Influence of variation in machining parameters on chip morphology while drilling titanium alloy Ti 6Al 4V with high speed steel M35

[1] Mansi Yadav, [2] Pankaj R Rathod , [3] Khodu M Dhameliya
[1,3] P G Student, [2] Associate Professor,
Mechanical Engineering Department,
L D College of Engineering, Ahmedabad, India

***Abstract* - Titanium is a light weight, strong, highly corrosion resistant, biocompatible, and non-magnetic metal. The alloys of titanium are mainly used in aerospace, automotive, marine, and petrochemical industries due to their low specific gravity and high specific strength.Ti6Al4V is the most widely used alloy of titanium. In the present research work effects of different machining parameters and cutting conditions on chip morphology such as chip shape and chip thickness have been analyzed while drilling Ti6Al4V plates with HSS M35 drill bit in wet machining condition. Important conclusions have been made after minutely observing the chip morphology. Correlation among cutting speed, feed rate and chip thickness has been established.**

***Index Terms* – Drilling, Machinability, Titanium Alloy, Ti6Al4V, Chip Morphology, HSS M35**

I. INTRODUCTION

Titanium is light in weight, strong, highly corrosion resistant, biocompatible, and nonmagnetic. As titanium processes low specific gravity and high specific strength, titanium and its alloys are used mainly in aerospace, automotive, marine and petrochemical industries. Among all the alloys of titanium, Ti6Al4V is the most widely used alloy, having chemical composition of 6% aluminum, 4 % vanadium, 0.25% (max) iron, 0.2% (max) oxygen and the remainder titanium. Titanium and its alloys are highly reactive with oxygen, nitrogen, carbon, and hydrogen. As Ti6Al4V has good fatigue and fracture properties, it is used in all product forms including forgings, bar, castings, foil, sheet plate, extrusions, tubing and fasteners. There are various Difficulties in machining titanium and its alloys like High strength at elevated temperature opposes the plastic deformation needed to form a chip, The chip obtained after machining titanium is very thin and possesses small contact area which causes high stresses on tip of the tool. [1] Table: 1 gives details of physical properties, thermal properties, mechanical properties and electrical properties of Ti6Al4V. Table 1 displays different physical, thermal, mechanical, and electrical properties of Ti 6Al 4V

Table- 1 Properties of Ti6Al4V

	Property Name	**Description**
Physical Properties	Crystal structure	HCP(<882.5^{0}C)
		BCC(>882.5^{0}C)
	Atomic Volume(m^3/kmol)	0.01
	Density(g/cm^3)	4.42
Thermal Properties	Melting point(^{0}C)	1667
	Thermal Conductivity (W/m-k)	7.2
	Specific Heat Capacity (J/g ˚C)	0.560
	Linear co-efficient of Expansion (inch/inch ^{0}F)	5 x 10^{-6}
Mechanical Properties	Hardness (HRC)	36
	Tensile strength (Ultimate) (MPa)	950
	Tensile strength (Yield) (MPa)	880
	Modulus Of Elasticity (GPa)	113.8
	Compressive Yield Strength (MPa)	950
	Poisson's ratio	0.342
Electricl and Magnetic Properties	Magnetic Susceptibility (cgs/g)	3.3e-006
	Volumetric Electrical resistivity (ohm.cm)	170
	Magnetic Permeability (at 1.6 kA/m)	1.00005

II. LITERATURE REVIEW

Intense literature review had been carried out before drilling Ti6Al4V with tool material HSS M35. Methodology had been decided in fulfillment of practical work using concepts of several authors listed below. Ezugwu et al [2] studied machinability of titanium alloys. They found straight grade tungsten carbide cutting tools were found to be the most suitable ones HSS M33, M40 and M42 had been found economical to machine titanium alloys. Rahman et al [3] studied machinability of titanium alloys. It was concluded that machining of titanium alloys required tools with high hardness, wear durability, hot hardness, good thermal resistance, and high co-efficient of thermal conductivity. da Silva et al [4] investigated tool life and wear mechanisms in high speed machining of Ti6Al4V alloy with PCD tools under various coolant pressures. Segmented chips had been generated when machining with high pressure coolant supply, while long continuous chips had been generated when machining with conventional coolant flow.

Ogawa et al [5] established at to drill titanium alloys, high pressure supply of coolant gave remarkable benefits. During drilling major cutting edges were cooled and chips were ejected smoothly. D Saini et al [6] optimized drill life when drilling Ti6Al4V with HSS drills. Feed of 0.14 mm/rev and a cutting speed of 9 m/min had been observed to give smooth chip formation and flow through the drill flutes. Rui Li et al [7] found that to drill Ti6Al4V balance of cutting speed and feed was essential. Spiral point grill design was found exerting low thrust force, torque, energy and burr size. S.Sharif et al [8] compared the performance of TiAlN coated and uncoated carbide tools during drilling of Ti6Al4V TiAlN coated carbide drills outperformed uncoated carbide drills in terms of tool life and surface finish. F.R Wong et al [9] established while drilling Ti6Al4V that tools having greater point angle and helix angle performed better.

Yakup Yildiz et al [10] studied on cryogenic cooling in machining processes. They noted that application of a coolant in a cutting process, increased tool life and dimensional accuracy; decrease cutting temperature, surface roughness and amount of power consumed. Kai Xuan [11] studied the effects of cryogenic treatment on the microstructure and properties of Ti6Al4V. Cryogenic treatment increased elongation of Ti6Al4V and strength. Cryogenic treatment improved comprehensive mechanical properties. Pradeep Joshi et at [12] concluded that cryogenic treatment improved mechanical properties like toughness, wear resistance, and resistance to fatigue cracking. Bermingham et al [13] observed tool life, cutting forces and chip morphology in cryogenic machining of Ti6Al4V. It was concluded that different machining parameters produced different chip morphologies.

III. EXPERIMENTAL WORK

Experiment had been carried out on a VMC (Vertical Machining Centre Jyoti CNC PX 10). Kistler- 9272 four component stationary dynamometer had been used to measure cutting forces and torque while drilling Ti6Al4V.Work-piece material of Ti6Al4V had thickness of 10 mm. Drill material used was HSS M35. Detailed composition of M35 has been given in Table 2.

Table-2 Chemical composition of M35 [14]

Grade	C	Si Mn	Ni Cu	P	S	Cr	Mo	V	W	Co
M35	0.88	MAX	MAX	MAX	MAX	3.8	4.75	1.75	6.00	4.60
Wt%	0.95	0.4	0.25	0.03	0.03	4.5	5.2	1.9	6.7	5.00

Selection had been carried out after intensive literature review. Drill diameter was of 10 mm. Selected drill was having high point angle of 135°. For the chosen drill material five various cutting speeds and feeds had been selected. By implementing full factorial method total different 25 combinations of cutting speeds and feeds were made available to drill holes within Ti6Al4V discs. Different cutting speeds and feeds chosen to drill holes with M35 drill were as below.

Table-3 Machining conditions for drilling holes in Ti6Al4V with HSS M35

Cutting speed (RPM)	300	400	500	600	700
Feed rate (mm/rev)	0.25	0.2	0.15	0.1	0.05

During drilling, all the chips were collected and then to make avail the chip cross-section they were made brittle by treating them cryogenically with liquid nitrogen. Fig below is the set up used to treat chips cryogenically with liquid nitrogen. The collected chips were dipped in the bath of liquid nitrogen stored at -198 °C in an ice box of 5 liters capacity. The chips were dipped for 12 to 13 hours to make them brittle and to improve their breakability.

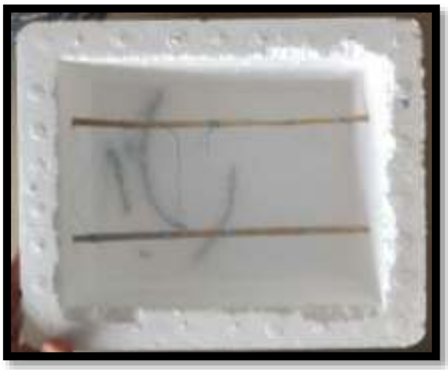

Fig-1 Set up of cryogenic treatment of chips obtained after drilling holes

After cryogenically treating chips, they were broken easily and then viewed under a 3D microscope QSL2010ZB.

IV. RESULTS

Figure below represents chips obtained after drilling holes at cutting speed of 300 RPM and feed rate of 0.25 mm/rev and 0.05 mm/rev respectively.

Fig-2 Chips collected after drilling holes at cutting speed of 300 RPM and feed rate of 0.25 mm/rev as well as 0.03 mm/rev respectively

Trend of torque exerted while drilling holes into work piece material was as per following graph. From the graph it can be observed that at constant cutting speeds as the feed rate increases cutting forces and torque also increase. So, it can be interpreted that lower values of cutting speeds and higher values of feed rate are desirable as torque exerted at the same speed increased as the feed rate increased..

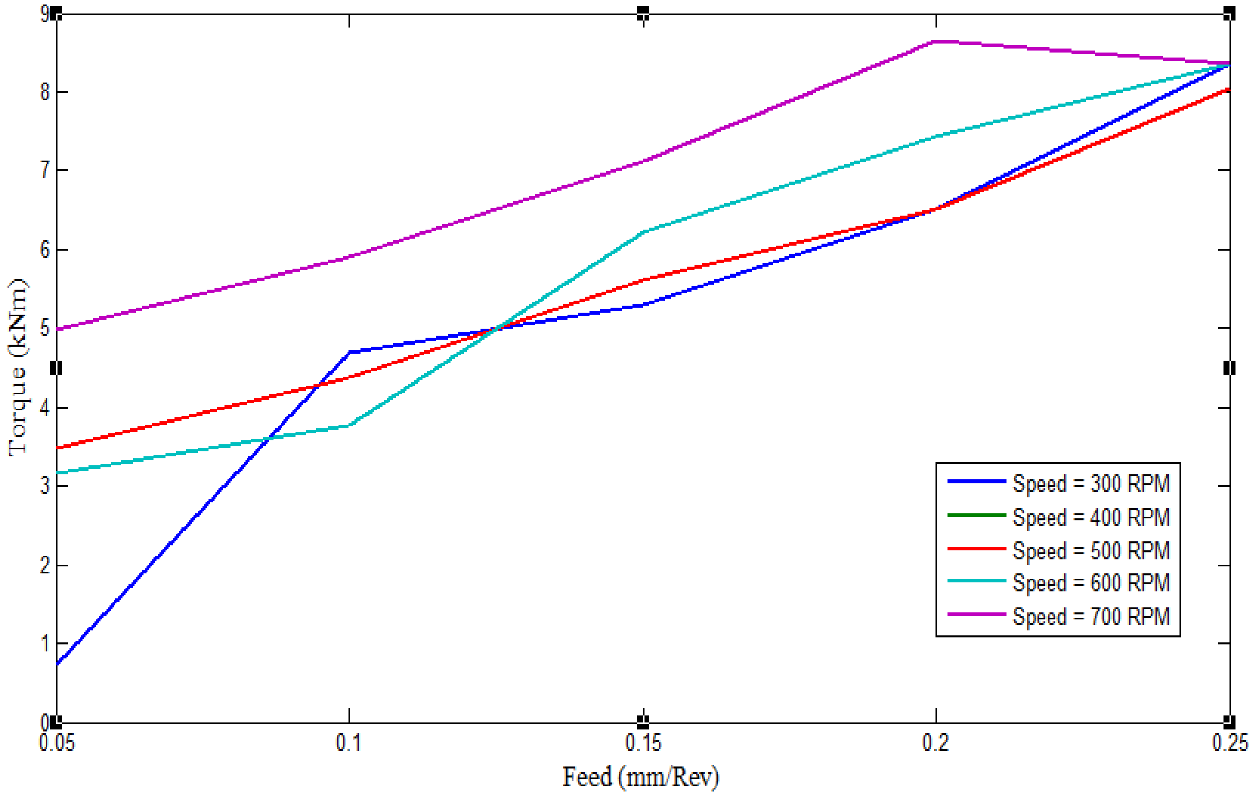

Fig-3 Relationship between torque and feed rate

Fig.4 is cross section of a chip at cutting speed of 300 RPM and feed of 0.25 mm/rev. Thickness of all the chips had been measured using a 3D microscope QS L2010ZB by Mitutoyo.

Fig-4 Cross-section of chip of Ti6Al4V at cutting speed of 300 RPM and feed rate of 0.25 mm/rev

Measured values of thickness of the chips of Ti6Al4V were as tabulated below. Thickness of the chips were measured using a 3 D microscope known as a Quick Scope QS L2010ZB.Chip shapes are also identical and clearly visible through the microscope.

Table-4 Measured chip thickness of different chips

Sr No	Cutting Speed (RPM)	Feed (mm/rev)	Measured thickness(mm)
A	300	0.25	0.105067
B	300	0.2	0.082933
C	300	0.15	0.092533
D	300	0.1	0.0802
E	300	0.05	0.0881
F	400	0.25	0.1575
G	400	0.2	0.133567
H	400	0.15	0.1321

I	400	0.1	0.086167
J	400	0.05	0.0343
K	500	0.25	0.1338
L	500	0.2	0.076967
M	500	0.15	0.102133
N	500	0.1	0.093933
O	500	0.05	0.059867
P	600	0.25	0.1436
Q	600	0.2	0.0973
R	600	0.15	0.125067
S	600	0.1	0.0979
T	600	0.05	0.055533
U	700	0.25	0.149833
V	700	0.2	0.1207
W	700	0.15	0.0809
X	700	0.1	0.0874
Y	700	0.05	0.0545

Figure-5 represents relationship among cutting speed, feed rate, and measured thickness of cross-section of all the 25 chips. From the graph and table it was observed that maximum thickness of the chip occurred when the cutting speed was minimum and feed rate was higher. Minimum thickness of the chip was gained at higher cutting speed and lower feed rate which was an undesirable phenomena. Maximum thickness was achieved for F and minimum was measured for J and T as well.

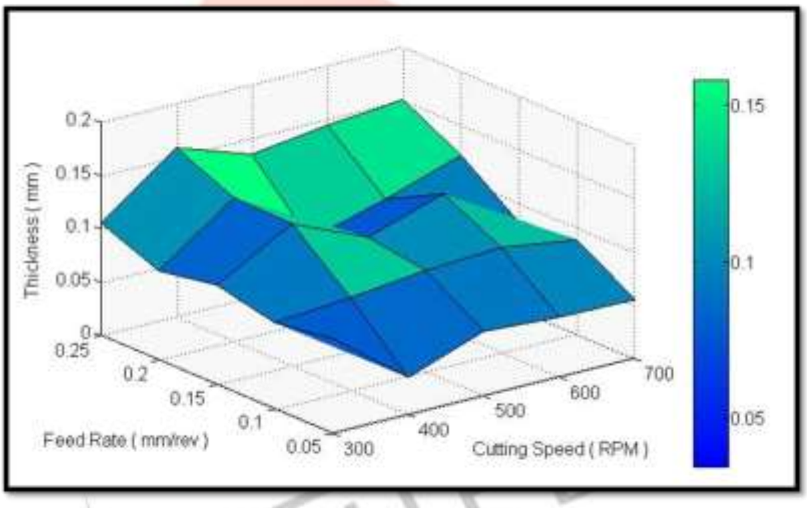

Fig-5 Correlation among cutting speed, feed and thickness of chip

V. CONCLUSIONS

From above resultant data several important conclusions can be made as below.

- HSS M33, M 40 and M42 are considered compatible to drill Ti6Al4V economically.
- In order to improve the drilling performance of titanium alloy high pressure supply of coolant is desirable. Drilling of titanium assisted by high pressure water jet system had been found effective.
- Spiral point drill design showed advantages of low thrust, torque, energy, and burr size.
- At constant cutting speed, decreasing the feed rate step by step shape of the chip obtained varied from (closed coil) conical or spiral chips to folded wavy chips. It is observed from the graphs that at constant cutting speed as the feed rate decreased cutting forces required to drill the work-piece decreased.
- From Fig.5 and Table.4 it can be said that lower values of cutting speeds and higher feed rates produced chips which had highest thickness. Lower cutting speeds and higher feed rates are found suitable for machining Ti6Al4V.
- Thickest chips were produced at cutting speed of 400 RPM with M35 drill at feed rate of 0.25 mm/rev.
- As cutting speed increased and feed rate decrease, chip thickness also experienced decrement. Cutting forces were lower.
- .Thinnest chips were obtained while drilling at 600 RPM with HSS M35 at feed rate of 0.05 mm/rev.
- Lower values of cutting speed and higher or moderate feed rate are desirable to improve machining of Ti6Al4V alloy.

VI. REFERENCES

[1] http://cartech.ides.com/
[2] Ezugwu, E. O., and Z. M. Wang., "Titanium alloys and their machinability—a review.", Journal of materials processing technology 68, no. 3, pp: 262-274,1997
[3] Rahman, Mustafizur, Zhi-Gang Wang, and Yoke-San Wong. ,"A review on high-speed machining of titanium alloys.", JSME International Journal Series C 49, no. 1,pp: 11-20,2006.
[4] da Silva, Rosemar B., Álisson R. Machado, Emmanuel O. Ezugwu, John Bonney, and Wisley F. Sales., "Tool life and wear mechanisms in high speed machining of Ti–6Al–4V alloy with PCD tools under various coolant pressures.", Journal of Materials Processing Technology 213, no. 8 pp: 1459-1464,2013.
[5] Arai, M., and M. Ogawa., "Effects of high pressure supply of coolant in drilling of titanium alloy.", Journal of Japan Institute of Light Metals(Japan) 47, no. 3 ,pp: 139-144,1997.
[6] Saini, Devi P., and P. Woodall. ,"Drill life optimisation when drilling TI-6AL-4V with HSS drills.",2003.
[7] Li, Rui, Parag Hegde, and Albert J. Shih, "High-throughput drilling of titanium alloys.", International Journal of Machine Tools and Manufacture 47, no. 1,pp: 63-74, 2007.
[8] Sharif, S., and E. A. Rahim., "Performance of coated-and uncoated-carbide tools when drilling titanium alloy—Ti–6Al4V.", Journal of Materials processing technology 185, no. 1,pp: 72-76,2007
[9] Wong, F. R., S. Sharif, and Kamaruddin Kamdani., "The effect of drill point geometry and drilling technique on tool life when drilling titanium alloy, Ti-6Al-4V.", 2008.
[10] Yildiz, Yakup, and Muammer Nalbant. "A review of cryogenic cooling in machining processes." International Journal of Machine Tools and Manufacture 48, no. 9 (2008): 947-964.
[11] Gu, Kai Xuan, Zhi Qiang Li, Jun Jie Wang, Yuan Zhou, Hong Zhang, Bing Zhao, and Wei Ji. "The Effect of Cryogenic Treatment on the Microstructure and Properties of Ti-6Al-4V Titanium Alloy." In Materials Science Forum, vol. 747, pp. 899-903. Trans Tech Publications, 2013.
[12] Joshi, Pradeep, Jaspreet Singh, Prashant Dhiman, Hirendra Shekhar, and Viranshu Kumar. "Effect of Cryogenic Treatment on Various Materials: A Review."
[13] Bermingham, M. J., J. Kirsch, S. Sun, S. Palanisamy, and M. S. Dargusch., "New observations on tool life, cutting forces and chip morphology in cryogenic machining Ti-6Al-4V.", International Journal of Machine Tools and Manufacture 51, no. 6 ,pp: 500-511,2011.
[14] www.gmtc.com
[15] Parameters on the Chip Geometry During Machining Alloy UNS A97075.", Procedia Engineering 132, pp: 513-520,2015.
[16] http://jyoti.co.in/
[17] https://www.kistler.com/fileadmin/files/divisions/sensor-technology/cutting-force/960-002e-05.14.pdf
[18] http://www.mirandatools.in/
[19] http://ecatalog.mitutoyo.com/cmimages/003/316/2079_QuickScope.pdf