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ScienceDirect
Procedia CIRP 46 (2016) 139 – 142
www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Performance Analysis of Process Parameters on Machining Titanium (Ti-6Al-4V) Alloy Using Abrasive Water Jet Machining Process

Vasanth S[a] ,Muthuramalingam T[a,*],Vinothkumar P[c], Geethapriyan T[b] , Murali G[a]

[a]*Department of Mechatronics Engineering, SRM University, Kattankulathur,India-603203.*
[b]*Department of Mechanical Engineering, SRM University, Kattankulathur,India-603203.*
[c]*Department of Mechanical Engineering, Indian Institute of Technology Madras,Chennai-600036.*

* Corresponding author. Tel.: +91-9994872013; *.E-mail address:muthu1060@gmail.com*

Abstract

Owing to its light weight and corrosive resistant, Titanium (Ti-6Al-4V) alloy is mainly utilized in fabricating medical device applications. Since it has high strength, it is very difficult to machine alloy using conventional machining. In the present study, an endeavor has been made to machine titanium alloy using AWJM process. Since the process involves with less heat affect zone and higher material removal, it is possible to enhance machinability of workpiece. It has attempted to find the influence of process parameters on surface roughness and topography for enhancing the process. It has been observed that the abrasive flow rate and standoff distance has the most significant role on determining surface quality.

Keywords: Waterjet machining; Roughness; SEM.

1. Significance of the study

Titanium (Ti-6Al-4V) alloy is a high strength, excellent corrosion resistance, light weight and fire resistance material. Due to its higher temperature withstanding capacity, Titanium alloy is being widely used in high performance automotive parts, marine, medical, aircraft industries[1]. It is highly difficult to machine such material due to its high hardness. Since it is very hardened material, it is very difficult to machine such material with intricate shapes using conventional machining processes. Among the unconventional processes, Electrical discharge machining (EDM), electro chemical machining (ECM) and abrasive water jet machining (AWJM) are generally used to machine such material. Since the AWJM process involves with no heat affected zone, higher material removal and no tool wear[2].

Nomenclature

AWJM	Abrasive water jet machining
R_a	Surface roughness

It can be used to machine titanium alloy with complex shape for enhancing the machinability. Owing to its ability of producing micro level of material removal, micro machining can produce better surface finish than conventional machining process. The machinability of the water jet machining can be improving by understanding the investigation of process parameters involved in such process[3]. Even though many literatures are available on machining of Titanium (Ti-6Al-4V) alloy, only very little attention has been given to analyze the influence of parameters on surface quality of machined alloy using abrasive water jet machining (AWJM) process. Hence the present investigation has been carried out.

1.1. Objectives of the study

The main objectives of the present study are as follows:

- To analyze the influence of process parameters on surface roughness of machined alloy.
- To analyze the influence of process parameters on surface topography.

doi:10.1016/j.procir.2016.04.072

2. Experiments and methods

2.1. Selection of workpiece and performance measures

Due to its importance of making piston rings and biomedical implants, Titanium (Ti-6Al-4V) alloy has been used as workpiece specimen material in the present study[4]. The chemical composition of α-β Titanium is shown in Table 1. The triangular shape specimens have been made for the the particular food processing application using AWJM

Table 1. Chemical composition of (Ti-6Al-4V) alloy

Elements	% composition
Al	6.321
V	3.714
C	0.006
Fe	0.091
Si	0.010
Mn	0.0053
Cr	0.021
Sn	0.001
Ti	Remaining

Owing to its importance on determining the machinability, the average surface roughness has been considered as the performance measures in the present study. The average line surface roughness (R_a) of side of the machined triangular specimens(i.e. perpendicular to lay made by machining) has been computed using TALYSURF CCI LITE non-surface roughness tester as per ISO 4287 standard with high pass filtering. The diameter of orifice is 0.254mm. The selection of abrasive particles plays a most significance role on determining the machinability in AWJM process. Hence Garnet has been utilized as abrasive powder with mess size of 40 in the present investigation.

2.2. Selection of input process parameters

Owing to the importance of the process parameters in the AWJM process, Water pressure (P), abrasive flow rate (Q_A), feed rate (FR) and standoff distance (SOD) have been selected as the input process parameters for the present study. The Titanium plate of 2mm thickness has been made to cut for producing triangular specimens with 3mm in each side using ECMM process. Since the trial experiments have to be conducted in smaller, medium and larger level rating of energy, Water pressure has been selected as 2000bar, 2500bar and 3000bar with abrasive flow rate of 300mm^3/min, 400mm^3/min and 500mm^3/min. The feed rate has been chosen as 1000 mm/min, 1200 mm/min and 1500 mm/min. The standoff distance has been selected as 2mm, 2.5mm and 3mm.

2.3. Selection of design of experiments

The selection of orthogonal array (OA) is the important factor while designing the experiments using Taguchi method which has been used to conduct experiments in the present study. Since four process parameters have been chosen with number of levels equal to three, L_9 orthogonal array has been selected as per Taguchi's design of experiments theory[5].

3. Results and discussion

In the present section, the influence of input process parameters on surface roughness (R_a) and surface topography has been analyzed. Table 2. shows the combinations of input factors with their R_a under L_9 OA based Taguchi design of experiments respectively. Figure 1. shows the machined specimens of Titanium (Ti-6Al-4V) alloy.

Fig. 1. Machined Titanium alloy specimens

Table 2. R_a of machined titanium alloy under L_9

Trial number	P (bar)	Q_A (mm^3/min)	FR (mm/min)	SOD (mm)	R_a (μm)
1	2000	300	1000	2	4.15
2	2000	400	1200	2.5	1.29
3	2000	500	1500	3	4.87
4	2500	300	1200	3	5.25
5	2500	400	1500	2	2.38
6	2500	500	1000	2.5	2.60
7	3000	300	1500	2.5	2.33
8	3000	400	1000	3	3.20
9	3000	500	1200	2	2.52

3.1. Influence of process parameters on R_a

The main effect plot is used to find the influence of the process parameter in any process. The deviation from the horizontal line indicated the higher influence of input process parameter on the response parameter. Figure 2. shows the influence of process parameters on surface roughness of machined Titanium (Ti-6Al-4V) alloy in AWJM process using Minitab software package. From Figure 2, it has been understood that the abrasive flow rate and standoff distance has the most influent nature on surface roughness in AWJM process.

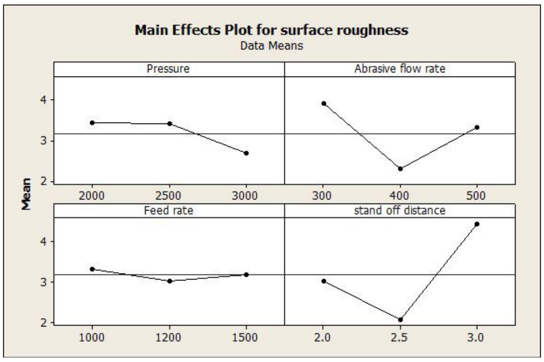

Fig. 2. Main effect plot of process parameters on MRR

Since the standoff distance determines the mechanical force applied over the machined surface in abrasive water jet machining process, it has the most significant role on determining the surface roughness. If abrasive flow rate is higher than the optimized value, then the larger craters will be formed over the machined surface due to the higher mechanical energy happened between the abrasive and the work piece surface. Owing to its importance on material removal from the work piece specimen, the abrasive flow rate has also most influent nature on determining surface roughness.

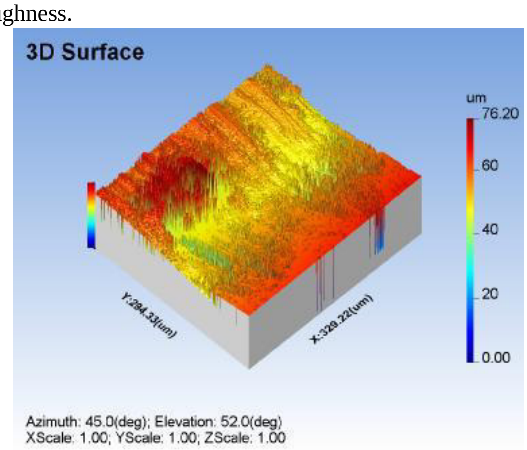

Fig. 3. Non contact R_a measurement under trial number = 2

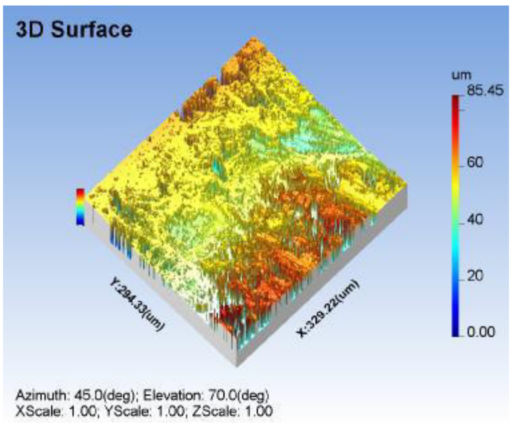

Fig. 4. Non contact R_a measurement under trial number = 4

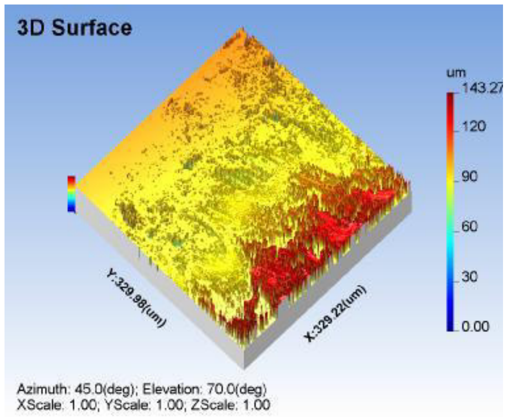

Fig. 5. Non contact R_a measurement under trial number = 8

3.2. Influence of process parameters on surface topography

. Figure 3, Figure 4 and Figure 5 shows the three dimensional surface roughness measurement with different process parameters combination such as trial 2, trial 4 and trial 8 on surface roughness in AJMM process. In AWJM process, the taper and surface roughness is mainly influenced by the material removal happened during the machining process.

Figure 6, Figure 7 and Figure 8 shows the SEM images of machined workpiece specimens with lower, moderate and higher surface roughness respectively. It has been observed that the higher surface roughness has been observed higher abrasive flow rate. The energy is influenced by the mass flow rate of the abrasive particle. Since the higher abrasive flow rate has generated higher energy , it has removed the more material removal from the work piece specimens.

While the higher flow rate has been used with higher standoff distance, the material has been removed in higher level with random in nature. Hence it has produced higher surface roughness. It has been also observed that the lay marks of trial 4 and 8 have been observed as discontinuous pattern owing improper way made to water jet as observed in Figure.7 and Figure. 8.

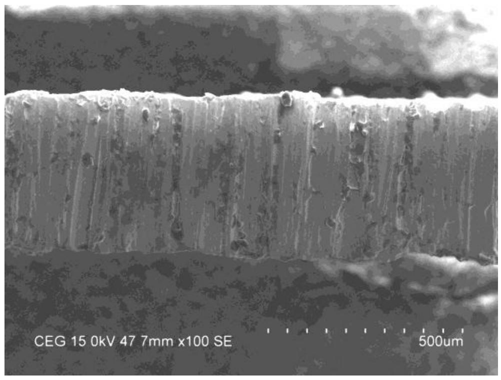

Fig. 6. SEM image of machined surface with lower R_a under trial 2

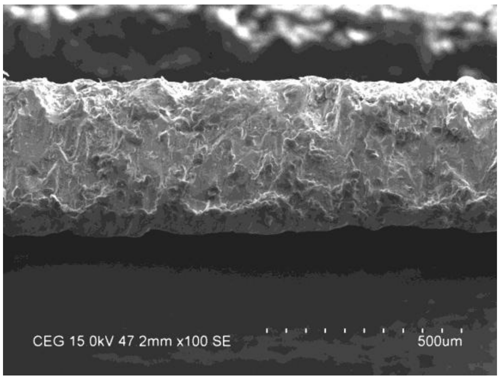

Fig. 7. SEM image of machined surface with moderate R_a under trial 8

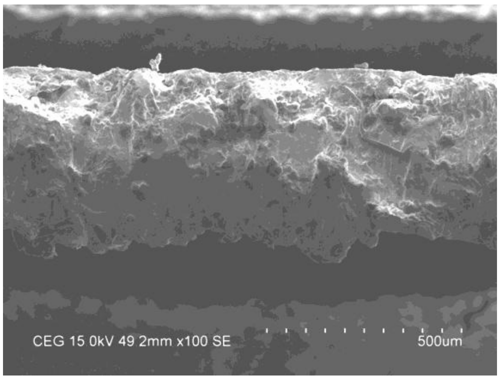

Fig. 8. SEM image of machined surface with higher R_a under trial 4

4. Conclusion

In the present study an experimental investigation made to analyze the effects of process parameters on machining Titanium (Ti-6Al-4V) alloy using AWJM process. From the experimental results the following conclusions have been made.

- Abrasive flow rate and standoff distance has the most significant role on determining surface quality.
- Higher abrasive flow rate with higher standoff distance produces higher surface roughness owing to larger and random energy distribution

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