A Critical Review on Machining Of Titanium and Its Alloy under Cryogenic Cooling Environment

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Abstract. Titanium and its composite has superb properties, for example, high clear cut quality, consumption obstruction, light weight which makes it generally fitting for application in biomedical, aviation and vehicle area and so forth. Titanium composite has helpless machinability on the grounds that the low warm conductivity & high pressure so extortionate tool wear during machining of titanium combination and lead to higher machining cost. In this circumstance, cryogenic machine set-up is used for development of machinability and lower instrument wear rate. This exploration article accommodating for give great rundown on machining of titanium amalgams with cryogenic cooling climate. Additionally, these audit paper can be strong to survey, comprehend the machinability of titanium combinations and determination of the machining cycle.

Keywords: Titanium alloy; Tool wear; Cryogenic cooling; Machinability.

1. Introduction

Titanium alloy has, superb properties e.g. strength retention, corrosion resistance at high temperature due to these properties it is mostly applicable in biomedical, aerospace, petroleum and automotive industries. Fig. 1. Represents the early milestones in cryogenic technology.

Fig. 1. History of cryogenic machining process [6]
Titanium alloy is hard to cut materials on the grounds that contrasted with aluminum, carbon, hardened steel and so forth cutting velocity of these materials is exceptionally restricted, for example, if speed of titanium compound are between 60 m/min to 100 m/min then tungsten carbide and HSS instrument is utilized separately. Cryogenic and MQL machining is utilized for improve machinability of difficult to cut material. Therefore, MQL and cryogenic cooling machining are considered as feasible answer for machining of various to cut materials [1].

In 1953 initially imagined machining by cryogenic cooling CO2 [2]. In 1961 W.S. Holi expressed that when machining of titanium compound utilizing cryogenic CO2 as a coolant at that point device life is additionally increment [3]. Airplane producing by Grumman revealed about expands MRR (Metal expulsion rate) in machining of titanium with LN2 and CO2 [4]. Tested works completed on machining of titanium amalgam, tempered steel and carbon with cooling climate and locate that distinctive conduct for various metals and having impact on device life, SR and flank wear [5]. Various sorts of cryogenic coolant are accessible for machining yet generally CO2 and LN2 is utilized as a coolant. To recognize fluid LN2 and CO2, we need to investigate further the system making the low temperatures happen. Fig. 2 shows schematic phase diagrams for nitrogen gasses & carbon dioxide.

![Schematic phase diagrams for CO2 and nitrogen.](image)

Machining measure assume significant function in assembling businesses. Numerous individuals were researched on the diverse machining cycle and cooling climate to upgrade the machining execution of titanium and its combination. For maximize the tool life, different types of coated tool is used e.g. PVD, coated carbide, CVD coated carbide, CBN and PCBN. These all types of coated tool are providing longer tool life.

| Work Piece       | Cooling Environment                     | Response Variables       | Tool                  |
|------------------|-----------------------------------------|--------------------------|-----------------------|
| Titanium & its alloy | Cryogenics cooling (Internal, external, hybrid & indirect cooling) | Tool life(TL), Ra, Cutting force, Chip morphology (CM), Cutting temperature | CVD coated carbide tool, PVD coated carbide tool, PCBN, CBN, Ceramic |

In this paper a short writing survey on machining of titanium and its composite under various cooling climate. Table.1 present the aspect of study covered in this review paper.

2. Process on machining of cryogenic cooling system

In this machining cycle cryogenic fluid (LN2 and CO2) is provided by various way and machine arrangement to cutting area. These cryogenic fluids are put away fit as a fiddle barrel shaped and circular with pressure control and vaporizer. During the time spent splashing the cryogenic cooling, the weight in the tank itself powers the coolant to the cutting zone and no supplemental energy is required.
The inside cooling is given through an extraordinarily planned device where the nitrogen or CO2 enters the cutting zone in the most proximate vicinity to the apparatus chip-work piece interface surface. The outer cooling can either be given utilizing by a spout which is arranged to point the coolant where required or through a cap-like repository which can be used in turning activities where the supply is put over the addition. Fig. 3 show machining set-up of cryogenic innovation.

![Fig. 3. Schematic diagram of cryogenic cooling setup [8]](image)

3. Literature survey

L.Shakeel Ahmed et.al [09] in this research paper experiment work was carried out on titanium ASTM B265 grade utilized as work piece with PVD coated insert. In the experiment input process parameter e.g. feed rate & cutting speed with constant depth of cut. After this experiment work ascertain that 6-65% minimization in cutting temperature when LN2 is utilized, for LN2 coolant condition higher thrust force were recorded and higher surface roughness (Ra) but hole quality is not auspicious in LN2 coolant supply. K.A.Venugopal, S.Paul et.al [10] in this paper trial examination on Ti-6A-4A by turning activity with microcrystalline uncoated carbide embeds. Investigation work was completed under wet, dry and cryogenic cooling condition in the cutting speed scope of 70-100m/min. Also, found that apparatus life is augmented by utilized fluid nitrogen as a coolant through diminishing in grip disintegration device wear through controlled machining temperature and machining parameters. Shane Y.Hong et.al [11] has been developed an incipient cooling approach. The cooling method / approach implemented a minimum quantity of LN2 injected by micro nozzle setup between the tool rake and the chip breaker. In this approach, not wasted of coolant in dispensable areas. This types of cooling approach is better than other cooling approach because in this approach improvement of implement life.

Kyung-Hee park et.al [12] in this paper have been analyzed the machining performance with different cutting approach such as cryogenic, flood cooling and MQL on end milling machine. Developed a specially liquid nitrogen spray system for evaluating cutting force and tool wear of machining condition. After this investigation found that improve tool life by the combination of MQL and internal cryogenic cooling environment compared to other conventional cooling method. Cutting force also reduced. Mohd Azlan Suhaimi et.al [13] in this paper, for improve machinability and tool life the novel cryogenic (indirect cryogenic) method is developed. In this type of mechanism novel cryogenic cooling approach compared with other cooling method and LN2 is utilized as a coolant medium. For novel cryogenic machining, a specially designed tooling unit that able to supply the liquid nitrogen. After this investigation found that novel cryogenic cooling method improve machinability of Ti-6A-4V, improve tool life by 90% and reduced cutting force by 54% compared to conventional flood cooling method. Fig. 4. show cutting force underdifferent machining conditions. And Fig.5. show flank wear under different cooling cooling conditions.

Alborz shokrani et.al [14] in this paper built up another cooling approach, for example, half and half cryogenic cooling MQL cooling/grease contrasted & flood cooling, MQL and ordinary cryogenic cooling. The examination work was completed on Ti-6Al-4V with covered strong carbide device in end processing machine set-up and discovered another mixture cryogenic MQL approach expanded instrument life of multiple times and half expanded profitability contrasted and other cooling method. Upendra kumar et.al [15] in this paper built up another cooling approach, for example, half and half cryogenic cooling MQL cooling/grease contrasted and MQL, flood cooling and ordinary cryogenic cooling. The examination work was completed on Ti-6Al-4V with covered strong carbide device in end processing machine set-up and discovered another mixture cryogenic MQL approach expanded instrument life of multiple times and half expanded profitability contrasted and other cooling method. Damir et.al [16] in this paper research work carried out on
Ti-6Al-4V with wet cooling and cryogenic cooling approach in turning operation. After this investigation found that cryogenic cooling approach significantly improved tool life and surface roughness compared to other cooling conditions.

Figure 4. Showing force for all lubrication methods [13]

Figure 5. Showing flank wear for all lubricant methods [13]

Vinothkumarsivalingam et.al [17] in this paper experimental work was carried out on Ti-6Al-4V alloy with PVD NBN coated tungsten carbide tool under different condition such as untreated condition and cryogenic treated condition (i.e. 24h and 48h). After this experimental investigation found out that machinability and tool life increased by utilized cryogenic treated condition. Sanjeev kumar et.al [18] experimental work was carried out on Ti-5Al-2.5sn alloy by using Electro discharge machining under different process parameter. And find out that current is most significant parameter which is affected on TWR compared to other process parameter. Table 2. Shows experiment result.

Table 2.

| Source of variation | DF | Seq.SS  | Adj.MS   | F      | P     | Remark         |
|---------------------|----|---------|----------|--------|-------|----------------|
| CT of electrode     | 1  | 11.147  | 11.147   | 15.19  | 0.005 | Significant    |
| Peak current (Ip)   | 2  | 402.958 | 201.479  | 274.54 | 0.000 | Most Significant|
| Pulse-on-time (Ton) | 2  | 9.168   | 4.584    | 6.25   | 0.023 | Significant    |
| Pulse-off-time (Toff)| 2  | 4.099   | 2.049    | 2.79   | 0.120 | Not Significant|
| Flushing pressure   | 2  | 7.995   | 3.998    | 5.45   | 0.032 | Significant    |
| Residual error      | 8  | 5.871   | 0.734    |        |       |                |
| Total               | 17 | 441.238 |          |        |       |                |

Renu.K.Shastri et.al [19] has been investigation on cryogenic treated copper and brass tool which were used for machining of Ti-6Al-4V. The experimental work was carried out on these parameters such as voltage (V), pulse on time(Ton), pulse off time(Toff) and current(I) with response viz. TWR, radial overcut and metal removal rate(MRR). After this investigation observed that radial over cut and tool wear rate reduced by using cryogenic treated copper and brass tool. Fig.6. represent graph between MRR with input variables. Fig.7. similarly shown variation of TWR with input variables.

Y.Sun,B.Hung et.al [20] main focus of this paper is that improvement of surface roughness and hardness by utilizing cryogenic machining compared to the flood cooling and dry machining. after this investigation found that cryogenic machining amend surface roughness by 35% and 6.6% respectively. Additionally, the hardness is increased 33.6% and 14.7% by utilizing cryogenic machining compared to other machining.
Fig. 6. Showing MRR together I, Ton, Toff and V for Cryogenic method treated copper electrode [19]

Fig. 7. Showing of TWR with Ton, I, Toff and V [19]

(a)  
(b)  
(c)  

Fig. 8 Ra of machined surface of of Ti-6Al-7Nb alloy: (a) Showing Surface of dry machining; (b) Showing Surface of flood- cooled machining; (c) Showing Surface of cryogenic machining system [20]

**Shoujin sun et.al [21]** the paper presents a effect of cryogenic compressed air on cutting force and tool life during machining of Ti-6Al-4V. After this investigation found that tool life is increased compared to dry machining process. Fig. 9 shows snapshots of infra-red image.

Fig. 9 Showing (a) and (b) between 0 and 5.4 s, (c) between 16.2 and 21.6 s, (d) between 37.8 and 43.2 s. (a) and (c) are machining with dry machining , (b) and (d) are machining with cryogenic compressed air cooling system [21]
**Stano imbrogno et al.** [22] for forecast of cutting power, temperature and machining-instigated miniature basic adjustments during machining of Ti-6Al-4V under dry with cryogenic cooling condition built up a 3-D limited component model. The mathematical model is tentatively adjusted and approved. **Y. Sun et al.** [23] in this paper trial examination was done on Ti-5553 under cryogenic machining contrasted and the flood cooling, MQL for investigation of cutting power, device wear and surface harshness. After this examination discover that slicing power decline up to 30% by used cryogenic machining and MQL give higher surface harshness. Additionally, created limited component model of reproduce cutting power.

**M.Dhananchezian et al.** [24] in this examination article, cryogenic machining contrasted and the wet machining for investigation of cutting power, surface harshness, device wear and cutting temperature of Ti-6Al-4V on turning activity. After this examination results was that cutting temperature, surface unpleasantness, cutting power and flank wear diminished 66%, 36%, 35-42%, 27-35% separately by used cryogenic machining contrasted with other machining process. **Alborz shokrani et al.** [25] concentrated on impact of cryogenic machining on surface of Ti-6Al-4V work piece by used end processing machine. The outcome was that cryogenic machining improve surface of Ti-6Al-4V compound in end processing machine. **A.Bordin et al.** [26] this paper presents the component of hardware wear when turning of Ti6Al4V under dry and cryogenic machining. This examination was acting in EBM and utilizing distinctive investigation procedures. SEM (Scanning electron microscopy) is actualized for measure flank wear at commotion area and Energy dispersive X-Ray spectroscopy utilized for investigated the work piece material followed on the bleeding edge and rake face of cathode. After this examination discover that cryogenic machining decreased instrument wear contrasted with dry machining process. **Ampra aramcharoen** [27] in this paper analyzed the effect of cryogenic machining on chip formation and tool wear rate in turning operation for Titanium alloy. After this investigation results show that tool wear resistance is increasing by utilized cryogenic machining. Also, the thickness of secondary deformation zone and different chip formation if machining by oil-based coolant.

**Christian machai et al.** [28] in this exploration article, carbon dioxide is utilized as a coolant for turning activity of Ti-10V-2fe-3A. The coolant carbon dioxide is given in a pressurized tank and flexibly to apparatus tip by openings in the instrument holders clamping jaw. The coolant carbon dioxide contrasted and the flood emulsion cooling. The outcome shows that apparatus life was expanded and instrument wear rate is diminishing. Fig.10. speak to trial set-okay with machining. **S.M.Yuan et al.** [29] in this paper, experimental work was carried out under different coolant conditions such as wet, dry, MQL and MQL with cooling air for study cutting force, tool wear, chip morphology and surface roughness on milling machine of Ti-6Al-4V alloy with uncoated carbide tool. After this experimental investigation result was that MQL with cooling air is most significant parameter compared to other tested parameters. According to experimental observation MQL with cooling air -15° provide most significant result compared to 0°, -30°, -45°. Fig. 12 shows the experimental set-up of cryogenic machining. **Simranpreet Singh Gill et al.** [30] in this paper concentrated on device life diminishing by using profound cryogenic treated addition contrasted with untreated supplement shows the ruinous impact of profound cryogenic temperature (— 196 1C) on TiAlN covered supplements. This is additionally upheld by VDI-3198 space. Test.
M.J. Bermingham et al. [31] this paper zeroed in on chip morphology and device life during machining on Ti-6Al-4V composite. After this exploratory examination found that high weight water based emulsion offer somewhat better device life contrasted with cryogenic coolant. Along these lines, the best boundary is the coolant spout position in machining, set-up. K.A. Venugopal et al. [32] in the current examination concentrated on device life and apparatus wear under various cooling machining, for example, dry, wet, cryogenic machining on Ti-6Al-4V compound. After this exploration found that cryogenic machining is most noteworthy machining contrasted with wet & dry machining. Likewise, the SEM method is utilized for discipled affidavit of titanium chip material on the addition under all machining climate. M.Ibrahim sadik et al. [33] in this paper fluid carbon dioxide (Co2) is utilized e.g. coolant in face processing activity of Ti-6Al-4V as an instrument with PVD, covered supplement and furthermore investigation of coolant stream rate on apparatus life. Apparatus life is improve with higher coolant stream rate, the impact being more grounded in cryogenic contrasted with wet processing because of the way that the cryogenic coolant defers the wear advancement. Table 3. Represent conclusion of all literature survey in tabular form. Table 3 following.

Table 3. Summary of literature survey [9-33]

| S.No. | Author Name               | Material   | Machining Type          | Tested parameters                          | Response                  |
|-------|---------------------------|------------|-------------------------|--------------------------------------------|---------------------------|
| 1     | L. Shakeel Ahmed et al    | W/P-Titanium ASTM B 265, Grade=2 Tool- PVD coated carbide insert | CNC vertical machining centre | Coolant- Wet & LN2 Variables- Feed rate (f), Cutting speed(vc), Depth of cut(d) = constant | Cutting Temp., Ra, Hole quality, |
| 2     | K.A. Venugopal et al      | W/P-Ti-6A-4V Tool- Uncoated carbide insert | Centre lathe | Wet, Dry & LN2 cooling under cutting range 70 to 100 m/min. | Tool Wear. |
| 3     | Shane Y. Hong et al       | W/P-Ti-6A4V Tool- ANSI C2-C3 | CNC Turning centre | Dry cooling, cooling tool back by Liquid nitrogen, pre- Cooling w/p through LN2 process. | Tool life. |
| 4     | Kyung-Hee park et al      | Tool-Coated tool(AlCrN) W/P-Ti-6A-4V | Mori Seiki NVD- 400- DCG-HSC 3-Axis vertical milling centre | Flood cooling, nano+MQL, Nano-MQL+ internal spray, external internal spray. | Tool wear, Cutting force. |
| 5     | Mohd Azlan Suhaimi et al  | Tool- (AlCrN) W/p-Ti-6A-4V | 3-Axis vertical milling centre | Cooling- Indirect, internal and External spray system. Variables-Cutting speed, Feed rate, Depth rate, Width of cut, Cutting length. | Tool life (TL), Cutting force. |
| 6     | Alborz shokrami et al     | Tool-coated solid carbide W/P.Ti-6Al4V | End milling machine | Flood cooling, MQL, Cryogenic cooling, Hybrid | Tool life, Tool Wear.(Ra). |
| 7 | Upendra kumar et.al | Tool-uncoated tungsten carbide W/P-Ti-6Al-4V | CNC lathe machine | Cryogenic MQL treated and untreated of uncoated WC insert | Cutting force, chip morphology, Ra |
| 8 | A.Damir et.al | Tool-CVD coated insert W/P-Ti-6Al-4V | CNC turning centre | Flood cooling, cryogenic cooling. | Tool life, Surface roughness. |
| 9 | Remu.K.Shastri et.al | Tool-brass&copper W/P-Ti-6Al-4V | EDM setup | Cryogenic treated and untreated tool under I, Ton, V, Ton off parameters. | MRR, TWR, Radial overcut. |
| 10 | Y.Sun et.al | Tool-TiAlN coating CNMG 431RP W/P-Ti-6Al-7NB | HAAS TL-LC CNC lathe | Dry, flood cooled and cryogenic machining with constant input parameters. | Surface roughness, hardness. |
| 11 | Vinothkumar sivalingam et.al | Tool-PVD coated tungsten carbide W/P-Ti-6Al-4V | End milling machine | Cryogenic treated (i.e. 24h & 48h) and untreated tool. | Machinability, tool life, cutting force. |
| 12 | Sanjeev kumar et.al | Tool-copper tungsten carbide W/P-Ti-5Al-2.5n | CNC EDM machine | Cryogenic treatment of electrode, peck current, Ton, pulse off, flushing Pressure. | Tool wear rate (TWR). |
| 13 | Stano Imbrogno et.al | Tool-Uncoated tungsten carbide W/P-Ti-6Al-4V | CNC lathe machine | Validate experimental and theoretical result under dry and cryogenic Environment. | Cutting force, machining Temperature. |
| 14 | Y.Sun et.al | Tool- TiCN coated W/P-Ti-6Al-4V | CNC lathe machine | Compared cryogenic machining with MQL and flood cooling under input Process parameters. | Cutting force, SR, Tool wear. |
| 15 | Alborz Shokrani et.al | Tool- TiN-TiAlN coated solid carbide W/P-Ti-6Al-4V | CNC end milling | Dry, flood and cryogenic machining compared for Surface integrity. | Surface integrity. |
| 16 | A.Bordin et.al | Tool- TiAlN coating deposed by PVD. W/P-Ti-6Al-4V | Electron Beam Machining | Compared dry and Cryogenic machining. | Surface roughness and tool wear. |
| 17 | A.Mpr A Aaramcharoen et.al | Tool-coated carbide inserts W/P-Ti-6Al-4V | CNC lathe Machine | Compared dry and cryogenic machining with constant input Variables. | Tool wear, chip formation. |
| 18 | Christian machai et.al | Tool-cemented carbide W/P-Ti-10V-2f-3Al | CNC turning lathe Machine | Coolant-(Co2 & emulsion) Depth of cut, cutting speed, cutting length, feed Rate. | Tool life. |
| 19 | S.M.Yuan et.al | Tool-uncoated cemented carbide inserts W/P-Ti-6Al-4V | CNC milling Machine | Dry, wet, MQL and MQL with cooling air under constant input variable. | Tool wear, cutting Force, Ra, chip formation. |
| 20 | M.Dhananchezian | Tool-PVD TiAlN | CNC turning | Wet and cryogenic | Cutting |
4. Conclusion

These articles present a basic survey on machining of Titanium amalgam under cryogenic climate. These cryogenic machining compared with the different cooling environment for analysis the tool life, TW, Ra, CF, cutting temperature and chip morphology of work specimen. Today’s increasing demand for efficient machining process and sustainable environment so many people interesting in new cooling approach that most effective on response. So, in this review paper present different cooling conditions and different types of tool.

- The primary circumstance of hardware disappointment is attachment dispersion and all instrument endured disappointment mode.
- High weight emulsion and fluid nitrogen are successfully machining contrasted with dry machining. However, high weight emulsions give longer device life contrasted with fluid nitrogen.
- MQL cooling condition show better surface harshness contrasted with dry machining. However, best cooling condition was accomplished under half breed cooling climate.
- As per grater durability and instrument wear opposition CVD covered device give better outcome contrasted with PVD covered device.

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| 21 | Simpranpreet singh gill et.al | Tool- TiAIN coated tungsten carbide inserts W/P- Ti-6Al-4V | CNC turning centre. | Shallow cryogenically treated, Deep cryogenically treated, untreated. | Tool life. |
| 22 | M.J.Bermingham et.al | Tool-MF1 WC inserts. W/P- Ti-6Al-4V | CNC lathe Machine. | LN2, Dry and emulsion cooling environment with constant cutting parameter and constant nozzle Position. | Tool wear, Chip morphology. |
| 23 | K.A.Venugopal et.al | Tool-uncoated carbide inserts. W/P- Ti-6Al-4V | 11KW centre lathe. | Dry, wet and cryogenic machining with constant cutting Parameters. | Tool life. |
| 24 | M.Ibrahim sadik et.al | Tool- PVD inserts W/P- Ti-6Al-4V | Hermle C40U Dynamic centre. | Different flow rate in cryogenic and wet machining. | Tool life, tool wear Rate. |
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