Review on Optimum Process Parameters in Electrochemical Honing

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Abstract - *Electro chemical honing is a hybrid machining process designed for the micro-finishing of gear profiles, critical components, to impart long life and reduce failure due to wear. Study is made on the various experiments and methodologies carried out in the view to find the optimum process parameters that affect the outcomes of Electro chemical Honing process. It was found that the parameters such as the electrolyte concentration, Inter Electrode Gap (IEG), honing speed, machining time grit size play a predominant role in surface finish of the component.*

***Key Words*: Electro chemical honing (ECH), Electro chemical machining (ECM), Taguchi quality loss function strategy, Inter Electrode Gap (IEG), Honing speed, Electrolyte concentration (EC).**

1. INTRODUCTION

Electrochemical honing (ECH) is a hybrid electrolytic machining technology that involves, Electrochemical Machining (ECM) and conventional Mechanical Honing (MH) processes to create controlled surface feature and faster machinability. It has a unique range of benefits while machining, which cannot be obtained while performing process separately, i.e. honing and electro chemical machining [1]. The ECH process has about 5-8 times greater machining time than conventional grinding process with a surface finish up to 0.05μm [2]. It provides fine surface generation better than honing and fast material removal by ECM in a single operation [3]. In ECH, during the finishing operation, a very small amount of material is removed from the work piece by means of a honing process and remaining by electrolyte. Many researchers [4, 5 and 6] have carried out researchers in this field to explore various aspects of the ECH of bevel gears, spur gears and helical gears. From their experimental investigations the effect of the honing speed, electrolyte concentration and the inter electrode gap has on surface quality, tribological aspects are determined.

2. PROCESS PRINCIPLE

In ECH, most of the material is removed by electrolytic dissolution action of ECM. But during ECM, a thin micro-film of metal oxide is formed on the work piece. This film is insulating in nature and protects the work piece surface from further being removed. With the help of bonded abrasives, honing assists to remove the thin insulation layer of component high spots and thus produces fresh metal for further electrolytic dissolution.

Generally electrochemical machining is material removal process based on the Faraday's laws of electrolysis, details of which are available in standard text books [7]. Electrolysis occurs when an electric current passed between two electrodes dipped into an electrolyte solution that inhibits chemical reaction at the electrodes. This chemical reaction is known as anodic or cathodic reaction or Electrochemical Dissolution (ED) which is the basis for electro chemical machining of metals. A schematic of the conventional ECM process is presented in Fig.1. ECM process uses an electrolyte that completes the electric circuitry between anodic work piece and cathode tool and prevents the anodic material from being deposited on cathode. Thus, it is reverse process of electroplating [8].

Honing is a subtractive type manufacturing process in which material is removed by the cutting action of bonded abrasive grains and is used to improve the form, dimensional precision and surface quality of a work piece under constant surface contact with the tool. In general, honing is applied after precision machining (e.g. grinding).

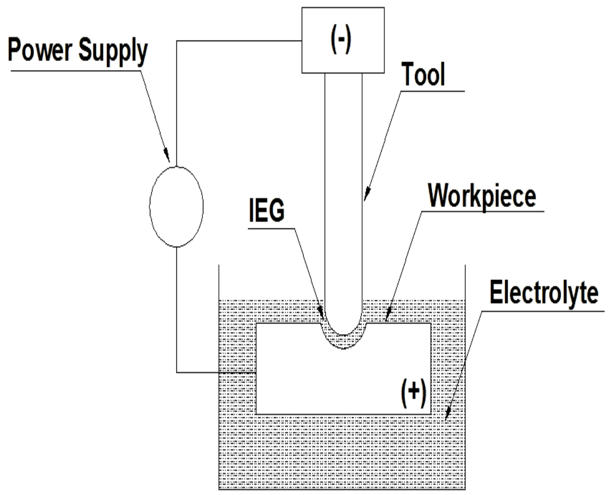

Figure.1. Schematic diagram of ECM process

3. LITERATURE SURVEY

3.1 Taguchi Method

Taguchi method is a widely used tool to determine the most appropriate values of parameters involved in an experiment. Here the parameters that affect the experiment are first assumed and are located in different rows in a specially designed orthogonal array for the required experiment. Signal to noise ratio is one important output of the method that expresses the data observed. These values helps to evaluate the specific and combined effect of the initial assumed parameters that create an impact on the output value. This advanced technique has been more analytical and proved experimentally, that it is more suitable to determine the optimum values of various process parameters.

Using the above method **A.K.Dubey** [9] had made a study with comprehensive experimental investigations on the effect of seven key ECH process input parameters, namely Current intensity (C), electrolyte concentration (EC), rotary-to-reciprocating speed ratio (SR), electrolyte flow rate (F), electrolyte inlet temperature to IEG. (T), stick-out pressure (SOP), and stick grit-size (G) and three prospective two-factor interactions, i.e., current intensity-electrolyte concentration (C-EC), current intensity speed ratio (C-SR), and electrolyte concentration-speed ratio (EC-SR) on the dominant machining criteria, i.e., the percent improvement in surface roughness value Ra (PIRa), percent improvement in out-of-roundness (PIOR). Improvements were expressed as the percentage of initial values of respective response characteristics. Work surface roughness Ra before and after ECH processing was measured by using a Mahr's Perthometer 4615 (Mahr Federal Inc., USA) set with a cut-off length of 0.8 mm. Five measurements were taken separately at the top, middle, and bottom of the work-bore and the average values were used.

Based on the results and using utility-concept-based Taguchi's quality loss function strategy, optimal process parametric setting for the honing process were determined as, PIRa, PIOR, DIR.

Taguchi method can also be used in combination with other optimization techniques such as Genetic Algorithm (GA) and Radial Basis Function Neural Network (RBFNN). **A.K.Dubey** [10] had also made his proposal on the Taguchi loss function-based hybrid strategy for the multi performance optimization of ECH process. The proposed strategy was carried out with a Radial Basis Function Neural Network (RBFNN) for the process parametric mapping with the loss functions of ECH multi-performance characteristics which were initially determined way through Taguchi matrix and Genetic Algorithm (GA) to predict the optimal process parametric settings for multi-performance optimization of ECH. The experimental setup was similar to the one used in [9]. The primary input values were fed to the RBFNN and the results were converted into desirable values based on the preference scale set as per the maximum and minimum obtainable values. These values are the unified to give a fitness value using genetic algorithm (GA). Simulated results confirm the feasibility of application and show good close agreement with actual experimental results over a wide range of machining conditions employed in the process.

3.2 Effect of Grain Size

In honing process the grain size plays an important role as the material removal rate and finish of the surface machined. Generally the coarse grains are used for the purpose of higher material removal rate and the fine grains for the fine finishing. Further these grain size has also proved to have some impact on the processing time and the average surface roughness of the material.

Damir Vrac et al., [11] had proposed the effect of the coarse grain and fine grain in quality machining. The experiment involved the use of two different tools, one made of honing stone with coarse grains (denoted as D-181, 5x5x80/2 mm /D 181/44/502M113/C50 Tyrolit 80/100 mesh with a (180*10^{-6} m diamond grain size with Bakelite bonding [20, 21]) and the other one with the fine grains represented as D151 (5x5x80/2 mm/D 151/44/502M113/C75 Tyrolit 100/120 mesh (150*10^{-6}m diamond grain size with Bakelite bonding).

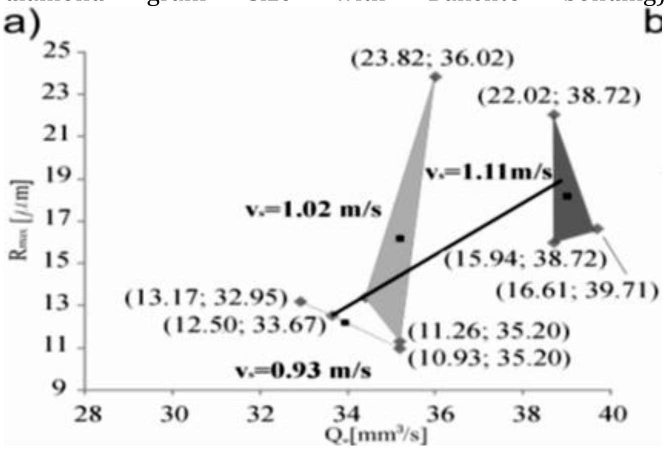

Chart 1(a) - average roughness value R_a vs. material removal rate Q in D181 tool.

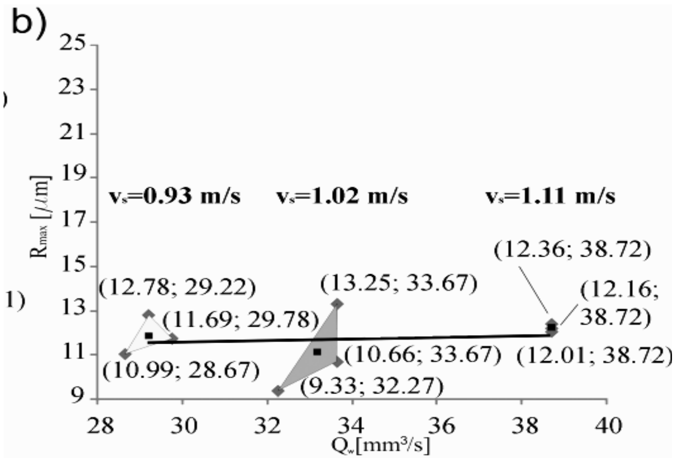

Chart 1(b) - average roughness value R_a vs. material removal rate Q in D151 tool.

Chart 1(a), 1(b) represents the dependency of the average roughness value R_a and material removal rate Q while using the tools D181 (a) and D151 (b).Results of the experiment indicates that by applying D181 tool, both material removal rate and then the specific volume can be increased at expense of increased roughness. However, by using D151 tool, trend line were obtained almost horizontal, which means that an increased material removal rate and specific volume material removal rate can be obtained without a significant impact on average and maximum roughness. Material removal rate and specific volume material removal rate of the surface machined by a finer grain tool (D151) shall have equal roughness producing parameters as with coarser grained tool (D181), but tool would produce 15%-20% higher material removal rate and specific volume material removal rate.

Similar experiment on the effect of the grit size was also **L.Sabri et al.**, [12] who had made an analysis on the effect of grit size on the surface roughness in honing machines specially used in large scale machining of components. The experiment involved the honing of engine cylinder with a vertical honing machine fitted with expansion tool. The factors taken into account while machining were expansion factor of the tool and the abrasive grit size. Their results found that the initial surface texture had no effect on the final texture and the expansion factor did not affect the roughness scale, but the depth of the groove made. The results conclude that the amount of surface finish reduces with the larger grit size and it becomes proportional for medium sized grits varying between 60 and 210μm.

Studies made by **F.Cabanettes et al.,** [13] had also made a conclusion regarding the grit size through their investigation on variation in surface roughness due to tool wear. They found that the variation in the surface roughness is mainly due to the abrasive grit size and its type.

3.3 Effect of Honing Speed

Super finishing operations are generally conducted at high speed to have the effective machining throughout the surface of the component. High speed operations also involves a lot of vibrations which must be taken care of and the inappropriate levels of the speed in operations may prove to be inefficient i.e., low speed operations cause poor surface finish and higher levels of speed leads to tool wear and loss of power.

Yu.N.Polyanchikov et al., [14] study presents the relationship between the speed of the honing tool and the surface roughness. Their analysis implies that the constant tool speed does not fully utilise the potential of the abrasive grain and the tool to produce the quality (surface roughness). They propose a relation for the effective utilization of the tool, i.e., variation of speed. During the experiment the A.C. frequency of the voltage was continuously varied with the E1-8001 frequency converter. The retaining constant velocity (N) of the reciprocating motion was kept unvaried and the azimuthal velocity V (cutting speed) as a variable parameter.

During tests of the proposed method, the honing speed V was varied within certain limits. Initial values of study showed that the depth of the cuts were too great when the angle of the grid of machining track (α_{tr}) < 65° (i.e., V/N < 2.2). As a result, the quality of the machined surface was affected. When α_{tr} > 82° (V/N > 7), the surface roughness reduced, but wear of the abrasive blocks increased. Thus, the optimal range was found to be V = (2.2–7) N.

The constant change in the velocity had led to the constant change in abrasive-grain trajectory, the load on its cutting surfaces varies continuously, and new surfaces come into operation. Consequently, it led to the complete utilisation of the grain potential and the wear of the abrasive blocks reduced considerably. From the results it was found that the surface roughness reduced up to 27.7% and the wear of the tool reduced by 30.3%.

Results obtained by **Pankaj S.Chavan et al.**, [15] during the experimental investigation on the effect of different honing parameters such as honing feed pressures during rough machining, finishing, and peripheral speed of the honing head for producing quality surface honing of grey cast iron liners of engine cylinder bores shows that honing velocity or speed is to be considered as one of the three parameters to achieve the significant out come during the machining process.

3.4 Effect of Processing Time

Effective machining time is to be calculated for any experiment in order to have less power consumption and utilisation of time to increase the production. There by reducing the cost and man power involved. **J.P.Misra et al.**, [16] made an experimental investigation to explore the influence of processing time on process performance parameters in effect with surface quality of gear teeth profile, tribological performance of the teeth surface and process capability. These considerations were to estimate the optimum processing time. The typical levels and ranges of input parameter (i.e. processing time) and the parameters were assumed to be fixed for experimentation. The surface roughness values, bearing ratio of the surface and the amount of material removed were used as measures of process performance. The surface roughness values of the work piece were measured before the machining and after each run using optical profiler to determine the rate of improvement in surface quality of gear teeth profile.

Results conclude that the surface quality of gear teeth profile enhances with the increasing processing time. The processing time period of about 120seconds was found to be effective in obtaining the effective machining of the surface with a fine surface finishing. It is also obvious from the study that, the process enhances the bearing ratio value of work surface and hence, it concludes that the process is capable of improving the tribological aspects of gear teeth profile. The process showed 106.750 mg/min as material removal rate which establishes the advantage of employing ECH for gear finishing.

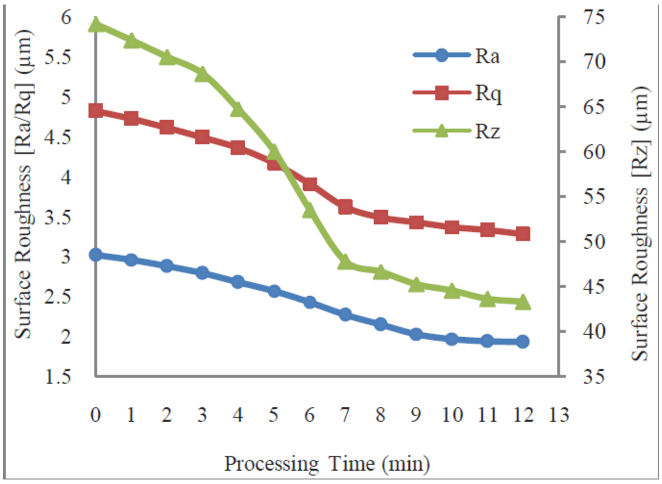

Figure 2. Representation of R_a vs. processing time

A similar study on the processing time was made by **Harpreet Singh, Pramod Kumar Jain** [17] in an experiment designed for comparative study between the micro grinding process and ECH. The optimum time for machining was chosen as 120s and the outcome was compared with the surface roughness value achieved in micro grinding. Results showed that the processing time of 120s, 75% lesser than the time for machining in micro grinding generated roughness much lesser values.

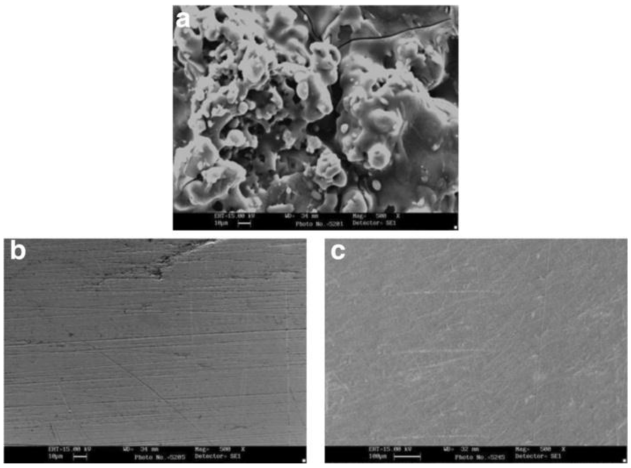

Figure 3- Representation of the typical SEM analysis (a – before machining, b – after micro grinding, c – after ECH).

3.5 Effect of Electrolyte Temperature and Concentration

It is a known fact that the conductivity of the electrolyte is based on the concentration of the solution and the temperature since, electron flow is inversely proportional to the availability of ions for conduction and the temperature. Hence an optimum temperature and an electrolyte concentration is required to make the machining process effective.

P.S.Rao et al., [18] had made analysis on the design and fabrication of an indigenously developed setup for ECH of external cylindrical surfaces with Titanium alloy (Ti 6AL 4V) and highlighted the key process parameters and their effect on ECH process. The influence of the machining parameters on the surface finish were investigated and optimization of the process parameters was made for improving the surface roughness.

Percentage improvements in surface roughness values Ra and other parameters like electrolyte temperature, composition and concentration were undertaken for study while changing the processing time (PT).

After the experiment, SEM images of the cut surfaces 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.

Results of the process were that the surface roughness values decreases with increasing processing time while the effect of processing time on PIRa i.e., (Performance improvement in surface roughness) reversed. Because, initially the surface remains more irregular and therefore, the rate of electrochemical dissolution was high. But, at later stage of experimentation, the intensity of EC dissolution deceased as the surface got smoothened. Temperature of 30°C as electrolyte temperature was found optimum as the highest PIRa values were achieved for particular temperature. It is also evident that after 30°C the PIRa values start decreasing with increasing temperature. The conductivity of the electrolyte depends on electrolyte concentration. As the electrolyte concentration increases, more numbers of ions were available in the solution for electrolytic dissolution which resulted in increasing electrolyte conductivity and increase in PIRa. But, the concentration of electrolyte when ≤ 15% gave better passivation effect. The electrolytic dissolution which results in increasing electrolyte conductivity leads to the increase in the percentage improvement in surface roughness values.

3.6 Effect of Inter Electrode Gap

Electrochemical machining process is truly based on the gap between the electrodes, without which the generation of the chemical reaction between the anode and the cathode becomes impossible. Similar to the welding process, the gap between the electrode and the work piece or the cathode must be maintained at appropriate such that maximum rate of reaction is achieved. It is also necessary to have a minimum gap to have the free flow of electrolyte.

H.Singh et al., [19] have focused their study on the type of power supply and inter-electrode gap in ECH of spur gears with the aim to determine most significant parameter applicable for the required output. ECH system was designed and fabricated for spur gear, different input power supply such as direct current and pulse current for anodic dissolution and both power supplies are compared in terms surface roughness and processing time. Secondly, a set of parametric experiments are conducted to find the effects of inter-electrode gap (IEG) on the process output.

Study was made with an electrolyte composition of 75% NaCl + 25% NaNO3 at a temperature of 30°C and flow rate of 20 l/min has been used for the work piece material of EN8. For conventional honing, EN24 tempered alloy steel was used with a honing tool, to scrub away the oxide layer that generate on the work piece surface during ECM.

Results of their experiment shows that significant processing time is 8 minutes for ECH and 24 minutes for PECH and pulse current assistance gives 7.59 % higher PIRa, and 8.94 % higher PIRt as compared with direct current and more significant range of IEG is from 0.4 mm to 1 mm. The increase of the IEG beyond 1mm causes the decrease of anodic dissolution at the constant level of input process parameters and therefore surface roughness decrease.

Further study on the influence of IEG on MRR was made through the experimental analysis done by **Javed Habib Shaikh, Neelesh kumar Jain** [20] describes the mathematical modeling of material removal rate (MRR) and surface roughness of the bevel gears finished by the electro-chemical honing (ECH) process. Since, ECH hybridizes electrochemical dissolution (ECD) and mechanical honing. Therefore, contribution of ECD in MRR and surface roughness were modeled. The developed models were experimentally validated for finishing of bevel gears by ECH with aqueous solution containing 25% NaCl + 75% NaNO3 as the electrolyte.

During the experiment, the improvement in surface finish and the geometry accuracy continues at a diminishing rate due to increasing value IEG between the surfaces of cathode and work piece gears, consequent decreasing MRR. From the developed models of MRR, it was found that the voltage and rotary speed of the work piece gear are the important ECH parameters influencing the surface finish and MRR of the bevel gears finished by the ECH process. MRR, though determining productivity of the process, increased MRR adversely affects the surface finish and form accuracy.

4. COMPARISON OF ECH AND PECH

P.K.Jain et al., [21] had presented their work as a comparative study on precision finishing of spur gears by using ECH and PECH (Pulse assisted Electro Chemical Honing) to indicate that pulse assistant in ECH though leads a marginally higher surface quality of PIRa of 7.59 and PIRt = 0.42 than the ordinary ECH process the processing time of PECH process is nearly three times higher than the ECH.. These values conclude that the processing time is one of the insignificant responses in PECH, which leads lower productivity. The value of IEG had enhanced the process performance characteristics. The lower value of IEG provided higher anodic dissolution, which decreased the surface quality and large IEG led to the decrease of surface quality at the selected processing conditions. The IEG value of 0.4mm to 1 mm had been predicted to be more significant for ECH of the spur gear.

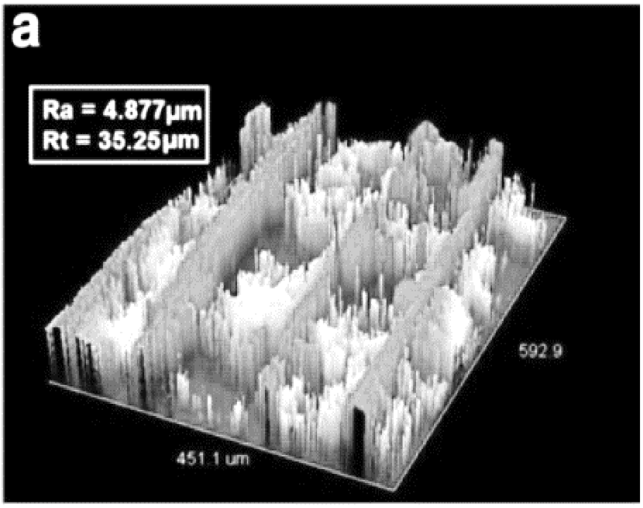

Figure 4(a) – before finishing

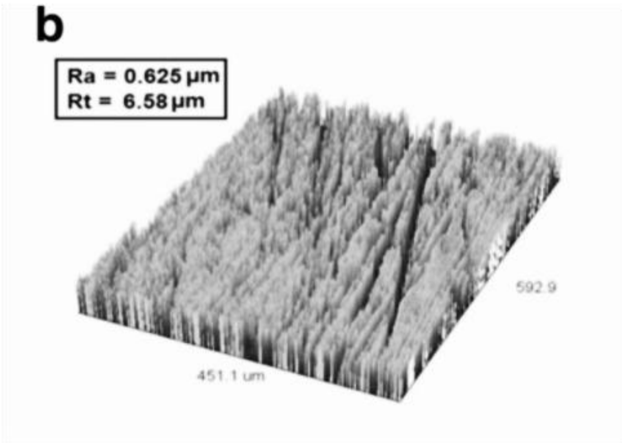

Figure 4(b) – after PECH

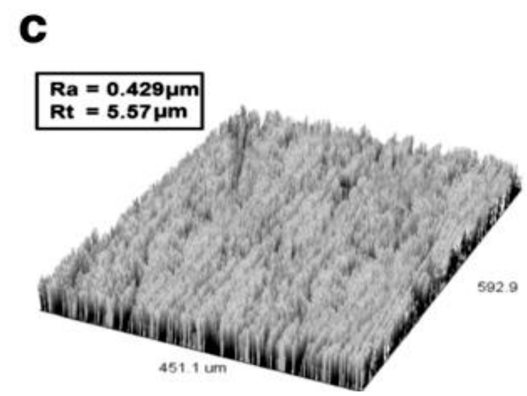

Figure 4(c) – after ECH

The above figures represent the differentiation in the effectiveness of the machining made in the component's topography obtained through optical profilometer;4(a) – before finishing, 4(b) – after PECH, 4(c) – after ECH.

5. COMPARISON OF ECH AND MICRO GRINDING

Harpreet singh and Pramod kumar Jain [17] had made a comparative analysis on process performance of micro-grinding and electrochemical honing, through rebuilding of engine valves. The discarded engine valve face was rebuilt using plasma transferred arc cladding technique and its surface finish was evaluated in terms of average roughness and maximum roughness value.

The optimum value of processing time was selected on the basis of average and maximum surface roughness. For ECH it was selected as 120s and 8 minutes for micro-grinding. Outcome of the experiment was that ECH gave a surface roughness value (Ra) = 0.59μm and Rt = 6.65μm as compared to micro- grinding which gave Ra = 0.77μm and Rt of 6.91μm.

It is observed that ECH gives a fine finishing operation at the processing time of 120 s, which is 75 % less than the optimum processing time of micro-grinding process. SEM analysis conducted on work pieces to investigate the morphology of finished surface clearly defines results. Figure (a) very clearly show that before finish, the work surface contains voids, spots, porosity, pits etc. The micro-grinding surface of work piece contains scratches, fused particles etc., but the surface had become uniform and smooth by removing irregularities as shown in Figure .a. In contrary The ECH surface presents a glazed appearance and the surface texture had become more uniform and smooth (Figure .6(b))

6. CONCLUSION

From the study made on various journals published in the recent times in relation to the electrochemical honing and honing process, the following were concluded as the advantages in ECH, requirements and range of values for various process parameters to obtain the most efficient machining of components,

1. ECH is more precise than PECH, in terms of surface quality. [21]
2. Varying the speed of honing tool while machining reduces the surface roughness value by 27.7%. [14]
3. Coarse grains are effective in increasing the material removal rate, but it also creates grooves in machining surface. [11]
4. Grit size plays a predominantly important role in honing tool efficiency and grit size of 60-120 microns is effective for machining. [12]
5. Surface roughness decreases with increasing in process timing and the optimum process timing is about 8 minutes. [18]
6. Optimum electrolytic temperature is about 30^{0}c [18].
7. Effective Inter Electrode Gap (IEG) is to be about 0.4-1 mm and with the increase in the gap the aniodic dissolution decreases [19, 20].

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