International Journal of Engineering Materials and Manufacture (2018) 3(4) 237-244
https://doi.org/10.26776/ijemm.03.04.2018.08

Effect of Coolant Temperature on Surface Finish during Turning of Titanium Alloy Ti6Al4V

Ogedengbe Temitayo Samson, Abdulkareem Sulaimon and Aweda Jacob Olayiwola

Received: 18 October 2018
Accepted: 04 November 2018
Published: 01 December 2018
Publisher: Deer Hill Publications
© 2018 The Author(s)
Creative Commons: CC BY 4.0

ABSTRACT

High temperature generated and stresses induced as a result of turning of Ti6Al4V results in poor surface finish. The aim of this study was to investigate the effect of coolant temperature on the surface roughness of Ti6Al4V which is a core material used as an implant. A cooling system was developed to reduce the temperature of the coolant (soluble oil) from room temperature to 2°C. Ti6Al4V was turned in dry and cooled (at temperatures 5, 7, 9 and 11 °C) conditions. The experiment was designed using central composite design of (Response surface methodology) Design Expert 11.0 to generate an array and optimize the machining parameters. The machining parameters used were cutting speed, feed rate, depth of cut and coolant temperature. Results analyses show that cutting speed and depth of cut had considerable effect on surface roughness of Ti6Al4V. Surface roughness reduced when coolant temperature was reduced. The results of this study shows that turning Ti6Al4V at a very low cutting temperature will ensure a better surface finish.

Keywords: Turning, Coolant temperature, TI6AL4V, Surface roughness, Machining Parameter

1 INTRODUCTION

Recent technological development especially in industries such as the medical, automobile and aviation is evidently driving the practical investigation into the use of light metals such as titanium, aluminium and manganese as prosthetics and general alternatives [1]. Titanium alloys have wide applications in the engineering fields, which include the aerospace, marine, automobile and medical industries. Ti6Al4V alloy is widely used to manufacture implants because it possesses excellent strength characteristics and oxidation resistance [2, 3]. The present day research target is developing implants that can serve for much longer period or until lifetime without failure or revision surgery [4]. However, the high cutting temperature generated during High Speed Machining (HSM) may result in the deterioration of surface quality of machined components and wear at the tool tip surface [5]. This is because thermal stresses as a result of machining operations on work pieces affect the surface integrity of machined parts [6]. Surface Finish is an important quality characteristic for machined parts [7] and is influenced by various factors some of which include feed rate, cutting speed, work piece hardness, coolant application, and the cutting tool type [8 , 9]. Since titanium alloys are generally used for a component, which requires the greatest reliability, therefore the surface integrity must be maintained [10]. Various researchers have attempted the improvement of surface finish using various methods. The cutting forces under dry and wet environment for machining of Ti-6Al-4V using uncoated inserts has been investigated [11]. The use of inserts further increased machinability of the titanium alloy. The influence of coolant on machining Ti-6Al-4V has also been investigated [12]. Findings showed an improved Ra value of 1.3μm with coolant as against 1.4μm without coolant. The machining parameters of Ti-6Al-4V for electric discharge machining

T. S. Ogedengbe[1] ✉, S. Abdulkareem[2] and J. O. Aweda[3]

[1]Department of Mechanical and Automotive Engineering
Elizade University, Ilara-Mokin
Ondo State, Nigeria
1E-mail: temitayo.ogedengbe@elizadeuniversity.edu.ng

[2,3]Department of Mechanical Engineering
University of Ilorin
Kwara State, Nigeria.
[2]E-mail: abdulkareem.s@unilorin.edu.ng
[3]E-mail: joaweda@unilorin.edu.ng

Reference: Ogedengbe, T. S., Abdulkareem, S. and Aweda, J. O. (2018). Effect of Coolant Temperature on Surface Finish during Turning of Titanium Alloy Ti6Al4V. *International Journal of Engineering Materials and Manufacture*, 3(4), 237-244.

using a neural network approach has been modelled [13]. A significant surface roughness value of 1.75μm and an improvement in material removal rate during machining was reported. A comparative study of the cutting forces in high speed machining of Ti-6Al-4V and Inconel 718 has been carried out [14]. The similarities and differences both quantitatively and qualitatively in terms of force related quantities have been explained. The effect of process parameters on surface roughness in turning of titanium alloy under different conditions of lubrication has been examined [15]. An overall average Ra value of 1.42μm with dry, and flooded cooling conditions was achieved. Apart from flooded cooling method of coolant application, other methods such as minimum quantity of lubricant (MQL) and cryogenic cooling have also been employed in the removal of heat during machining. Generally, the term "cryogenic" refers to fluids that have boiling point lower than -150°C (238°F). The effect of cryogenic cooling during machining of medium carbon steel on a conventional lathe machine has been studied [16]. Surface roughness, cutting forces, and friction coefficient were examined and the results for the cryogenic machining to wet and dry turning was compared. Results showed that machining without cutting fluid or liquid nitrogen produced higher roughness depth and indicates that cutting with conventional cutting fluid provided a stable surface roughness within the range of speed studied (175.93 – 226.19 m/min).

The effect of MQL on cutting performance in turning medium carbon steel using uncoated carbide inserts using various speed feed combinations has been investigated [17]. The input parameters considered were cutting speed (68 – 266m/min), feed rate (0.10 - 0.20mm/rev) and depth of cut (1.0 - 1.5mm). The flow rate of the MQL adopted was 150ml/hr with air pressure 23bar and oil pressure 25bar. There was significant reduction in tool wear rate, dimensional inaccuracy and surface roughness by MQL over dry machining mainly through reduction in the cutting zone temperature and favourable change in the chip-tool and work-tool interaction. This work is therefore an attempt to improve the surface integrity of Ti6Al4V using coolant applied through a developed cooling system.

2 METHODOLOGY

2.1 Design of Experiment

The design of experiment for this work was done using Design Expert software, version 10.0. The central composite designs (CCD) of the response surface methodology was used for this work because its designs accommodated and suited the experimental approach which is needed to be able to achieve a 3-level experiment with sufficient array. Three process parameters with three levels were used as the control factors for dry machining while a fourth parameter was introduced for cooled machining. The four control factors selected were cutting speed, feed rate, depth of cut and coolant temperature. The control factors and their levels are shown in Table 1.

Table 1: Control factors and their levels for dry and cooled machining

Factor	Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Coolant Temperature (°C)
Level 1	1178	50	0.1	5
Level 2	1374	60	0.2	7
Level 3	1570	70	0.3	9

Dry Machining:

The orthogonal array (Table 2) for three factors at three levels was used for the elaboration of the plan of experiments the array L20 was selected, which has 20 rows corresponding to the number of experiments. The first column was assigned to the cutting speed (m/min), the second column to feed rate (mm/min), and the third column to the depth of cut mm. The output (responses) studied were the surface roughness and the cutting temperature.

Cooled Machining:

A fourth factor was introduced to the plan of experiments and an array of 30 runs (Table 3) was generated. This resulted from the addition of a fourth factor (coolant temperature) during the cooled machining process.

2.2 Experimentation

The work piece material used for this experiment was Ti-6Al-4V alloy cylindrical bar of 100 mm long and 20 mm diameter (Fig 1.). The chemical composition of the work sample was checked and is given by Table 4. The tool material utilized for this work is PVD Coated TS 2000 (code SNMG120408-MR3 TS2000), made of tungsten carbide hard micro grain abrasives as shown in Fig. 2. An Ajax–EV 310 model CNC machine with a computer Interface unit from GE FANUC series D721-10 (Fig 3) was used for this study.

The temperature at the cutting zone was measured using a thermocouple meter. The thermocouple wire probe was attached to the cutting tool at a distance of 0.5mm from the edge of the tool to ensure a correct capture of temperature at the cutting zone during machining. A sample Ti6Al4V implant was acquired from a medical facility (Fig.1 a) and the surface roughness was measured, a Surface roughness value of 0.52μm was obtained.

Table 2: Orthogonal Array for dry machining from Design Expert

Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of Cut (mm)
1570	50	0.3
1374	60	0.2
1178	50	0.3
1570	70	0.1
1374	60	0.2
1178	70	0.1
1374	60	0.2
1570	70	0.3
1570	50	0.1
1178	70	0.3
1178	50	0.1
1374	60	0.2
1044.37	60	0.2
1374	76.8179	0.2
1374	60	0.2
1374	60	0.2
1374	60	0.368179
1374	43.1821	0.2
1703.63	60	0.2
1374	60	0.0318207

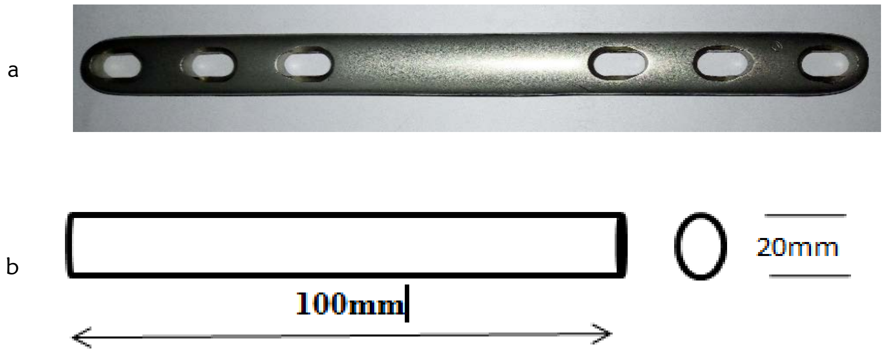

Figure 1: (a) Ti6Al4V implant (b) Schematic for specimen (Ti-6Al-4V)

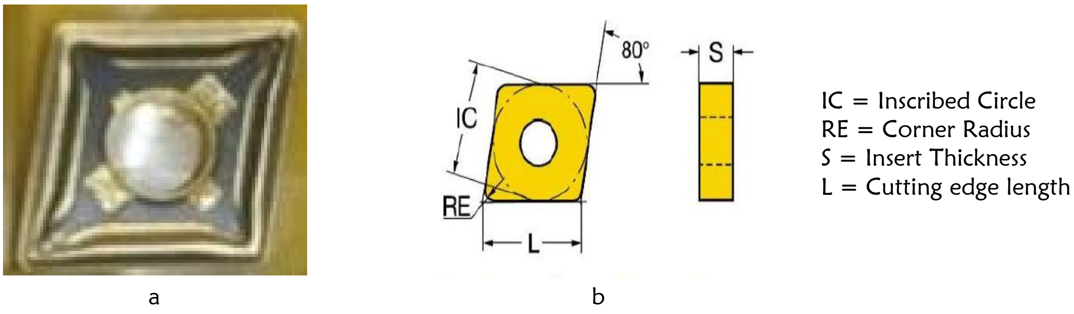

Figure 2: (a): PVD Coated Carbide Insert (b) Schematic for Insert

Table 3: Orthogonal Array for cooled machining from Design Expert

Cutting Speed (m/min)	Feed rate (Mm/rev)	Depth of Cut (mm)
1178	50	0.1
1570	50	0.1
1178	70	0.3
1570	50	0.1
1178	70	0.1
1178	50	0.3
1570	70	0.3
1374	60	0.2
1374	60	0.2
1570	50	0.1
1178	70	0.1
1570	70	0.1
1570	70	0.3
1178	50	0.1
1178	70	0.3
1374	60	0.2
1178	50	0.3
1570	70	0.1
1374	60	0.2
1570	50	0.3
982	60	0.2
1374	60	0.2
1374	60	0.2
1374	80	0.2
1374	60	0.4
1374	40	0.2
1374	60	0.2
1374	60	0.2
1374	60	0.2
1766	60	0.2

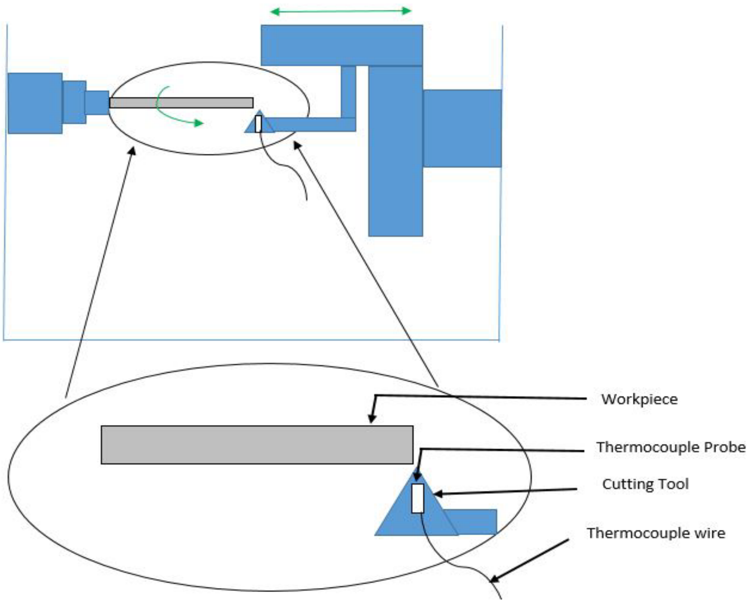

Figure 3: Experimental Setup showing probe attachment

Table 4: Chemical Composition of Ti-6Al-4V

Component	Al	V	C	Fe	N	O	H	Ti
% Composition	5.99	3.97	0.03	0.1	0.01	0.14	0.005	Balance

3 RESULTS AND DISCUSSIONS

The experimental results were analysed using signal-to-noise (S/N) ratio. Smaller-is-better was chosen for Surface roughness (SR) since smaller SR indicates better process performance. Table 5 shows the ANOVA of the dry and cooled machining results, with total error classified into pure error and lack of fit. Results show that p-value was < 0.0001 which showed that the models where significant at over 99% confidence level. In both models for machining parameters (cutting speed, feed rate, depth of cut, cutting speed x feed rate, cutting speed x coolant temperature, feed rate x coolant temperature) showed a significant value ($p \leq 0.05$).

Table 5: Analysis of Variance (ANOVA) for dry and cooled machining results

Source	Sum of squares	Degree of freedom	Mean square	F-Value	p-Value
Dry Machining					
Model	1.81	9	0.20	44.05	< 0.0001
A-Cutting Speed	*1.15*	*1*	*1.15*	*250.75*	*< 0.0001*
B-Feed Rate	*0.27*	*1*	*0.27*	*59.16*	*< 0.0001*
C-Depth of Cut	*0.15*	*1*	*0.15*	*33.42*	*0.1003*
AB	*0.011*	*1*	*0.011*	*2.30*	*0.0163*
AC	*0.014*	*1*	*0.014*	*2.98*	*0.1184*
BC	*2.112E-003*	*1*	*2.112E-003*	*0.46*	*0.5136*
A^2	*0.059*	*1*	*0.059*	*12.90*	*0.0058*
B^2	*0.020*	*1*	*0.020*	*4.42*	*0.0148*
C^2	*0.17*	*1*	*0.17*	*36.88*	*0.0002*
Residual	0.041	9	4.569E-003		
Lack of Fit	*0.041*	*5*	*8.159E-003*	*0.042*	*0.0003*
Pure Error	*3.250E-004*	*4*	*8.125E-005*		
Cor Total	1.87	19			
					Adjusted R-squared: 0.9556
Cooled Machining					
Model	0.32	14	0.023	28.46	< 0.0001
A-Cutting Speed	*0.25*	*1*	*0.25*	*311.06*	*< 0.0001*
B-Feed Rate	*0.022*	*1*	*0.022*	*27.62*	*0.0001*
C-Depth of Cut	*0.015*	*1*	*0.015*	*18.04*	*0.1008*
D-Coolant Temp	*0.014*	*1*	*0.014*	*16.84*	*0.0011*
AB	*1.562E-004*	*1*	*1.562E-004*	*0.19*	*0.6661*
AC	*7.562E-004*	*1*	*7.562E-004*	*0.94*	*0.3486*
AD	*1.806E-003*	*1*	*1.806E-003*	*2.25*	*0.0156*
BC	*5.256E-003*	*1*	*5.256E-003*	*6.54*	*0.0228*
BD	*5.625E-005*	*1*	*5.625E-005*	*0.070*	*0.0195*
CD	*5.625E-005*	*1*	*5.625E-005*	*0.070*	*0.7953*
A^2	*2.800E-003*	*1*	*2.800E-003*	*3.48*	*0.0831*
B^2	*3.407E-003*	*1*	*3.407E-003*	*4.24*	*0.0586*
C^2	*2.976E-007*	*1*	*2.976E-007*	*3.702E-004*	*0.9849*
D^2	*4.357E-003*	*1*	*4.357E-003*	*5.42*	*0.0354*
Residual	0.011	14	8.040E-004		
Lack of Fit	*0.011*	*10*	*1.116E-003*	*44.63*	*0.0012*
Pure Error	*1.000E-004*	*4*	*2.500E-005*		
Cor Total	0.34	29			
					Adjusted R-squared:0.9321

An interaction was observed between cutting speed and feed rate during surface roughness analysis for cooled machining. This shows that the effect of cutting speed during cooled machining depends on the level of feed rate used. However, cutting speed x depth of cut and feed rate x depth of cut were not significant parameters ($p>0.05$) for both models of dry and cooled machining.

The Surface roughness results obtained for all runs of the experimental design for the dry and cooled machining were represented by response surfaces (Fig. 4). The responses were represented by a three dimensional surface plots of two factors; cutting speed and feed rate with their corresponding contour plots. Feed rate and coolant temperature had a higher impact on the Surface roughness of dry and cooled machined Ti6Al4V respectively, while the effect of cutting speed was lower. The effect of depth of cut on surface roughness was minimal.

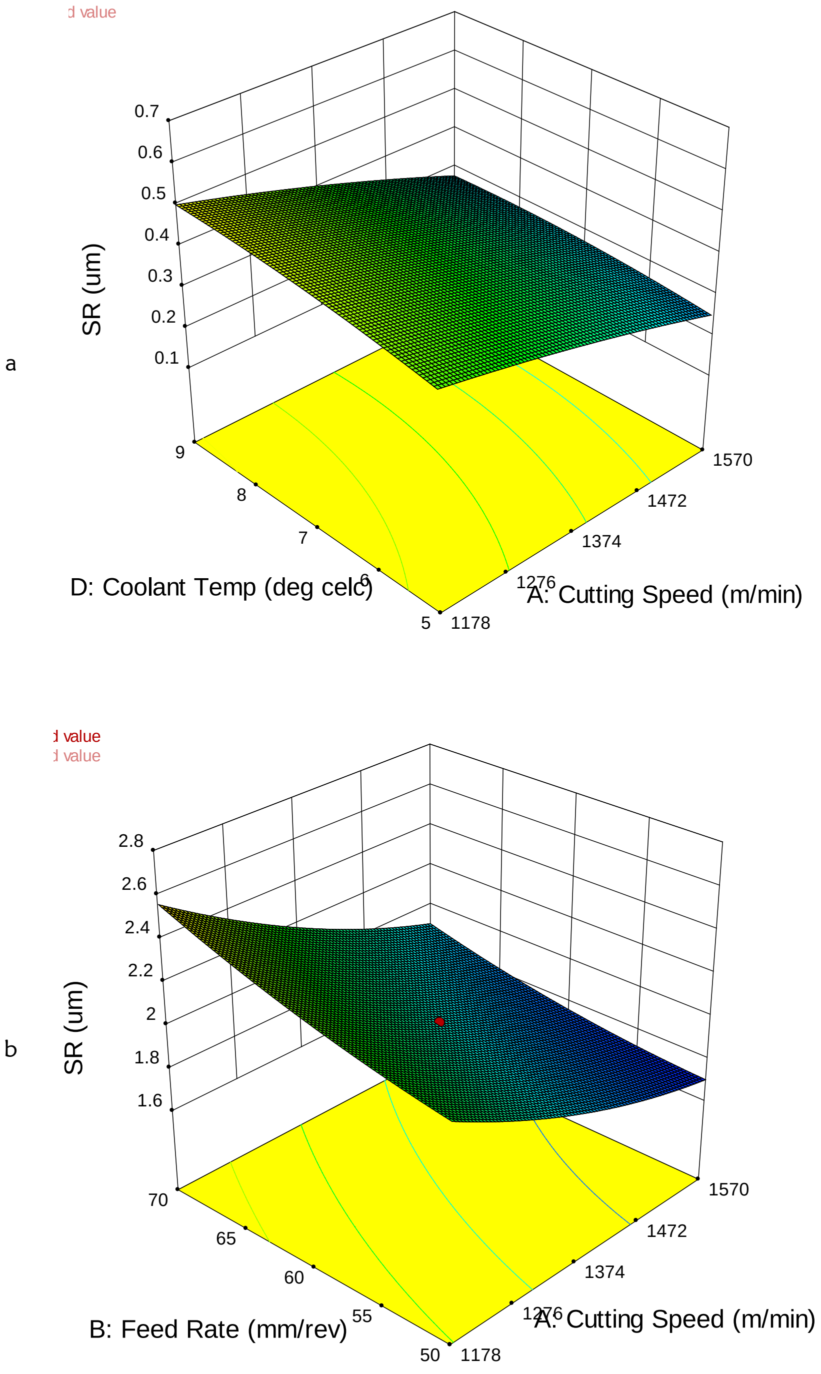

Figure 4: Response surface and contour plot for (a) dry machining and (b) cooled machining.

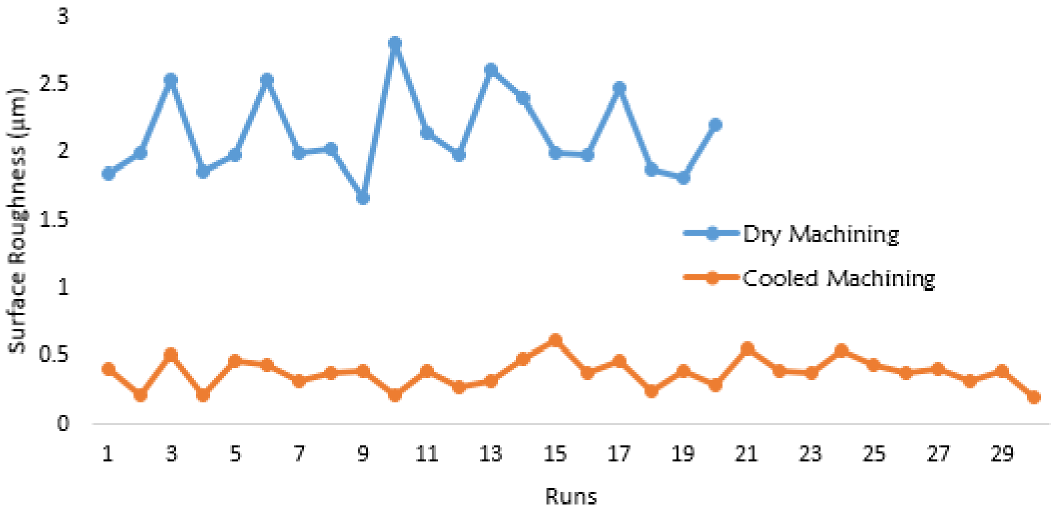

Figure 5: Surface roughness during dry and cooled machining conditions.

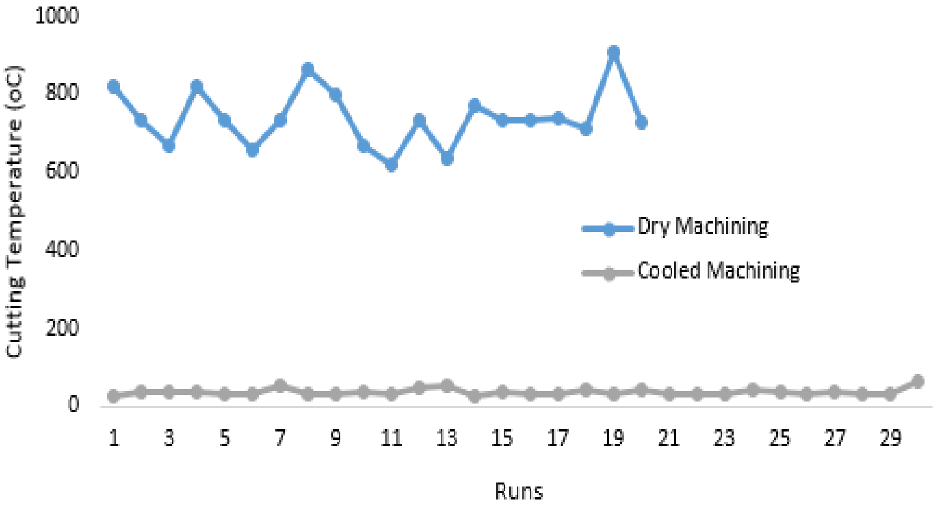

Figure 6: Cutting temperature during dry and cooled machining conditions.

During dry machining, the highest and lowest surface roughness values were 2.80µm and 1.67µm respectively. Results obtained (Fig.5) after coolant temperature was reduced from room temperature to 5, 7, 9 and 11°C showed an improvement in the surface integrity of the workpiece with a highest and lowest surface roughness values further reducing to 0.61µm and 0.19µm respectively. These improvements were as a result of a decrease in heat generation. Similar result was gotten by [18, 1] where they found that lubrication had a high effect on Surface roughness.

The surface roughness obtained during cooled machining showed a 63% improvement in surface integrity of Ti6Al4V during machining when compared with the Surface roughness of the implant acquired and measured. The coolant temperature reduction also affected the temperature at the cutting zone as the tool tip temperature was reduced (Fig. 6) from a maximum value of 909°C obtained during dry machining to 24°C during cooled machining. This represented an improvement of 97.4% a value better than that recorded by [1].

4 CONCLUSION

An experimental investigation on the effect of coolant temperature on machining of Ti6Al4V alloy with a view to improve surface roughness using a cooled coolant was attempted. The following are the conclusions reached / key findings from research.

- Coolant temperature, feed rate and cutting speed had strong impact on the surface roughness and cutting temperature.
- The effect of depth of cut was considerably low.
- Surface roughness for Ti6Al4V was improved to 0.19µm when the coolant temperature was reduced.
- Tool-work piece interphase was reduced by 97.4% during cooled machining.

Therefore, when the temperature of coolant is reduced during machining of Ti6Al4V, the surface profile could be improved and cutting temperature reduced to ensure a safer and more reliable workpiece and part especially as a biomedical implant.

ACKNOWLEDGEMENT

The authors are grateful for generous support from to Central Engineering Workshop, University of Ilorin, Kwara State, Nigeria and Central Engineering Laboratory/Workshop, Elizade University, Ilara-Mokin, Ondo State, Nigeria where this research has been conducted.

REFERENCES

1. Ogedengbe T.S., Abdulkareem S., Aweda J.O. (2018). Effect of Coolant Temperature on Machining Characteristics of High Carbon Steel, Covenant Journal of Engineering Technology, 1(1), 73-86.
2. Oldani C. and Dominguez A. (2012). Titanium as a Biomaterial for Implants, Recent Advances in Arthroplasty, Dr. Samo Fokter (Ed.), ISBN: 978-953-307-990-5, InTech, Retrieved from: http://www.intechopen.com/books/recent-advances-in arthroplasty/titanium-as-a-biomaterial-for-implants.
3. Andriya N., Venkateswara R.P. and Sudarsan G. (2012). Dry machining of Titanium alloy using PVD coated TiAlN tools, Proceedings of the World Congress on Engineering, Vol III, WCE 2012, London, U.K.
4. Virginia S. V. and Fuentes E, Titanium and Titanium Alloys as Biomaterials (2013). Tribology – Fundamentals and Advancements, Retrieved from http://dx.doi.org/10.5772/55860.
5. Abdulkareem S., Ogedengbe T.S., Aweda J.O, Khan A.A (2017). Comparative Analysis of AISI 1050 Steel Using N5-Soluble Oil and Arachis Oil in Metal Cutting Operation, Proceedings of the 30th AGM and International Conference of the Nigerian Institution for Mechanical Engineers. Kaduna, 2017, 195 – 206
6. Guesser W. L., Pereira F. S. and Boehs L. (2016). Surface changes during turning of grey cast iron, *Int. J. Machining and Machinability of Materials*, 18(3), 313-324.
7. Kalpakjian M., Moss T. and Kurat H. (2006), Tool life and surface integrity in turning Titanium alloy, Journal of Materials Processing Technology, 118, 231-237.
8. Rao M. and Venkatasubbaiah K. (2016). Effect and Optimization of EDM Process Parameters on Surface Roughness for En41 Steel. International Journal of Hybrid Information Technology, 9(5), 343-358.
9. Ezugwu Chinedu A. K., Okonkwo Ugochukwu C., Sinebe Jude E., Okokpujie Imhade P. (2016). Stability Analysis of Model Regenerative Chatter of Milling Process Using First Order Least Square Full Discretization Method, *International Journal of Mechanics and Applications*, 6(3), 49-62. doi: 10.5923/j.mechanics.20160603.03.
10. Che-Haron C.H and Jawaid M.L (2005). Tool life and surface integrity in turning Titanium alloy, Journal of Materials Processing Technology 188, 231-237.
11. Hong, S.Y., Markus, I., Jeong, W. (2011). New cooling approach and tool life improvement in cryogenic machining of titanium alloy Ti-6Al-4V. International Journal of Machine Tools &Manufacture, vol. 41, no. 15. p. 2245-2260, DOI:10.1016/S0890-6955(01)00041-4.
12. Nambi M. and Davim P. (2011). Influence of Coolant in Machinability of Titanium Alloy (Ti-6Al- 4V), Journal of Surface Engineered Materials and Advanced Technology, 1, 9-14.
13. Rahman, M., Wong Y. S., and Zareena A. R. (2003). Machinability of titanium alloys. JSME International Journal, Series C: Mechanical Systems, Machine Elements and Manufacturing. 46(1): p. 107-115.
14. Yuan, S.M., Yan L.T., Liu W.D. & Liu Q. (2011). Effects of cooling air temperature on cryogenic machining of Ti–6Al–4V alloy. Journal of Materials Processing Technology, 211(3), 356-362.
15. Ali S.M., Dhar, N.R. & Dey, S.K. (2011). Effect of MQL on cutting performance in turning medium carbon steel using uncoated carbide inserts using various speed feed combinations. Advances in Production Engineering & Management 6, Vol. 3, pp. 185-196.
16. Ramana M.V., Vishnu A.V., Rao G.K.M. & Rao D.H (2012). Effect of Process Parameters on Surface Roughness in Turning of Titanium Alloy under Different Conditions of Lubrication, Recent Advances in Robotics, Aeronautical and Mechanical Engineering, ISBN: 978-1-61804-185-2, 83-91.
17. Yap T.C, Sivarao C. S. Lim, J. W. Leau (2015). Surface roughness and cutting forces in cryogenic turning of carbon steel, Journal of Engineering Science and Technology, 10(7), 911–920
18. Ali S.M., Dhar, N. R. & Dey, S.K. (2011): Effect of MQL on cutting performance in turning medium carbon steel using uncoated carbide inserts using various speed feed combinations. Advances in Production Engineering & Management 6(3), 185-196.
19. Shetty, R., Jose, T. K., Revankar, G. D., Rao, S. S., & Shetty, D. S. (2014). Surface Roughness Analysis during Turning of Ti-6Al-4V under Near Dry Machining using Statistical Tool. *International Journal of Current Engineering and Technology*, 4(3), 2061-2067.