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Electro Chemical Honing (ECH) of External Cylindrical Surfaces of Titanium Alloys

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Abstract

Surface roughness has become the most significant functional requirement and it is an index of the product quality. In order to increase the efficiency of hard to machine alloys like titanium and nickel alloys, an Electro Chemical Honing (ECH) process has been employed to achieve highest material removal rate with the best surface qualities. This extended abstract describes the design and fabrication of an indigenously developed tooling setup for ECH of external cylindrical surfaces of Titanium alloys (TI 6AL 4V) and also highlights the key process parameters and their affect on ECH process. The influence of the machining parameters on the surface finish has been investigated and optimized the process parameters for improving the surface roughness is also evaluated. Percentage improvements in surface roughness values Ra and other parameters like electrolyte temperature, composition and concentration were studied while changing the processing time (PT). And also the study of surface characteristics of micro and macro level and micro hardness too examined.

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Keywords: Electro Chemical Honing; Titanium alloy; Process Parameters; Surface Characteristics; Optimization

1. Introduction

Nowadays, the manufacturing industries are specially focusing on dimensional accuracy and surface finish. In order to improve the tribological properties, fatigue strength and corrosion resistance, a reasonably good surface finish is desired. With tremendous development in modern technology, more and more challenging problems are faced by the engineers and researchers in the field of manufacturing era. The rapid development in advanced

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industries like aerospace, automobile, nuclear power and turbine industries has been accompanied by the development of very hard, high strength, difficult-to-machine ,non-ferrous materials and alloys and titanium is one of the most potential among them [1]. And other alloys such as super alloys, stainless steel, tantalum, nimonics, ceramics, composites etc. having high strength to weight ratio and low machinability are also some examples. Producing complicated geometries and maintaining high dimensional accuracy in such materials become extremely difficult with the conventional machining methods. This necessitates the exploration of Advanced Manufacturing Processes (AMPs) [2]. Hybrid Manufacturing Processes are conceptualized by combining either two or more than two AMPs or AMPs and Conventional Process to simultaneously exploit the potentials and capabilities and also to minimize the adverse effects of individual. Electro Chemical Honing (ECH) is one of the Advanced Manufacturing Process which is having more scope in coming modern scenario [3]. ECH process has its own advantages to remove any hard material with controlled surface generation with excellent surface finish. Furthermore, it provides highest productivity and increasing the service life of the components. However, so far these investigations were carried out to provide precision finishing to the internal cylinders as well as Gears. After that a number of researchers were carried out detailed study on ECH of gears, its prospective features and its applications. It is now one attempt to carry out the research on ECH of external cylindrical surfaces to discuss the development of productive, high-accuracy, good surface finishing method based on ECH principle. The electro chemical honing process is even used to obtain precise dimensions and surfaces in cylindrical shapes with a wide range of diameters. This process applies to parts such as Hydraulic Cylinders, Pistons, Bearing Bores, Pin Holes and to some external cylindrical surfaces. The paper describes about the surface finishing of external cylindrical surfaces of Ti alloy Ti 6Al 4V.

1.1. Titanium and its Alloys

Due to the combination of low density and high strength titanium alloys like Ti6Al4V is widely used in mechanical engineering, especially in the fields of automobile and medical engineering. Titanium alloys are extensively used in aerospace, petroleum and chemical industry due to their specific strength, fracture resistance, strong corrosion resistance and ability to retain high strength at elevated temperatures. Recently, the titanium and its alloys are also widely used as biomedical materials to act as a load bearing implant in orthopedic surgery However, titanium and its alloys have poor machinability due to their low thermal conductivity, high chemical reactivity and low modulus of elasticity resulting in high cutting temperature and rapid tool wear [4].During machining of titanium and its alloys by conventional processes, the above characteristics lead to high temperature at cutting interfaces. Keeping in view the severity of machining of titanium and its alloys by conventional machining processes, the need of development of newer concept for machining of titanium with other hybrid machining processes has been explored [5]. Among other advanced machining processes, electrochemical honing (ECH) is one of the latest process which can to be used for machining of titanium alloys because of its feasible favorable features. Moreover, the process is particularly useful for rapid removal of metal from the surface. In this process, the more material is removed at atomic scale by electrolytic dissolution and the rest by mechanical honing abrasive action. And therefore, the process can produce good surface finish and also, it has no damaging effect on the mechanical properties of the metal [6].

1.2. Electro Chemical Honing

Electrochemical honing (ECH) is a hybrid electrolytic micro finishing technology characterized by a distinct coupling of electrochemical machining (ECM) and conventional mechanical honing (MH) processes to provide controlled functional surface generation and fast material removal capabilities in a single operation. ECH can offer a unique range of benefits to the machined surface which cannot be obtained by either of the processes when applied independently [7]. The ability of ECH to apply these benefits productively, has led to its widespread use in industries, especially in aerospace, automobiles, petrochemical reactor, roller and gear manufacturing industries [8]. The ECH process is five to eight times faster than honing and four times faster than grinding. It can provide surface finish up to 0.05 μm. It provides fine surface generation by honing and fast material removal by ECM in a single operation [9]. The ECH process offers advantages of high metal removal rate and extreme accuracy of 0.001mm in a wide variety of hard to cut materials. Other advantages include the ability to correct out of roundness, cylindricity, circularity and axis straightness in relatively round cylindrical work pieces [10].Work piece bore length-to-diameter ratios of 1.5:1 and longer are ideal for the ECH process. In this ECH finishing operation a very small amount of material is removed from the work piece by means of a honing process and remaining by Electrolyte [11].Many researchers [12,13,14] have carried out researchers in the field to explore various aspects of the ECH of bevel gears, spur gears and helical gears. Their study proves ECH as highly productive alternating finishing process for the bevel gears what they actually achieved [15, 16]. It has special feature of better understanding the ECH process behavior on electro chemical mechanical finishing especially. They found from experimental investigations to explore the influence of processing time, electrolyte composition and electrolyte concentration on various process performance parameters like surface quality, tribological aspects and process capabilities of interior system [17]. Recently a concept of remanufacturing with ECH was introduced by researchers and has been exploded to improve the quality of engine parts. It has many advantages with regard to quality and productivity of finishing over the other conventional finishing methods [18].

2. Experimental details

2.1. Experimental setup

The application of ECH for surface finishing of external cylinders has not been given kind attention so far and as a consequence even no such experimental setup has been reported neither from the academicians nor from the industrialists. Therefore, based on objectives of study an experimental setup for surface finishing of external cylinders has been developed for the titanium alloys. As the process involves the electrolytic dissolution and mechanical scrubbing, the design, fabrication and material selection can achieve based on some relevant considerations such as electrical conductivity, anti-corrosiveness, electrical insulation, mach inability and economic feasibility. The setup consists of power supply system, electrolyte supply system, tooling system, tool motion system and machining chamber and fixtures. A schematic diagram has been shown in Fig.1. The power supply system consists of 0-100 V and 100A DC supplying unit having provision for operating at both continuous and pulsating condition. This subsystem is employed to provide power supply to the anodic work piece and cathode tool to complete the electric circuit. The electrolyte supply system is consisting of reservoir, pump, flow meter, pressure gauges, heat exchanger, chamber drains, magnetic filters, settling tank, etc. The purpose of this sub-element is to supply the filtered electrolyte with controlled flow rate and pressure to the machining zone. The entire tooling system is enclosed in a machining chamber. Machining chamber also has provisions for supply of fresh electrolytes, for removal of used electrolyte, and for escape of gases generated during ECH process. The machining chamber is connected to the cast iron frame using four brass screws. Thus, it is attached to the machine column of bench drilling machine using a swivel arrangement for ease in loading and unloading. The swivel system can slide on the machine column to achieve axial positioning of the tool with respect to work piece. After the proper alignment and positioning of the work piece and tool, work table can be locked in position.

The abrasive action of the honing tool removes the material from the outer surface of work piece, as the tool is designed for external cylindrical surface components. The tool rotates and reciprocates while the work piece is stationary fixed in machine chamber. This rotary & reciprocation movement of ECH tool is the single most important point in achieving the closer tolerances required and surface finish desired. Honing stones comprise an embedded abrasive particles (Al_2O_3, SiC, CBN) bonded in vitreous bonding material with particular grit size honing stones. Selection of the abrasive type and size (80 to 600 mesh sizes) depends on the type of work piece and the rate of surface finish required. The honing stones are mounted on a stain less steel tool holder which is simultaneously given a rotary motion as well as reciprocating (or oscillatory) motion to perform a complete cycle. The rotary movement of tool can be controlled by stepper motor and while reciprocating motion can be controlled by Micro controlled based programme. The reciprocating motion is along the axis of the work piece to bring the entire work surface in contact with the honing stone.600 Grit size SIC honing stones are used to perform the experimentations for Ti alloys of Grade 2.

The machining chamber is made of Perspex to obtain a better visibility of the operation. Machine chamber consists of work piece fixture and ECH tool holder as shown in Fig.2.The work-holding system consists of a fixture and an electrolyte chamber and is attached to the foundation with proper insulating arrangements. The worktable and machine chamber fixture design considerations include corrosion resistance and strength to take over the machining torque without deforming the work-piece. The fixture and the electrolyte chamber are made of stainless steel and Perspex respectively. Automatic gauging devices, such as air gauge, are often built into the ECH setup. This study also investigates the effects of process parameters on microstructure and surface roughness of the machined surface. Fig.3. shows the composition of Ti alloy examined by EDX technique. The inter-electrode gap (IEG) is maintained between work piece and the tool to avoid short circuiting, and filled with the electrolyte. During this, non-conductive spring controlled honing tool is applied with controlled pressure on the work piece. Then the honing tool is given simultaneous rotary and reciprocating motions, as in conventional honing, to finish the work picece surface. The mechanism of material removal in ECH is based on the interaction between electrolytic actions with mechanical abrasion as explained earlier.

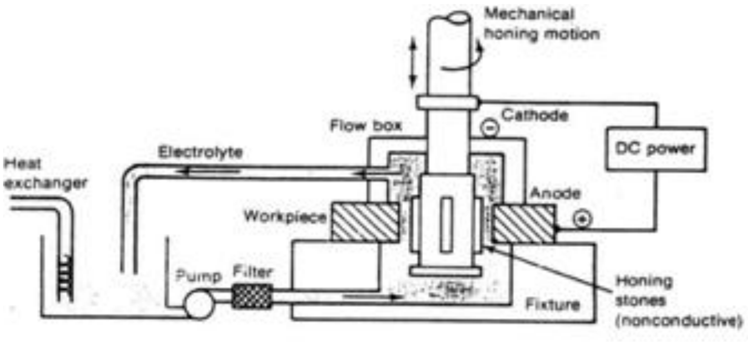


Fig. 1. Schematic view of ECH tool with Work piece Interaction.

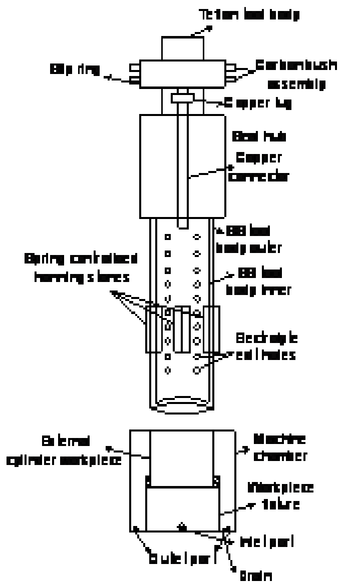


Fig. 2. Exploded view of ECH tool with Work piece fixture.

2.2. Experimental Procedure

Experiments were carried out to study the effect of process parameters on process performance. The experiments on Ti alloys have been done by using one-parameter-at-a-time approach, which intern to explain the effects among various process parameters. Finishing time, and three electrolyte-related parameters (i.e., composition, temperature and concentration) have been used as key process parameters in to the investigations to study their effect on the surface finishing performance of ECH. Initially the Effect of finishing time has been examined through experiments by varying one factor at a time approach and also later electrolyte composition electrolyte temperature and electrolyte concentration have been studied. The surface roughness values before and after ECH are measured. In this work, processing time was used as input process parameter and surface texture parameters were used as response parameter. The surface roughness parameters were measured by Wyko NT 1100 optical profilometer. The percentage improvements in surface roughness values were also calculated to visualize the improvement in the surface quality of Ti alloys. Table 1. presents the input and fixed process parameters selected for the experimentation. The parameters and their ranges were selected on the basis of literature review, pilot experiments and machining constraints.

Experimental investigations were carried out to study the effects of important ECH process parameters such as electrolyte composition, electrolyte concentration; electrolyte temperature and finishing time on the surface roughness characteristics (i.e. R_a).Micro-hardness and surface integrity aspects were also examined. Pre-experiment and post-experiment measurements of process performance characteristics were examined using the suitable measuring instrument like Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) to study the surface integrity and surface texture aspects of electrochemically honed external cylinders of Titanium alloys(Ti 6 Al 4V) of Grade 2 The Composition of Ti6Al4V is obtained by EDX(Energy Dispersive X-ray) analysis as 6% Aluminium,4% Vanadium and remaining % of Titanium alloy.

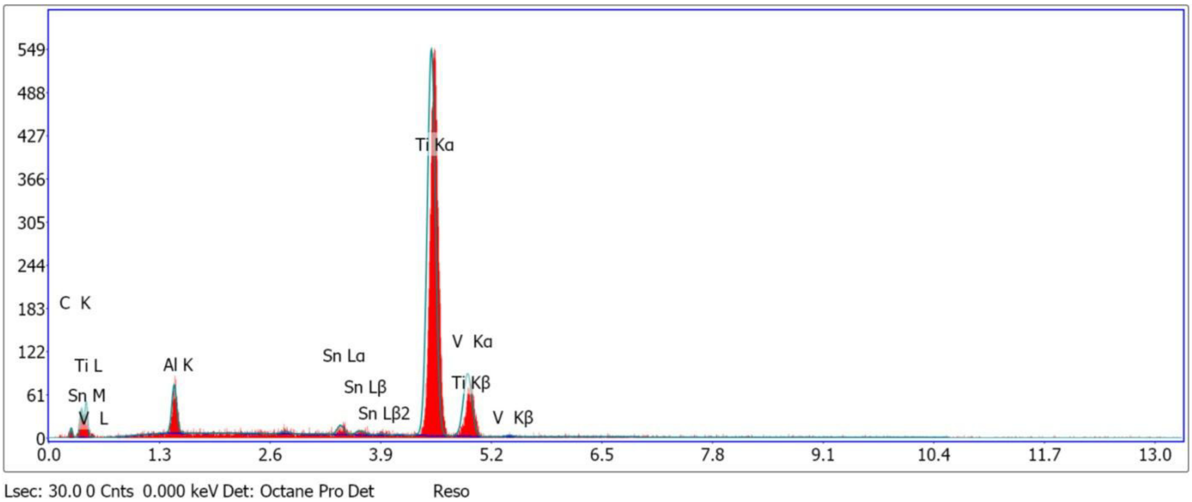


Fig. 3. Ti 6AL 4V composition data by EDX analysis.

Table 1. Values of input and fixed parameters for experimentation.

Parameter	Values
Type of power supply	Continuous DC
Current	20 A
Processing time	08 min
Voltage	30 V
Rotating speed	60 rpm
Electrolyte pressure	1 MPa

Electrolyte flow rate	30 l/min
IEG	0.75 mm

3. Results and discussions

Table 2. to 5. presents the surface roughness (Ra) value, of work piece before and after machining for each experimental run. The calculated percentage improvement in surface roughness values (PIR_a) are also shown. The initial and final R_a values and the percentage improvement in surface roughness (PIR_a) values both are presented in Table 2,3,4 and 5 for different processing time, electrolyte temperature and electrolyte concentation and electrolyte composition respectively. A higher value of PIR_a represents lower value of final average surface roughness. Percentage improvement in average surface roughness value (PIR_a) is used as process response and this helps to study the material removal, finished surface characteristics, and surface integrity aspects of ECH process. A higher value in PIR_a indicates better surface finish of work-surface as shown in Table 3. Fig.4 (a) shows Average surface roughness and (b) Average surface roughness 3D interactive image respectevely for ECHed workpiece material captured by profilometer . Fig. 5 shows Average surface roughness 3D Plot.

Micro-structure study and Micro-structure characterization have been carried out to investigate the impact of the process on surface integrity aspects of the machined surface. SEM images of the cut surfaces have revealed that the fine surface finish was obtained when machining was done at a combination of lower levels of input process parameters. When machining was done at combination of higher levels of input process parameters, some burrs arise on the machined surface. Fig. 7 shows SEM photographs of electrochemically honed (ECHed) Ti alloy TI6AL4V surface (a) before ECH and (b) after ECH. . It is clear from the plots that the surface roughness present in the surface after ECH is significantly reduced by the process.

Table 2. Average surface roughness and percentage of improvement in average surface roughness values at different finishing time.

Trial No	Finishing Time (min)	Top portion		Middle portion		Bottom portion	
		R_a (μm)	PIR_a	R_a (μm)	PIR_a	R_a (μm)	PIR_a
1	Before ECH	1.46	-	1.43	-	1.50	-
2	2	1.21	17.18	1.22	14.69	1.31	12.67
3	4	1.01	30.82	1.04	27.27	1.12	25.33
4	6	0.80	45.21	0.799	44.13	0.891	40.60
5	8	0.38	79.45	0.201	85.94	0.314	79.07
6	10	0.28	87.67	0.115	91.96	0.210	86.01

Table 3. Increment in PIR_a for different finishing time periods.

Finishing Time (min)	Top portion	Middle portion	Bottom portion
	Increment of PIR_a	Increment of PIR_a	Increment of PIR_a
2-4	13.64	12.58	12.66
4-6	14.39	16.86	15.27
6-8	34.24	41.81	38.47
8-10	08.22	06.02	06.93

Table 4. Average surface roughness (in μm) and percentage of improvement in it for different electrolyte temperatures.

Temperature	Top portion			Middle portion			Bottom portion		
	Before	After	PIR_a	Before	After	PIR_a	Before	After	PIR_a
20^0C	1.54	0.412	73.25	1.58	0.410	74.05	1.45	0.312	78.48

25^0C	1.46	0.314	78.49	1.50	0.315	79.00	1.52	0.315	79.28
30^0C	1.51	0.215	85.76	1.52	0.209	86.91	1.49	0.210	85.95
35^0C	1.42	0.301	78.80	1.48	0.310	79.05	1.41	0.320	77.30

Table 5. Average surface roughness (in μm) and percentage of improvement in it for different electrolyte compositions.100% NaCl Electrolyte solution.

Electrolyte Solution	Top portion			Middle portion			Bottom portion		
	Before	After	PIR_a	Before	After	PIR_a	Before	After	PIR_a
5.0% NaCl	1.46	0.660	54.72	1.58	0.640	59.50	1.45	0.650	55.48
7.5% NaCl	1.58	0.630	60.12	1.59	0.615	61.32	1.61	0.620	61.49
10.0% NaCl	1.46	0.510	64.83	1.69	0.610	63.90	1.65	0.640	63.03
12.5% NaCl	1.54	0.412	73.25	1.58	0.418	74.25	1.41	0.304	75.44
15.0% NaCl	1.52	0.315	79.20	1.50	0.314	79.01	1.42	0.301	78.80
17.5% NaCl	1.58	0.410	74.05	1.54	0.412	73.25	1.56	0.410	73.32

From the experimental results, it can be observed that a very good improvement in average surface roughness Ra about 79.45% at top portion of the cylindrical work piece, 85.94% at middle portion of the cylindrical work piece and 79.07% at bottom portion of the cylindrical work piece respectively at 8 minutes of Finishing Time as shown in Table 2. and Table 3. If total percentage improvement in surface roughness Ra concerned, improvement about 34.24 % at top portion of the cylindrical work piece, 41.81% at middle portion of the cylindrical work piece and 38.47% at bottom portion of the cylindrical work piece respectively obtained at 8 minutes of Finishing Time as shown in Table 3.

As per the electrolyte temperature concerned, Table 4. results reveals that better surface finish at maximum 30^0C of electrolyte temp and shows a very good percentage improvement in surface finish about 85.76% at top portion of the cylindrical work piece, 86.91% at middle portion of the cylindrical work piece and 85.95% at bottom portion of the cylindrical work piece respectively. Fig.6 (a) shows Average surface roughness Bearing ratio and (b) Average surface roughness Histogram profile .

It is evident from the Table 5., that the NaCl pure solution alone gives better surface finish at maximum 15% of concentration and shows a very good percentage improvement in surface finish about 79.20% at top portion of the cylindrical work piece, 79.01% at middle portion of the cylindrical work piece and 78.80% at bottom portion of the cylindrical work piece respectively. Fig. 8 (a) shows AFM analysis of 2D histogram and (b) 3D surface finish of machined surface and there is considerable decrease in surface roughness with increase in processing time.

3.1. Effect of finishing time

Table 2. and 3. presents the R_a values and their percentage improvement (PIR_a) for different processing time. It is found that the surface roughness values are decreasing with increasing processing time while the effect of processing time on PIR_a is reverse. It is evident from the results that the increment in percentage improvement values is most significant at initial stage and at later stage it is very less insignificant. Because initially the surface remains more irregular and therefore, the rate of electrochemical dissolution is high. But, at later stage of experimentation, the intensity of EC dissolution deceases as the surface gets smoothened. It is evident from Table 3, that up to processing time of 08 minutes, the rate of increment is significant while after processing time of 08 minutes the rate of increment is marginal and hence, 08 minutes was selected as optimal processing time for further study.

3.2. Effect of electrolyte temperature

The variations of PIR_a with electrolyte temperature are shown in Table 4. It is obvious from the plots that surface finish improves with increasing electrolyte temperature. Electrolyte conductivity is very much sensitive towards electrolyte temperature and increases with it results in higher current density and thus provides the higher value of

PIR_a . But, at higher temperature chance of formation of hydrogen gas at cathode is higher. It deteriorates the surface finish. Based on results, 30°C as electrolyte temperature is optimum for present study. At 30°C, the highest PIR_a values achieved. It is also evident from table that after 30°C the PIR_a values start decreasing with increasing temperature.Increase in temperature increases electrolyte conductivity and consequently current density.

3.3. Effect of electrolyte concentration

It is evident from Table 5., that an increase in electrolyte concentration continuously increases the PIR_a value. The conductivity of the electrolyte depends on electrolyte concentration. As the electrolyte concentration is increased, more numbers of ions are available in the solution for electrolytic dissolution which results in increasing electrolyte conductivity and increase in PIR_a. But, the concentration should be ≤ 15% to get better passivation effect. The electrolytic dissolution which results in increasing electrolyte conductivity increases the percentage improvement in surface roughness values.

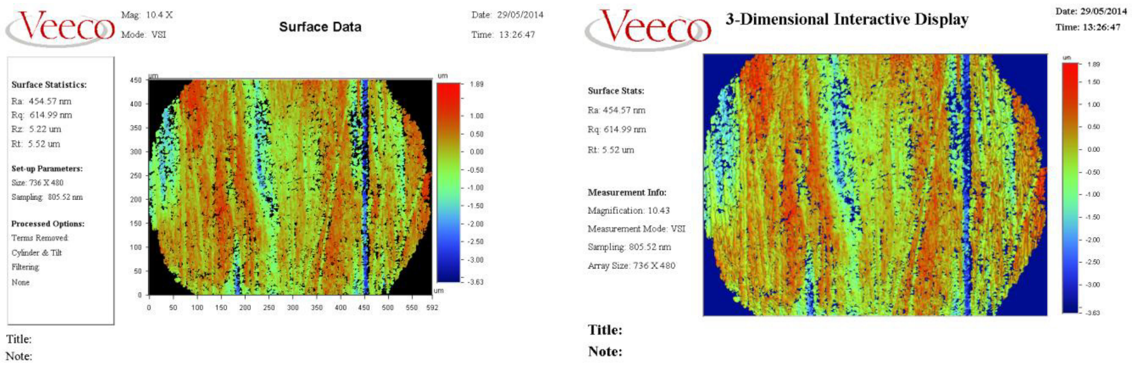


Fig. 4. (a) Average surface roughness data; (b) Average surface roughness 3D interactive data.

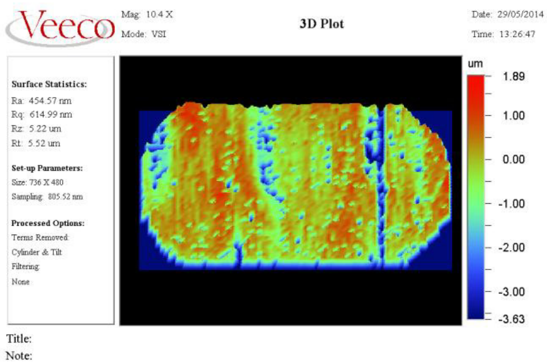
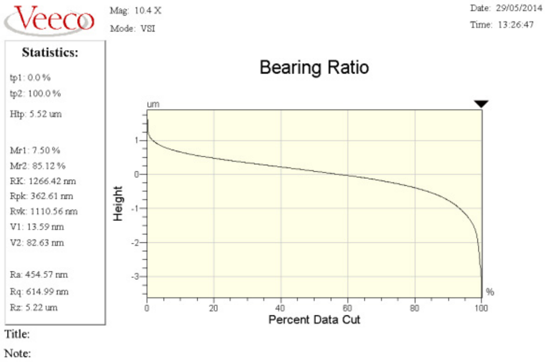
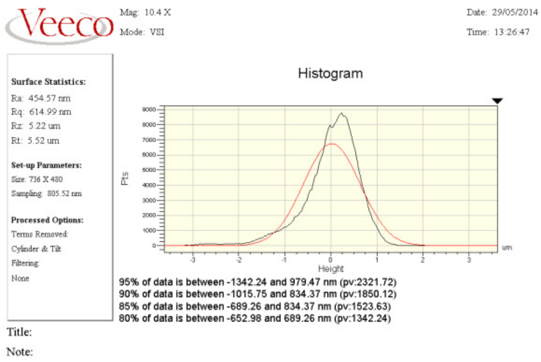


Fig. 5. Average surface roughness 3D plot data.

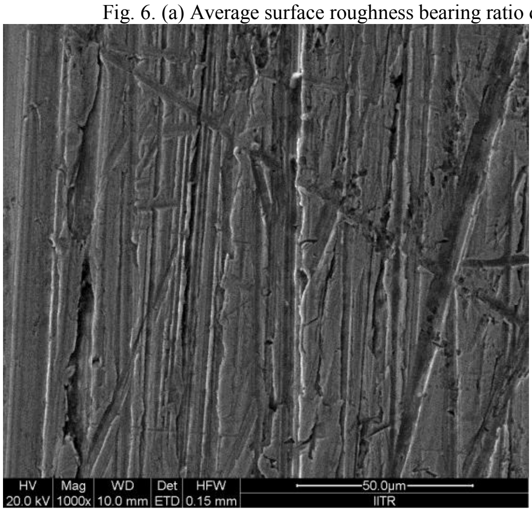


(a)

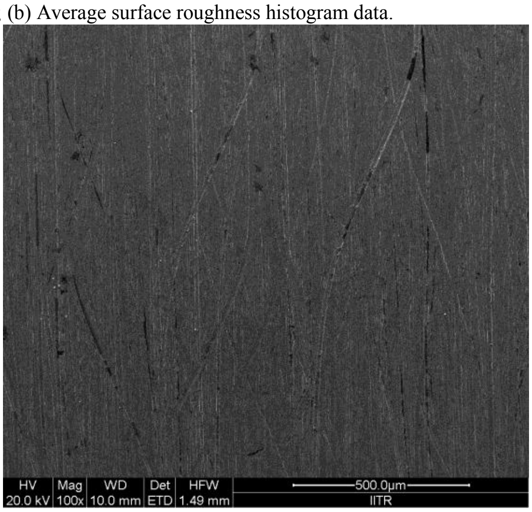


(b)

Fig. 6. (a) Average surface roughness bearing ratio data; (b) Average surface roughness histogram data.

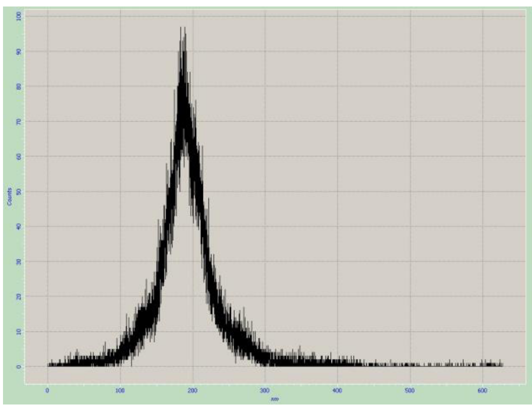


(a)

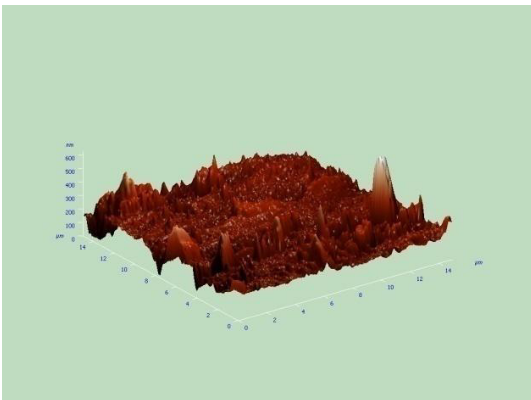


(b)

Fig. 7. SEM photographs of electrochemically honed (ECHed) Ti alloy TI6AL4V surface (a) before ECH; (b) after ECH.



(a)



(b)

Fig. 8. (a) 2D histogram by AFM analysis; (b) 3D surface finish By AFM analysis.

Conclusion and future Scope

Based upon the results of experiments, 08 minutes as finishing time, 30^0C as electrolyte temperature and 15% of NaCl pure electrolyte solution are found optimum for precision super finishing of Titanium alloys. The result shows that, all the four parameters are highly important to achieve the better surface finish.

In this work, an attempt was made to study the effects of Input process parameters like processing time, electrolyte temperature, electrolyte composition, and electrolyte concentration and found that they play a significant role in the minimization. This paper established the feasibility of using ECH for high precision finishing of Ti alloys to improve the micro-topographical characteristics .It is evident, that the processing time has immense influence on material removal mechanism of the process. The study illustrates that initially the processing rate is high, but it slows down as the processing time increases. But even with increased processing time, its productivity and mechanical properties are good enough. It is also found, that the process is highly capable of reducing the irregularities on cylinder surfaces.

However, like most of the hybrid machining processes, ECH is also in the development phase and therefore, a sustained global research is still required to perform it into other tough materials as well as other process parameters. Further research could consider the study of effect of different parameters like Inter electrode gap, voltage, current, honing abrasive grit size, other different electrolyte related parameters etc. on surface quality for its successful industrial applications, commercialization and matured technology.

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