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Ultrasonic Drilling of Titanium: Surface Roughness and Geometrical Form Assessment

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Abstract— The objective of this work is to find out the difference between the Geometric forms of holes which are drilled in Grade 5 Titanium using Ultrasonic machining by two different approaches. One is with single tube trepanning drilling and other is with multiple tubes trepanning drilling. The optimized Parameters for machining are taken from Literature Survey. The Geometric forms which are taken into consideration are Conicity, Oversize, and Surface Roughness. These Geometrical forms are assessed with the help of Video Measurement System and Talysurf Non-Contact Surface Measurement system. From experiment and further analysis, it is concluded that geometric forms are apparently equal in both the machining process. It is further identified that, among the three holes which are drilled with three tips trepanning drilling have difference in the geometric forms along the direction of slurry flow. The effects of the Geometric form in two different approaches are compared, for application in Medical implant and Spectacle frame industry.

Keywords— Gang drilling**,** Geometric assessment, Surface Roughness, Ultrasonic machining

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1.INTRODUCTION

ADVANCE engineering materials such as polymers, ceramics, composites, and super alloys play an ever increasing important role in modern manufacturing industries, especially, in aircraft, automobile, cutting tools, die and mould making industries [1], [2]. Higher costs associated with the machining of these materials, and the damage caused during their machining is major impediments in the processing and hence limited applications. Further, stringent design requirements also pose major challenges to their manufacturing industries. These include precise machining of complex and complicated shapes and/or sizes(i.e. an aerofoil section of a turbine blade, complex cavities in dies and moulds, etc.), various hole-drilling requirements(i.e. non-circular, small or micro size holes, holes at shallow entry angles, very deep holes, and burr less curved holes), and surface integrity requirements. This manufacturing revolution is now, as it has been in the past, centred on the use of new tools and new forms of energy. The result has been the introduction of new manufacturing processes used for material removal, forming and joining, known today as non-traditional manufacturing processes or Advance Manufacturing Process (AMP). Ultrasonic machining (USM) is one among such Advance manufacturing process (AMP), which is used for the machining of non-conductive, brittle work piece materials such as engineering ceramics. Because the process is non-chemical and non-thermal, materials are not altered either chemical metallurgical [3], [4]. The process is able to effectively machine harder materials, whether or not the material is an electrical conductor or an insulator.

In this Paper one of the difficult to machine super alloy material, titanium is machined with Ultrasonic machining process by single point drilling horn and triple point drilling (USM gang drill tool) horn. Production accuracy for holes obtained by USM involves both dimensional accuracy (oversize) and form accuracy (out-of-roundness and conicity). Production accuracy and surface integrity is assed to check weather, is there any difference between these holes drilled in single point and multi point holes drilled in Gr.5 Titanium using USM drilling machine under same process parameters.

2.MATERIALS AND MACHINE

A. Titanium and its uses

The widespread use of titanium alloys both in structural and corrosion-resistant applications is well known. There is growing interest concerning the process ability of titanium alloys since they exhibit a good compromise between density and yield strength and also have good creep and fatigue resistance at mid temperatures

As a result of more applications, world production statistics indicate that the production of titanium and its alloys increases tremendously from 1937 onwards. The reason for this dramatic growth lies with the properties of titanium [8]. The job material used for this experiment is Ti-6Al-4V plate of thickness 2 mm. The chemical composition and the Physical properties of the work piece material are listed in Tables I and II, respectively.

TABLE I
COMPOSITION OF TI-6AL-4V

Element percentages	
Aluminium	5.5 to 6.75
Carbon	≤0.10
Iron	≤ 0.50
Hydrogen	≤0.015
Nitrogen	≤ 0.05
Oxygen	≤ 0.45
Other	< 0.4
Vanadium	3.5 to 4.5
Titanium	Balance

TABLE II

PHYSICAL AND MECHANICAL PROPERTIES OF TI -6AL-4V

Physical property	typical mvbv value
Density (g/cm3)	4.42
Melting range (°C±15°C)	1,649
Specific heat (J/Kg°C)	560
Thermal conductivity (W/m-K)	7.2
Tensile strength (MPa)	897
Elastic modulus (GPa)	114
Hardness rockwell C	36

B. USM for machining

Titanium alloys are branded as difficult to machine materials but have high utility in manufacturing sector. Poor thermal conductivity of titanium alloys retard the dissipation of heat generated, creating, instead a very high temperature at the tool–work piece interface and adversely affecting the tool life as shown in Fig. 1. Titanium is chemically reactive at elevated temperature and therefore the tool material either rapidly dissolves or chemically reacts during the machining process resulting in chipping and premature tool failure [11]. Compounding of these characteristics is the low elastic modulus of Titanium, which permits greater deflection of the work piece and once again adds to the complexity of machining these alloys [12].

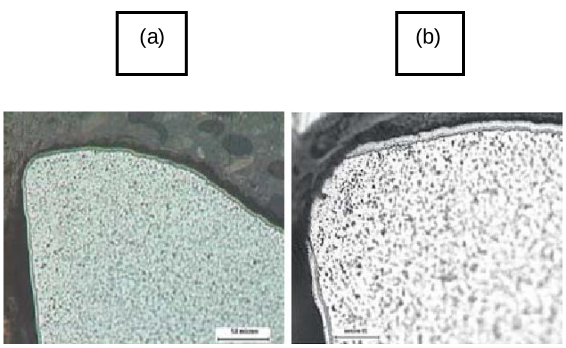

Fig. 1: The location of the damaged zone in the cutting tool.(a)New sectioned cutting edge, and(b)worn cutting edge just after total cutting length of250mm(115m/min,0.165mm/tooth,2.25,8.8mm)[11]

The macroscopic effect of the heating during EDM is a leads to form transformed layers near the surface. The subsurface characteristics are occurring in various layers or zones, which are usually termed as altered material zones. The near surface of EDM machined Ti6Al4Vis inspected; three distinguished layers were obtained as seen in Fig. 2. The upper recast layer of this zone is called the ‘‘white layer.’’

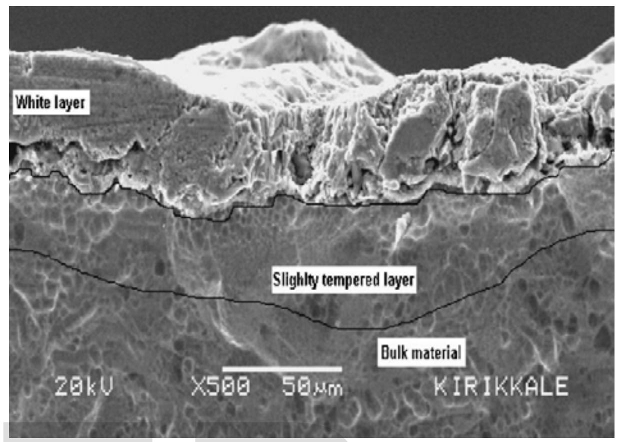

Fig. 2: Cross-sectional view of white layer (electrode Material: graphite) [12].

The existence of the white layer at the surface of EDM— processed work pieces is due to the solidification of the molten metal which is not flashed away by the dielectric. This white cast layer which is formed over the surface of machined titanium will add advantage in some application. But it is not desirable in some of the applications in aerospace and medical industries. To avoid this ultrasonic machining is used to machine titanium and its alloys, because the process is non-chemical and non-thermal, materials are not altered either chemical or metallurgical.

3. USM AND ITS PROCESS PARAMETERS

In USM process, high frequency electrical energy is converted into mechanical vibrations through a transducer, which are transmitted to the abrasive particles in the slurry via an energy-focusing device or horn/tool assembly. USM is characterized by low MRR and almost no surface damage to the work material. It can be used for machining both electrically conductive and non-conductive materials preferably with low ductility and high hardness (above 40 on Rockwell C-scale). Shaw [7] proposed a static and analytical model giving relationship between MRR and vibration amplitude, frequency, abrasive grit size and concentration, and feed force, which can be used for all type of materials. Miller [8] developed MRR model based on plastic deformation restricting its application to ductile materials only.

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Even though hardness value of Titanium is less than 40 (on Rockwell C-scale), It is consider for machining based on Plastic deformation proposed by miller [7].

Before the experiment, the factors that could influence the machining of titanium material are identified [5]-[6]. The important parameters are shown in Table. III

TABLE III

IMPORTANT PARAMETERS FOR USM

Symbol	Quantity	SI units
A_t	Cross-sectional area of cutting tool	(mm^2)
F_s	Static feed force	(N)
A_v	Amplitude of vibration	(mm)
H_w	Brinell hardness number of work piece material	(N/mm^2)
Ht	Brinell hardness number of tool material	(N/mm^2)
λ	Indentation ratio, [λ= ht/hw =Hw/Ht]	No Unit
Cav	Concentration of abrasive particles by volume	No Unit
d_m	Mean diameter of abrasive particles	(mm)
f_v	Frequency of vibration	(Hz or cycles/s)

4. EXPRIMENTAL SETUP

The experiments were conducted with a horizontal-type Diatron ultrasonic drilling machine with a power output of 0.9 kW, frequency range 18 - 22 kHz, water-cooled transducer and air-cooled power tubes. The static load was varied by changing the sliding drill head inclination. Boron carbide abrasives were mixed with water in the ratio 1:4 wt.%.. The tool was brazed onto the shank. The slurry suspension was supplied externally under pressure by a single jet. In the machining process the abrasive slurry feed and circulation, amplitude and the oscillator power level were maintained constant. The static load was measured by means of a precision spring balance to an accuracy of +- 5 g.

(a) (b)

Fig. 3**:** Single point (a) and Triple point (b) tool horn used for machining.

The cone shape horn is brazed with the Single tube and Triple tubes as shown in fig. 3. for two different machining approaches. Conical shape horn is selected for this experiment, because of it easy manufacturability and optimal frequency concentration [15]. The Diameter of Stainless Steel tube is 3.32 mm. USM drilling horn with multiple Tubes is also called as a Simultaneous USM Drilling. Rupinder Singh, J.S. Khamba have done simultaneously USM drilling to drill the Glass material for optical Fabrication without compromising the Quality [10]. The other important Parameters Such as Frequency, Static Load, Abrasive, Abrasive Size (diameter), Amplitude, Tool Materials are considered as 20 KHz, 1.5 Kg, 0.027 mm, B_4C, 0.0200mm, stain less steel Respectively. The Experiments have already done on titanium and its alloy by varying all these parameters.It is found that the above mentioned Process Parameters Gives the Best Result in terms of Surface Roughness and Tool Wear [17].

5.RESULTS

A. Conicity and Over Size

The profiles of the holes at both entry and exit sides with respect to tool position, were viewed under a magnification of 18X with a Video Measurement System (VMS). Video measuring system is a photoelectric measuring system of high precision and efficiency. It is composed of CCD color camera of high resolution, continuous zoom lens, Color monitor, video crosshairs generator, precision linear scale, multi-functional digital readout (DRO), 2D measuring software (M2D) and high precision working table. The Output image and the graph are recorded with the help of PC and M2D software.

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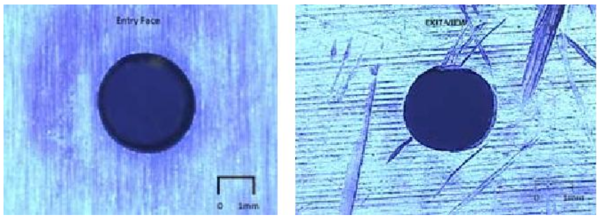
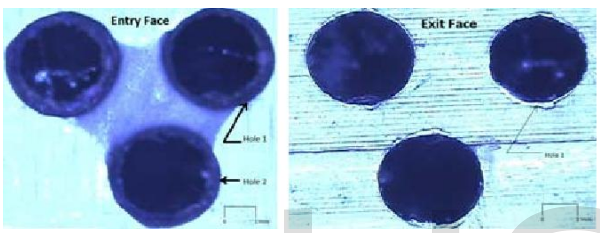
From the measured dimension geometric form such as Oversize, Conicity was computed. The images Observed is shown in Fig. 4. Fig. 5 shows how errors of geometrical form of the drilled holes such as oversize and Conicity were computed. The computed values are shown in Table IV.



(a) (b)



(c) (d)

Fig. 4: VMS image of USM Drilled Holes in titanium with single tube entry, exit (a,b) and three tubes entry, exit (c,d).

From the calculated values, it is observed that Hole 3 has Large Conicity Angle (θ) Compare to Other holes in multi-point horn. The Reason is abrasive slurry flow is not uniform to all three holes. Conicity and over size increase in order from hole 1 to 3.The reason for which the slurry falls on hole one is the work piece is kept in the shown position Fig. 6. It flows on Hole 1 first because of the Gravity and then it falls on the Hole 2 and Hole 3 respectively. Conicity in three point holes can be reduced all by allowing slurry over the work piece equally.

B. Surface Roughness (Ra)

To Study the roughness of the holes Talysurf CCL-Lite Non contact 3D Profiler measurement System with Resolution 0.01nm, Repeatability greater than 0.02, with magnification 20X is used. The Magnification Scale is selected on the basis of Area of Measurement and slope angle (θ) of the surface

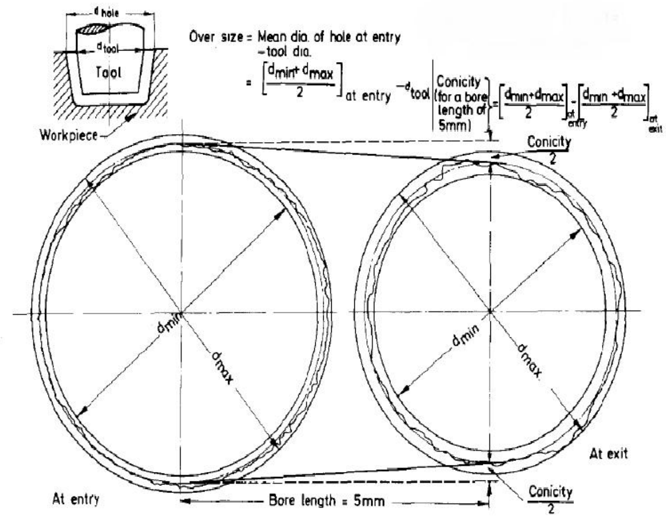
.The 3D Surface and roughness profile obtained from Talysurf CCL-Lite Non contact 3D Profiler is shown in the fig. 7. & fig. 8.

Since the measured surface is curved in nature the surface profile will have both Roughness and Waviness. To distinguish these parameters, Filtering options available in Talysurf CCL-Lite Non contact 3D Profiler measurement System .The pattern of the roughness and waviness profile of ultrasonic machining in titanium by two types of tool horn are plotted as shown in Fig. 8 & Fig. 9 as a function of the length of measured surface. It is observed that under identical machining conditions with different tool horn have almost same surface roughness (Ra) values. The Roughness values obtained is shown in table V.

TABLE IV

GEOMETRIC MEASUREMENT VALUE FROM VMS

VIDEO MEASUREMENT SYSTEM					
SINGLE TUBE				**Conicity angle(θ)**	**Over Size(mm)**
Hole	Entry face(mm)	Exit face(mm)	Difference(mm)		
Single point hole	3.67	3.156	0.514	7.32	0.413
TRIPLE TUBES					
Hole	Entry face(mm)	Exit face(mm)	Difference(mm)		
Hole 1	3.647	3.164	0.485	6.91	0.5
Hole 2	3.75	3.091	0.659	9.35	0.64
Hole 3	3.751	2.934	0.823	11.62	0.71



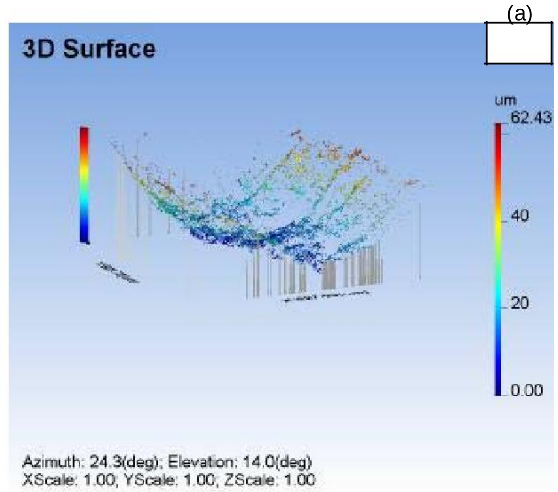
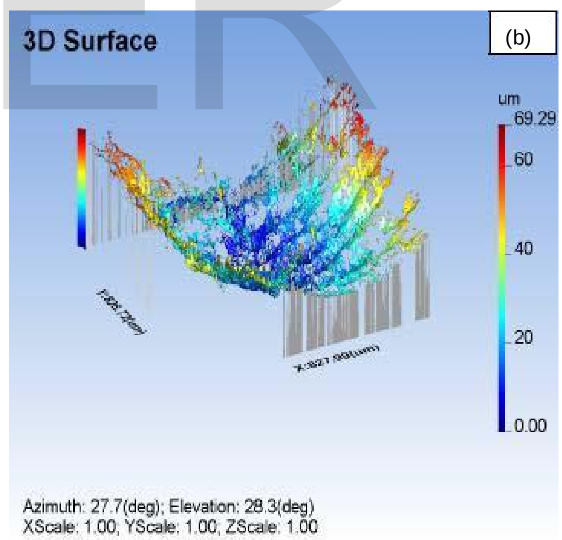


Fig. 5: The scheme of computation for the errors of the geometrical form of the holes drilled.



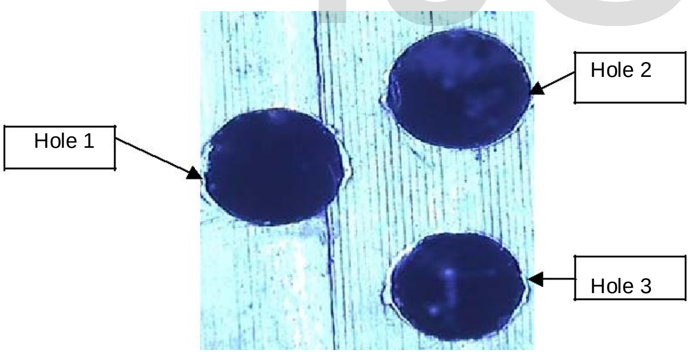
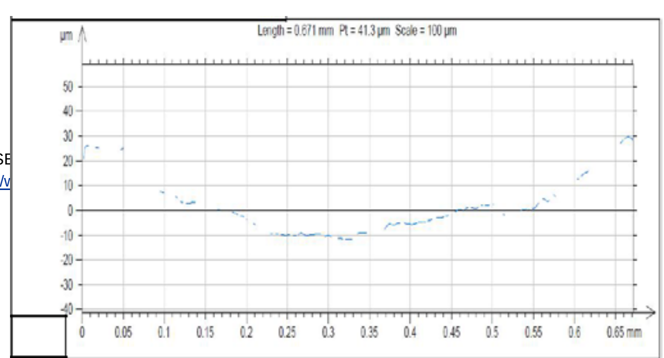


Fig. 6: Position of the work piece during machining Operation



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a

Fig. 7: 3D surface of the hole of single tube (a) and three tubes (b) USM drilling.

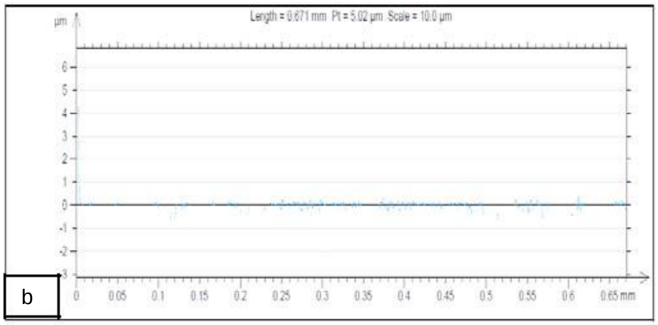
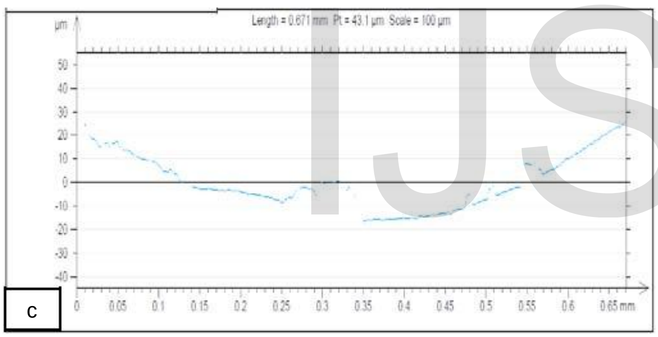


Fig. 8: Waviness (a) and Roughness (b) Profile of single tube Machined Surface.



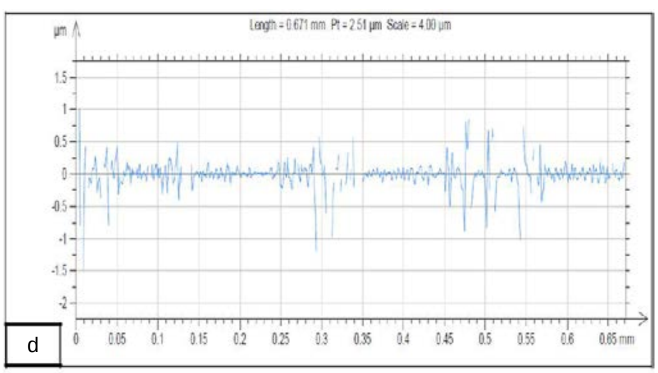


Fig. 9: Waviness (a) and Roughness (b) Profile of three tubes Machined Surface.

6. Conclusion

In this work two approaches are used to machine the Gr.5 titanium and the geometric form and surface integrity obtained by these machining processes are analyzed. The analyzed results are:

TABLE V

MEASURED ROUGHNESS PARAMETER OF SINGLE TUBE AND TRIPLE TUBES MACHINED SURFACE

Amplitude parameters(unit)	Single Tube	Multiple Tubes
R_p(µm)	0.284	0.602
R_v(µm)	0.416	0.990
R_c(µm)	0.278	0.294
R_a(µm)	0.083	0.089
R_q(µm)	0.138	0.206

1. Under identical Machining parameters with different tool horns have almost the same surface roughness (Ra) values. (See Table V). So it is concluded that in the simultaneous drilling process the (Ra) value remains same irrespective of single point or multi-point horn.
2. Conicity angle and Oversize varies with respect to the Slurry flow direction. It is observed that in the single tube drilling the values are minimum and in the triple tubes the values are high with respect to slurry flow direction.
3. In triple point horn, machining area is increased to 66% and material removal rate is increased to 68.20% with respect to Single point horn.

Scope for future work:

Conicity and Over-Size variation in the machining can be overcome by Special arrangement for the slurry flow. Such that the slurry will flow in all direction irrespective of the work piece position.

The effect of tool wear during the machining process is not considered. It can be taken into consideration for its influence in the geometric form.

7. Appendix

ISO -4287 Roughness parameters description:

R_p- The largest profile peak height within a sampling length. R_v- The largest profile valley depth within a sampling length. R_c- Mean value of the profile element heights within a sampling length.

R_a- Arithmetic mean of the absolute ordinate values within a sampling length.

R_q- Root mean square value of the ordinate slopes within a sampling length.

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