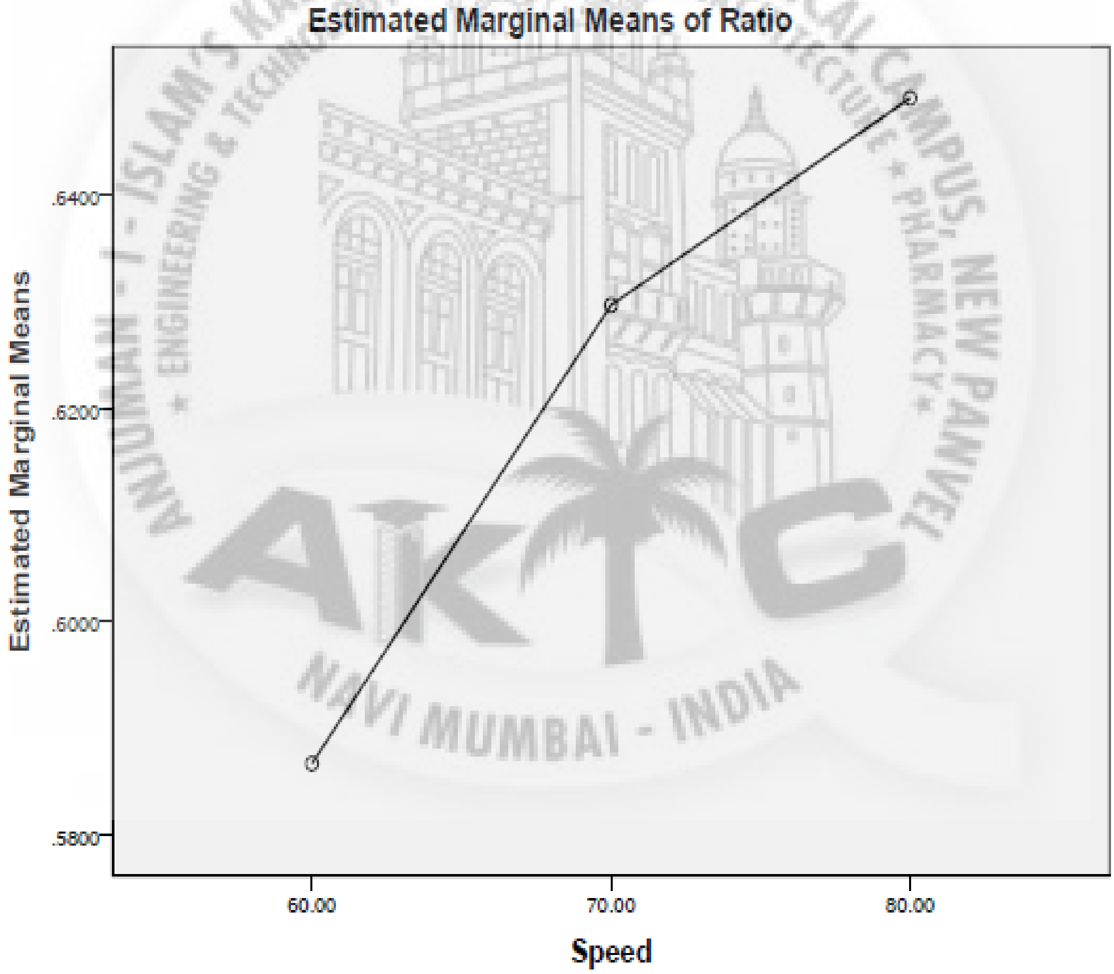

Figure 5

[B] EFFECTS OF FEEDRATE ON CHIP THICKNESS RATIO.

The effects of feed rate on chip thickness ratio show that the federate has linear relationship with the chip thickness ratio. At 0.08 mm/rev federate the chip thickness ratio is minimum. As the federate increases to 0.16 mm/rev the chip thickness ratio also increases. And at 0.32 mm/rev feed rate the chip thickness ratio is maximum Fig.2 shows the effect of federate on chip thickness ratio.

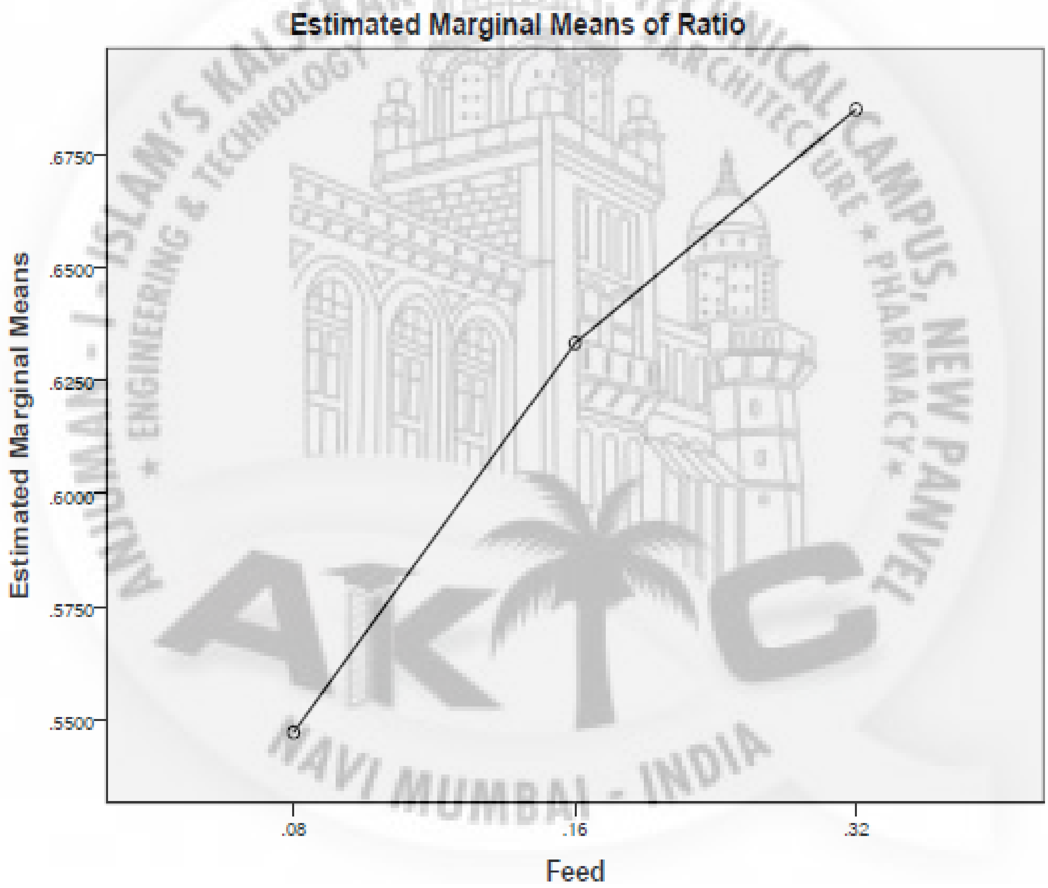

Figure 6

[C]INTERACTION BETWEEN CUTTING SPEED AND FEEDRATE.

It is observed that when cutting speed and feed rate, both this variables are kept at minimum value, the chip thickness ratio is minimum. Gradually as we increase the values of both the variables, the chip thickness ratio also increases. And the maximum chip thickness ratio is obtained when both cutting speed and feed rate are kept maximum Fig.3 shows the effect of cutting speed and feed rate.

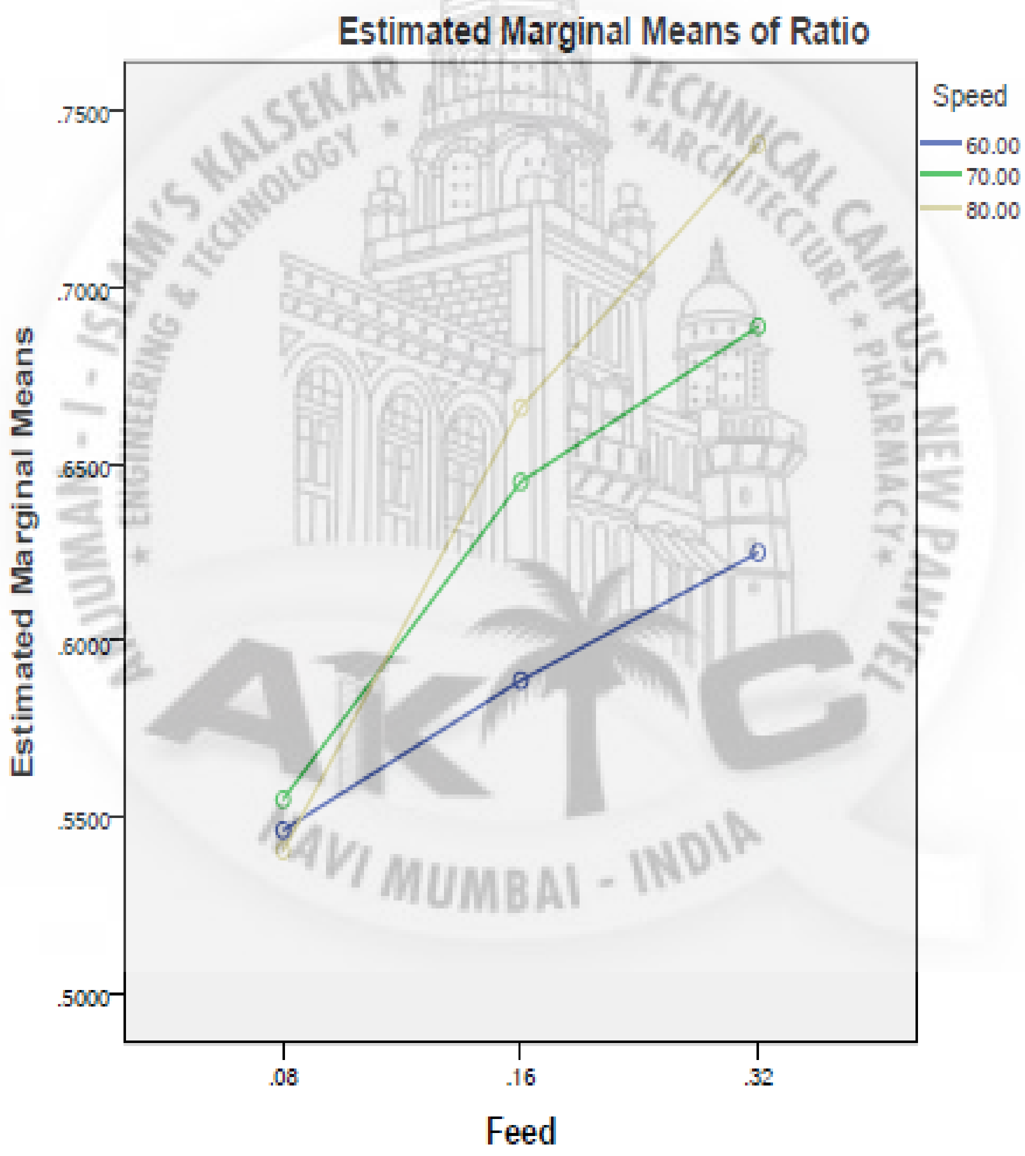

Figure 7

3.ANALYSIS OF VARIANCE (ANOVA) FOR CHIP THICKNESS RATIO.

It is observed from the ANOVA table that the feed rate influence the chip thickness ratio when compared to cutting speed.

Tests of Between−Subjects Effects

Dependent Variable: Ratio

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.039a	8	.005	.	.	1.000
Intercept	3.480	1	3.480	.	.	1.000
Speed	.006	2	.003	.	.	1.000
Feed	.029	2	.015	.	.	1.000
Speed * Feed	.004	4	.001	.	.	1.000
Error	.000	0	.			
Total	3.519	9				
Corrected Total	.039	8				

a. R Squared = 1.000 (Adjusted R Squared = .)

Table 7

CONCLUSION

i. It is observed the feed rate and interaction between the cutting speed and feed rate shows significant influence on the chip thickness ratio.

ii. It is observed that with increase in speed the chip thickness ratio also increases. At 60 m/min the chip thickness ratio is lowest and at 80 m/min the chip thickness ratio is highest.

iii. The effect of feed rate on chip thickness ratio shows that the feed rate has almost linear relationship with chip thickness ratio. It is observed that the chip thickness ratio increases with an increase in feed rate during machining. At 0.08 mm/rev the chip thickness ratio is less. And at 0.32mm/rev the chip thickness ratio is more.

iv. It is observed that highest chip thickness ratio is produced when speed and feed rate both are more. And lowest chip thickness ratio is produced when speed and feed both are less.

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