ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

MACHINABILITY STUDY ON TURNING OF Ti-6Al-4V ALLOY UNDER HIGH PRESSURE COOLING USING NEAT OIL & WATER SOLUBLE OIL

Gowri Shankar M.C[*1] Jayashree P.K [2] Shivaprakash Y.M[3] Gurumurthy B.M[4] Manjunath Shettar[5] S S Sharma[6]

[1*]Assistant Professor-Sl Grade, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

[2]Assistant Professor-Sl Grade, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

[3]Assistant Professor-Sl Grade, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

[4]Assistant Professor, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

[5]Assistant Professor, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

[6]Professor, Department of Mechanical & Manufacturing Engineering, Manipal Institute of Technology,Manipal University, Manipal, Karnataka, India.

KEYWORDS: High-pressure-cooling, Ti-6Al-4V-alloy, Chip-morphology, Tool life, Tool wear.

ABSTRACT

Mechanical unrest was a noteworthy foundation in mankind's history. The world now a days is totally fixated on science and innovation and thusly the countries are arranged right now in venture with their level of industrial development. All through the world now a days, there's an everlasting battle for less expensive generation with higher quality and value battle. The machining of Ti and its compounds has been a subject of pleasant enthusiasm for mechanical creation and examination around the world. Parcel of examination and exertion of have been given to comprehend the fundamental art of machining this remarkable gathering of amalgams as far as chip arrangement, cutting strengths, machining temperatures, tool wear, and suitable machining conditions.. A portion of the above issues are basically brought on by high machining temperature prompting lesser productions. The effective cooling strategies viz., cryogenic cooling and high pressure cooling can be used to control machining temperature. In this work, the machinability concentrate on turning of Ti-6Al-4V alloy combination under high pressure cooling utilizing neat oil & water solvent oil, to get high effectiveness in metal cutting.

INTRODUCTION

Machining of titanium and its alloys have been a theme of extraordinary enthusiasm to the assembling businesses and exploratory exploration group because of their high temperature quality, low thermal conductivity, moderately low

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

modulus of elasticity and high chemical reaction. Parcel of examination have been given to comprehension of the fundamental art of machining this interesting gathering of combinations as far as chip development, cutting strengths, particular vitality prerequisite, machining temperatures, apparatus wear, suitable machining situations and so on. A percentage of the properties of Ti-6Al-4V contrasted with medium carbon steel are recorded in Table 1[1-3].

Table 1, Properties of Ti-6Al-4V compared to Medium carbon steel

	Ti-6Al-4V (annealed bar)	**Ti-6Al-4V** (solution treated)	**AISI1045** (cold drawn)
Tensile strength (MPa)	895	1035	625
Yield strength (MPa)	825	965	530
Elongation (%)	10	8	12
Mod. of elasticity (GPa)	110	-	207
Hardness (Hv)	340	360	179
Sp.heat at 20-100 ° C J / kg- K	580	-	486
Thermal conductivity W / m- K	7.3	7.5	50.7

The machinability of titanium and its alloys are generally considered poor owing to several inherent properties of titanium viz,

High cutting zone temperature

High cutting zone temperatures are generated in machining titanium alloys. A large portion (about 80%) of the heat produced is conducted into the tool because it cannot be removed with the fast flowing chip or fed back into the workpiece due to the low thermal conductivity of titanium alloys. Dispersion of cutting temperature has demonstrated that the temperature gradients are much steeper and the heat – affected zone much smaller and much closer to the cutting edge. While machining titanium alloys, the thinner chips produced and the presence of a thin flow zone between the chip and the tool which causes high chip tool temperatures of upto about 1100 oC [1].

High cutting pressures

Much higher mechanical stresses occur in the immediate vicinity of the cutting edge when machining titanium alloy. The stresses are about three to four times of those observed when machining steel. This may be attributed to the unusually small chip–tool contact area on the rake face and partly to the high resistance of Ti–alloy to deformation at elevated temperatures, which only reduces considerably at temperatures in excess of 800 oC [5-7].

Global Journal of Engineering Science and Research Management

Chatter

The low modulus of elasticity of titanium alloys is the chief reason for chatter amid machining. At the point when subjected to cutting pressure, titanium redirects almost twice as much as carbon steel, prompting more noteworthy spring back behind the front line brings about untimely flank wear, vibration and higher cutting temperature. The reason for chatter might likewise be part of the way credited to the high element cutting powers in the machining of titanium alloys [8-11].

HIGH PRESSURE COOLING-LUBRICATION

The main purpose of delivering coolant under high pressure to the cutting region is to enhance life of tool, to achieve lower cutting forces and to minimize chip-tool contact length while machining. The essential goal of this machining system is to essentially diminish the temperature produced at the tool–work piece and tool–chip interfaces when cutting at higher pace conditions. This is accomplished by directing coolant under high pressure at the chip–tool interface.

Under normal coolant supply chip breakage is by contact of the chips with an obstacle that leads to break at the shear plane. It's very difficult for coolant to reach to the tool–work piece or tool–chip interfaces, which are principally under seizure condition when machining at rapid. Coolants have a tendency to be vaporized by the high temperature produced near to the tool edge, shaping a high temperature cover that renders their cooling impact ineffectual. The film boiling temperatures of normal cutting fluids is around 150 ˚C [10-12].

The application of cutting fluid within the sort of a jet at high into the cutting zone is additional advantageous. The mechanism of chip fragmentation projected beneath the high fluid provide may be a cyclic method. The chip starts to grow when deformation at the first shear plane. By the action of the high jet, the chip curls overly. The bending force of the jet can increase with extra growth of the chip until it reaches the strength limit of the chip. As a result of the surface made by the first leading edge (transient surface) showed no proof of crack separation, it seems that the crossroads cannot be at the first shear zone, and so fracture cannot occur at this stage of chip formation. The foremost doubtless purpose of fracture is wherever the chip losses contact with the tool as a result of this can be wherever the jet exerts its most result. The secondary shear zone is intimately secured to the tool throughout machining, that resists the bending moment, and rupture happens. The high fluid jet creates a hydraulic wedge between the tool and work, penetrating the interface with a speed exceeding that needed even for high speed machining and conjointly alters the chip flow conditions as shown in Fig. 1. [13-15].

 ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

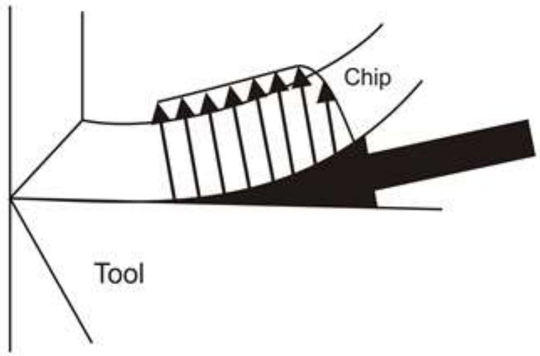


Fig.1. Coolant jet under high pressure is capable of creating a hydraulic jet.

OBJECTIVES

Objective of the present work is to study the machinability of Ti-6Al-4V alloy in turning under conventional wet and high pressure cooling-lubrication environment with neat oil (Trimofin-23) and water soluble oil as coolant by using uncoated tungsten carbide (K20-microcrystalline) insert at different cutting velocity (Vc), feed (So), pressure (p) and nozzle diameter (dn) in terms of:

- form and geometry of the chips
- cutting forces and specific machining energy
- extent of tool wear and tool life

RESULTS AND DISCUSSION

Machining was carried out under Conventional wet and high pressure neat oil and high pressure water-soluble oil environments. Under conventional wet environment, overhead flood cooling was undertaken at a flow rate of 5 let/min using a standard coolant delivery system fitted with the lathe. In all the three environment condition, chips were collected, photographed and studied for their macroscopic morphology. Tool life test were planned based on half factorial design of experiments for high pressure neat and water soluble oil and full factorial design for conventional wet, both with the central points. A range of cutting speed (Vc), feed rate (So), pressure (p) and nozzle diameter (dn) have been established in the TABLE 2 and experiments were carried out as per design of experiments.

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

TABLE- 2, Process parameters selected for machining of Ti-6Al-4V alloy

Sl No.	Parameters	Units	Min	Centre points	Max
1	Cutting speed (V_c)	m/min	90	100	111
2	Feed rate (S_o)	mm/rev	0.16	0.20	0.24
3	Pressure (p)	bar	71	100	140
4	Nozzle diameter (d_n)	mm	0.6	0.8	1.0

CHIP MORPHOLOGY

Several turning tests were carried out for various speed-feed combinations as per design of experiment to examine the process of chip formation for both conventional wet, high pressure neat oil and high pressure water soluble cooling-lubrication. The results of such categorization of the chips produced under different conditions and environments have been shown in Fig.2. The continuous snarled type chips and primarily broken type of chips are obtained under conventional wet machining conditions and high pressure cooling environments, viz., neat oil and water soluble oil respectively.

Chip breaking occurred due to interaction of the chip with the side surface of the cutting tool. As can be seen in Conventional wet, within the experiment domain, variation in process parameters seem not to have any effect on chip morphology. High pressure cooling-lubrication by soluble oil as well as neat oil predominantly provided broken chips irrespective of process parameter and nozzle diameter, where very less closely curled chips were obtained.

Global Journal of Engineering Science and Research Management

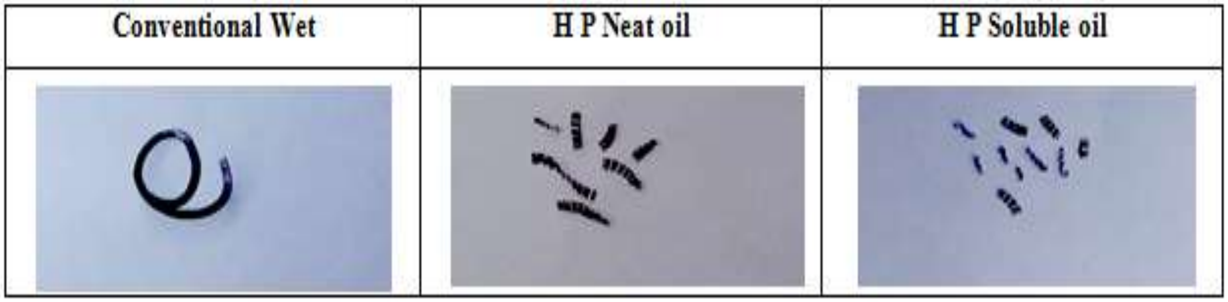


Fig.2 Macro-Photograph of the chips produced during turning of Ti-6Al-4V bars under Conventional wet, high pressure neat oil & high-pressure water-soluble oil environments.

CUTTING FORCES AND SPECIFIC MACHINING ENERGY

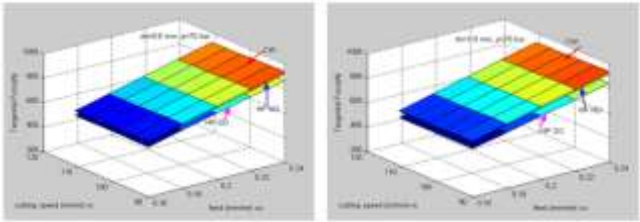
Upsurge in cutting speed and feed causes upsurge in tangential force (P_z). Chip curling under dry cutting occurs due to temperature difference involving the chip surfaces. The contact surface of the chip reaches a greater temperature. With introduction of high pressure coolant the temperature difference increases evoking the chip to curl with smaller radius. Smaller the chip curl radius lesser would be the contact length. Moreover higher density of water soluble oil regarding neat oil, the jet momentum exerted on the chip for curling increases.

The reduction in of % P_z, with high pressure neat oil was greater than that obtained under high pressure soluble oil mixture. The higher temperature reduction at the chip/tool interface and at the primary shear zone with high pressure soluble oil due to its high specific heat and thermal conductivity. The combined effect of high dynamic yield shear strength (τ_s) and comparatively low lubrication effect results in higher value of tangential force (P_z). With high pressure neat oil lubrication effect is high, but temperature reduction is not substantial, resulting in lower value of chip reduction co-efficient (ζ). Due to which a higher reduction in tangential force (P_z) is obtained compared to high pressure soluble oil as shown in Fig. 3 and Fig. 4.

The specific energy in machining is an indication of energy consumption per unit volume of material removed. In all experimental runs there was a reduction in P_Z with the application of high pressure soluble oil and high pressure neat oil mixture (compared with conventional coolant), it was observed that the percentage reduction in tangential force (P_z) obtained under high pressure neat oil was greater than that obtained under high pressure soluble oil mixture. This was attributed to greater reduction in chip tool interface temperature due to better cooling-lubrication ability of the high pressure soluble oil mixture. Thus with high pressure neat oil a lower specific energy consumption was observed as shown in Fig. 5 and Fig. 6.

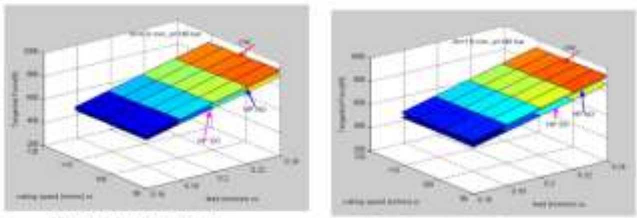
ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management



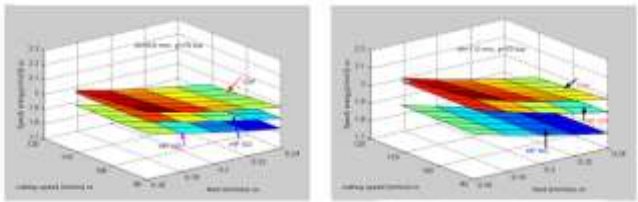
Nozzle diameter (d_n) =0.6 mm   Nozzle diameter (d_n) =1.0 mm

Fig. 3 Effect of conventional coolant, high pressure neat oil and high pressure soluble oil cooling lubrication on Tangential Force (P_z) under various nozzle diameter and pressure of 70 bar



Nozzle diameter (d_n) =0.6 mm   Nozzle diameter (d_n) =1.0 mm

Fig. 4 Effect of conventional coolant, high pressure neat oil and high pressure soluble oil cooling lubrication on Tangential Force (P_z) under various nozzle diameter and pressure of 140 bar

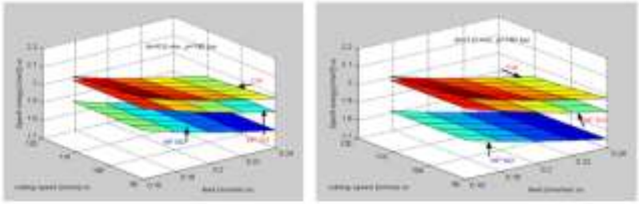


Nozzle diameter (d_n) =0.6 mm   Nozzle diameter (d_n) =1.0 mm

Fig.5 Effect of conventional coolant, high pressure neat oil and high pressure soluble oil cooling lubrication on Specific energy consumption (U_c) under various nozzle diameter and pressure of 70 bar

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management



Nozzle diameter (d_n) =0.6 mm Nozzle diameter (d_n) =1.0 mm

Fig.6 Effect of conventional coolant, high pressure neat oil and high pressure soluble oil cooling lubrication on Specific energy consumption (U_c) under various nozzle diameter and pressure of 140 bar

TOOL WEAR AND TOOL LIFE

The life of the cutting tool insert is generally evaluated on the basis of limiting value of average flank wear ($V_B \geq 300\mu m$) and maximum flank wear ($V_M \geq 600\mu m$). For machining chemically reactive alloys like Ti-6Al-4V, which causes very severe crater wear; even eroding the cutting edge, the amount of cutting edge depression ($E \geq 150\mu m$) also may be taken as tool life criteria.

However considering V_B=300μm or V_M=600μm or E=150μm, the actual tool life obtained for various combination of cutting velocity (V_c), feed (S_o), pressure (p) and nozzle diameter (d_n) as per design matrix for both conventional wet, high pressure neat oil and high pressure water soluble oil have been presented in the Table 3.

The benefits of application of high pressure cooling-lubrication as compared to conventional wet, on improvement in tool life, while machining Ti-6Al-4V alloy at various combination of cutting velocity (V_c), feed (S_o), pressure (p) and nozzle diameter (d_n) are shown in Figures from Fig 7 to 8.

Fig 7(a, b and c) clearly reveals the growth of average flank wear (V_B), maximum flank wear (V_M) and edge depression (E) during straight turning of Ti-6Al-4V alloy at higher V_c=111 m/min, S_o=0.24 mm/rev, p=140 bar and d_n=1.0 mm under conventional wet, high pressure neat oil and high pressure soluble oil cooling-lubrication technique. It can be noted that, the most significant tool wear parameter, V_B attained its limiting value of 300μm within 1.32 mins of conventional wet machining, about 3.6 mins, in high pressure neat oil but about 6.0 mins, in high pressure water soluble oil.

In case of conventional cooling technique there was an abrupt increase in the growth rate of V_B and V_M under all combination of V_c and S_o (especially when S_o was increased from 0.16 mm/rev to 0.20 or 0.24 mm/rev). This drastic change in wear rate has possibly due to ineffective accessibility of penetration of coolant into the region of heat generation and also conventional coolant undergoes film boiling at around 150 ^{0}C and losses their cooling stability.

Improvement in tool life were observed when same process will be performed at lower value of V_c=90 m/min, S_o=0.16 mm/rev, p=140 bar and d_n=1.0 mm. It can be noted that V_B attained its limiting value of 300 μm within 9.1 mins of

 ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

conventional wet machining, about 20 mins, in high pressure neat oil but about 28.65 mins, in high pressure water soluble oil.

On decrease in pressure (p) from 140 bar to 71 bar and nozzle diameter (d_n) from 1.0 mm to 0.6 mm, for same values of V_c=90 m/min, S_o=0.16 mm/rev, tool life was further improved as shown in Fig.8. This is because at higher pressure (p=140 bar) and nozzle diameter (d_n=1.0 mm), the velocity of the jet increases, which intern causes increase in kinetic energy of the jet and critical boiling action of the coolant at the tool edge takes place. Due to this it was possible to sweep the tool surface faster by the higher jet speed. Thus lowering the rate of boiling and cutting down the heat transfer.

From Table 3, it is observed that, on an average of about 130% improvement in tool life was obtained with high pressure neat oil and 250 to 400% improvement in tool life was observed with high pressure soluble oil as compared to conventional coolant. In case of high pressure cooling-lubrication improvements in tool life can be attributed to the deeper penetration of the high pressure jet into the cutting zone. On the other hand, tool life as obtained with high pressure water soluble oil cooling-lubrication can be attributed to higher specific heat of the water soluble mixture, which not only lubricates the rubbing surfaces but also rapidly withdraws heat from the cutting zone.

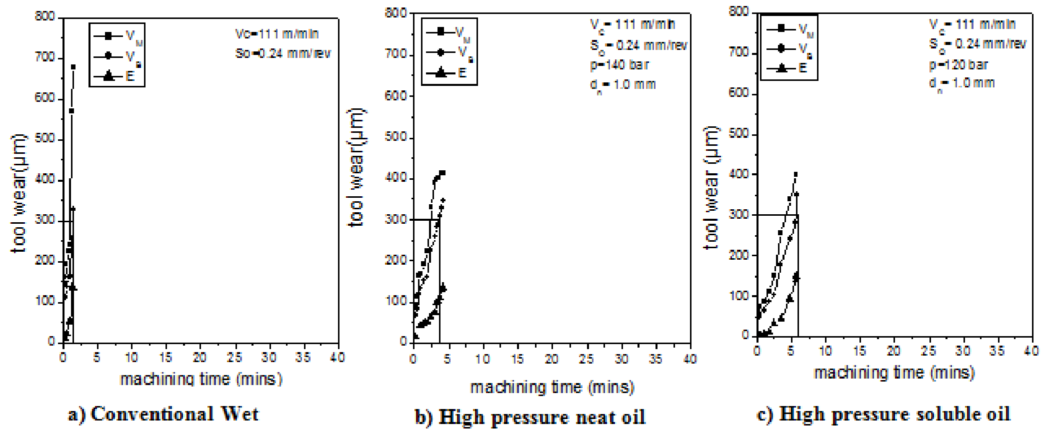
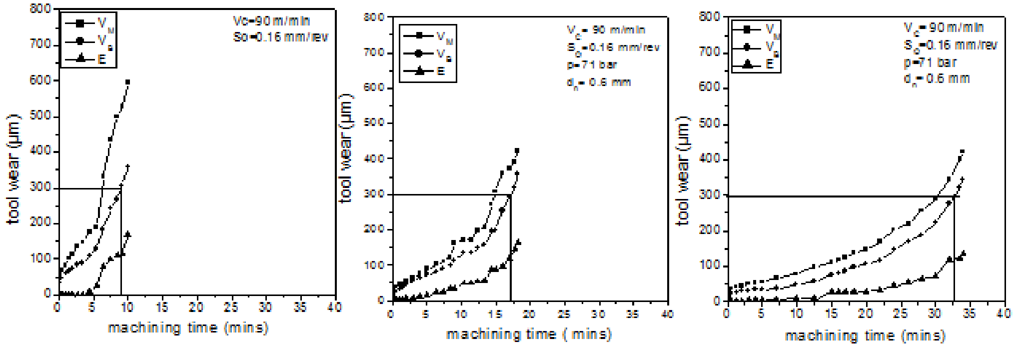


Fig.7 Growth of tool wear while turning Ti-6Al-4V alloy at V_c=111 m/min, S_o=0.24 mm/rev, p=140 bar and d_n=1.0 mm under a) Conventional Wet, b) High pressure neat oil and c) High pressure soluble oil.

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management



a) Conventional Wet **b) High pressure neat oil** **c) High pressure soluble oil**

Fig. 8 Growth of tool wear while turning Ti-6Al-4V alloy at V_c=90 m/min, S_o=0.16 mm/rev, p=71 bar and d_n=0.6 mm under a) Conventional Wet, b) High pressure neat oil and c) High pressure soluble oil.

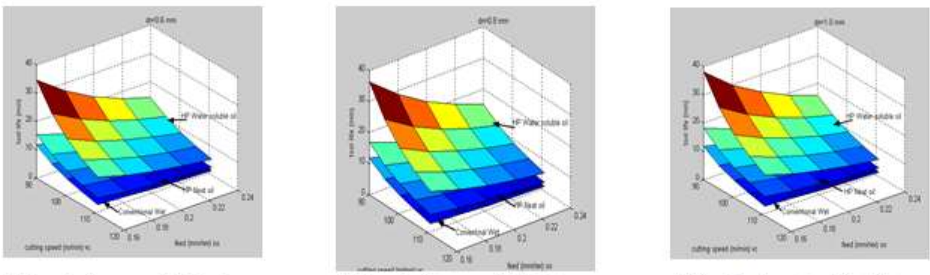
The effect of conventional coolant, high pressure neat oil and high pressure water soluble oil on tool life have been simulated with various nozzle diameter (d_n), by varying cutting velocity (V_c) and feed rate (S_o). Fig. 9, depict that the tool life decreases with the increase of V_c and S_o, under all environmental conditions when nozzle diameter (d_n) increases from 0.6 mm to 0.8 or 1.0 mm. The tool life improved to some extent particularly when the Ti-6Al-4V alloy was machined at relatively lower V_c , S_o, and d_n, but high pressure water soluble oil enhanced tool life more pronouncedly by decreasing the thermal stress and temperature gradient at the tool-chip and tool-work piece interface.

Table 3, Variation in Tool life (mins) while turning Ti-6Al-4V bar under Conventional Wet, High pressure Neat oil and High pressure water soluble oil environments under different combinations of cutting velocity (V_c), feed (S_o), pressure (p) and nozzle diameter (d_n).

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

Std. ord. #	Design matrix				Conventional Wet (*)	HP Neat oil	HP Soluble oil
	Vc m/min	So mm/rev	p bar	d_n mm	Tool life, mins	Tool life, mins	Tool life, mins
1	111	0.24	140	1	1.32	3.6	6.0
2	111	0.16	140	0.6	5.0	6.7	12.55
3	90	0.24	140	0.6	4.0	6.1	14.25
4	90	0.16	140	1	9.1	20.0	28.65
5	111	0.24	71	0.6	*	3.1	4.8
6	111	0.16	71	1	*	7.4	16.0
7	90	0.24	71	1	*	7.5	14.2
8	90	0.16	71	0.6	*	17.25	32.7
9	100	0.2	100	0.8	4.1	5.75	14.2
10	100	0.2	100	0.8	4.0	5.5	14.2
11	100	0.2	100	0.8	4.1	5.5	15.65
12	100	0.2	100	0.8	4.35	5.3	14.3
13	100	0.2	100	0.8	*	5.25	14.0



a) Nozzle diameter (d_n)=0.6 mm b) Nozzle diameter (d_n)=0.8 mm c) Nozzle diameter (d_n)=1.0 mm

Fig.9 Effect of conventional coolant, high pressure neat oil and high pressure soluble oil cooling lubrication on Tool life under various nozzle diameter, based on limiting flank wear criteria V_B= 300µm.

CONCLUSION

Based on the observations made and the experimental results obtained under high pressure cooling-lubrication technique as compared to conventional wet, the fallowing conclusions are made:

- Application of high pressure cooling-lubrication in turning Ti-6Al-4V alloy showed some significant effects on the chip formation, because it provides broken chips irrespective of process parameter and nozzle diameter (dn). Increasing in nozzle diameter with or without increasing pressure, the shape of closely curled chips changed to broken ribbon type chips. Thus nozzle diameter seems to have more effect on chip morphology rather than the pressure under the current experimental domain.
- The results of cutting force reveals that, the tangential cutting force (Pz) affected marginally for the same combination of cutting speed (Vc), feed (So) and environments, due to the retention of high yield strength of Ti-6Al-4V alloy at elevated temperature.
- Tool life has increased on an average of about 130% in case of high pressure neat oil and of about 250 to 400 % in case of high pressure water soluble oil as compared to conventional coolant, which ensures improved coolant penetration to the cutting interface.

REFERENCES

1. E.O.Ezugwu, Z.M. Wang, Titanium alloys and their machinability- a review, Journal of Materials Processing Technology, Vol. 68, 1997, pp-(262-274)
2. A.R. Machado, J.wallbank, Machining of Titanium and its alloys- a review, Proc. Instn. Mechanical engineers, Vol. 204, 1990, pp-(53-60).
3. R. Komanduri & B.F.Von Turkovich New observations on the mechanism of the chip formation when machining Titanium alloys, Wear, Vol. 69, 1981, pp-(179 – 188)
4. A.E Bayoumi, J.Q. Xie, Some metallurgical aspects of chip formation in cutting Ti-6Al-4V alloy, Material Science and Engineering, A190,1995, (pp-173-180)
5. E.O.Ezugwu, Key improvements in the machining of difficult-to-cut aerospace superalloys, International Journal of Machine Tools & Manufacture, Vol. 45, 2005 pp-(1353–1367).
6. P.A.Dearnly & A.N.Grearson, Evaluation of Principal Wear Mechanisms of Cemented Carbides & Ceramics Used for Machining Titanium alloy IMI 318, Matl. Sci. & Tech., Vol. 2, 1986, pp-(47 – 58).
7. A.R. Machado, J.wallbank, I.R. Pushby and E.O. Ezuguru, Tool performance and chip control when machining Ti-6Al4V and Inconel 901 using high pressure coolant supply, Machining Sci. and Technology, Vol. 2(1), 1998, pp-(1- 12).
8. E.O. Ezugwu, J. Bonney, Effect of high-pressure coolant supply when machining nickel-base, Inconel-718, alloy with coated carbide tools, Journal of Material Processing Technology, Vol. 153-154, 2004, (pp-1045-1050).
9. M. Mazurkiewicz, Z. Kubala, J. Chow, Metal Machining With High Pressure Water-Jet Cooling Assistance-A New Possibility, Journal of engineering industry, Vol. 111, 1989, (pp-7-12).

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

10. R. Kovacevic, C. Cherukuthota, M. Mazurkiewicz, High pressure waterjet cooling/lubrication to improve machining efficiency in milling, Int. Journal Machine tools manufacture, Vol. 35, 1995, (pp-1459-1473).
11. E.O. Ezugwu, J. Bonney, D.A. Fadare, W.F. Sales, Machining of nickel-base, Inconel-718, alloy with ceramic tools under finishing conditions with various coolant supply pressures, Journal of Material Processing Technology, (2005).
12. Website of Hindstan Petrolium corporation Ltd., http://www.hindustanpetrolium.com/; HP Lubricant product guide.
13. Roger.G.Peterson, Design and Analysis of Experiments.
14. A.K Nandy ,M.C Gowri Shankar, S. Paul, Some studies on high-pressure cooling in turning of Ti-6Al-4V, International Journal of Machine Tools & Manufacture, Vol. 49, 2009, pp-182-198.
15. Norihiko Narutaki and Akio Murakasi, Study on machining of Titanium alloys, Anuals of the CIRP, Vol.32/1, 1983, (pp-165-169).