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1 THE PREDICTION AND CONTROL OF ECM SURFACES

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4 ABSTRACT

The application of electrochemical machining for producing components under high degrees of accuracy and surface integrity conditions has increased markedly in an era of rapid and continuous engineering demands. The main attractions of the ECM process are its ability to machine very hard metals and to form complex shapes which are difficult to produce conventionally. The mechanism of surface generation in ECM is somewhat complicated and not quite understood because of the complex nature of the possible reactions occuring during machining in the inter-electrode zone. Incomplete data correlating surface integrity with mechanical properties could hinder the use of the ECM process. The present work highlights the effect of the various inter-related parameters on the surface integrity of electrochemically machined components with the objective to enable production engineers allocate the suitable working conditions for each specific operation to attain highest degrees of surface quality. The results are finally furnished in the form of empirical relationships with the aim to generalize simple and useful data to be suitable for ECM designers in predicting and controlling surface finishes as required for the intended service of the component.

INTRODUCTION

Electrochemically machined surfaces are affected by the multi-variable working parameters controlling the process. Since surface finish must usually be considered by the production engineer, it becomes almost inevitable that he should be provided with adequate knowledge of the surface finish under any set of prevailing conditions.

Despite the various investigations carried out to study the effect of the numerous and inter-related parameters on surface

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roughness, still it seems difficult to predict or control electrochemically machined surfaces. The objective of the present work is to furnish the production engineer with suitable recommendations in the form of empirical approaches to enable him reach a reasonable solution towards predicting or controlling surface roughness.

FACTORS AFFECTING SURFACE INTEGRITY

1. Current Density.

Feed rate and consequently the current density have a strong influence upon the surface generation. An increase in the working current density is accompanied by an improvement in surface roughness.

Strode et al (1) showed that a deterioration in surface finish occurs when machining cast and wrought steels at low current densities (29-47 A/sq.cm) under NaCl due to the selective attack of micro-constituents and pitting. The inter-action between material and passive electrolyte solutions was studied by Konig (2). The results showed that for sodium nitrate solutions with low steel alloys, protective layers were formed, particularly in the lower current density range, which largely prevent a dissolution. As the current density increases, these layers become unstable and break up in places so that in addition to the generation of oxygen in the covered surface areas an increasing dissolution of metal may occur in the break through places.

DeBarr and Oliver (3) and Meleka and Glew (4) have concluded that the best surface quality is attained with high rates of metal removal because as the current density increases the potential gradient in the electrolyte also increases. The results given by Weill (5) for various alloy steels show that the relation between current density and surface roughness is almost exponential and that little improvement can be attained beyond a current density of 600 A/sq.cm.

2. Electrolyte Flow Rate.

The effect of electrolyte flow rate on the surface integrity was studied by many authors. Chetty et al (6) showed that an increase in electrolyte flow velocity from 6 to 20 m/s improved the surface finish from 7 to 1.6 μm (CLA) when machining a 0.4% carbon steel using a 25% w/v NaCl solution. Mileham et al (7) characterised the integral ECM surface in terms of CLA, Skewness and Kurtosis. It has been found that the change in electrolyte flow velocity produces significant variations in surface parameters values.

For long flow path conditions, Moir et al (8) found that a change in the machining valency mode depends on the electrolyte flow rate and the distance from the flow inlet i.e. the point of breakdown of low valency to high valency is related to

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electrolyte flow rate.

Konig et al (2) illustrated that any disturbances in electrolyte flow rate may considerably affect the thickness distribution of salt electrolyte layers, which will manifest its self in the formation of flow streaks on the surface.

3. Workpiece Grain Size.

A careful match between the electrolyte and the metallurgical state of workpiece is necessary in order to prevent selective etching or intergranular attack. The influence of the workpiece structure on current density and metal removal rate has been previously reported (9). Improved metal removal rates have been observed for fine grained workpieces at high flow velocities.

The results obtained by Chetty et al (6) proved that with the decrease in grain size, the finished surface improved at 15 m/s NaCl flow velocity. Below 15 m/s the grain size plays an important role in reducing roughness. At velocities higher than 15 m/s the role of grain size is insignificant as far as the surface is considered. In another work (10), parameters affecting surface irregularities using a relocated machining fixture were studied. It has been shown that the rate of profile modification seems to be dependent on the type of profile present on the surface. Qualitatively it has been assessed that whatever may be the shape of the surface irregularity, it will tend to a sinusoidal wave form before it completely smoothes out.

Konig (2) illustrated the mechanism of surface generation for two materials with and without grain boundary carbides. The results showed that while the material containing carbide shows the formation of deep ditches, the one without carbide has a plane surface.

4. Electrolyte Temperature and Concentration.

Temperature rise in the inter-electrode gap is accompanied by an increase in surface roughness. This is due to deeper etching of grain interfaces. Gurumurty et al (11) showed that the normalised CLA values decrease as the concentration of the NaCl solution increases for steel specimens. In addition to the above parameters, the rise in the electrolyte temperature increases the pitting tendency towards the flow outlet (2). The chloride concentration has also a similar effect upon pitting.

Electrolyte alkalization is one of the main parameters affecting surface integrity. Alkalization up to pH values over 12 results in a considerable increase in roughness for iron and steel in sodium chloride and sodium nitrate solutions (12).

Atanasjanc and Savova (13) showed that an improvement in the surface quality can be reached by decreasing the concentration and lowering the electrolyte temperature and also by reducing the gap as shown by Movich (14).

5. Air-Electrolyte Mixture.

Previous work (12) during ECM of many titanium alloys in either potassium or sodium chloride and nitrate solutions showed that the surface roughness of BT-8 alloy was reduced by 4.5 times after compressed air bubbles were introduced into the inter-electrode space for sodium nitrate and 2.5 times for sodium chloride compared with ECM without compressed air.

Ghabrial and Ebeid (15) showed the beneficial effect of air-electrolyte mixtures in improving both surface and geometry of the workpiece. Also striations and dull spots were significantly diminished. Since air-electrolyte mixtures lead to a decrease in metal removal rate, they are thus recommended for finish machining.

EXPERIMENTAL WORK

Electrochemical honing and stationary ECM are taken as a typical example for studying the effect of the working parameters on surface roughness. A locally designed machining cell (Fig. 1) was used (16). The cell allowed for tool rotational speeds up to 11000 rpm. The electrolysing direct current was supplied by a DC supply under a constant voltage of 14v. Facilities were provided for flushing and for limiting the temperature rise of the NaCl electrolyte (10% w/v). The bulk temperature was limited to about 25 to 30 °C.

To assure smooth flow of the electrolyte, the tools were provided with conical tips. The shapes and sizes of the tools and specimens are shown in Fig. 2. The tools were made of brass and the specimens were made of mild steel (St 37).

During each experiment the inlet and outlet electrolyte temperatures, the cell pressure, flow rate, applied voltage, current and tool rotational speeds were measured. The processed shapes were measured using a horizontal metroscope (0.01 mm). The surface roughness was measured using a computerized Talysurf 6.

RESULTS AND DISCUSSION

Fig. 3a illustrates the relationship between the tool rotational speed and the workpiece surface roughness (CLA). The results are shown after a machining time of 60 s. The curve shows a quite evident relation indicating the improvement of the surface roughness with the increase of the rotational speed. Although all the tests of Fig. 3a were carried out under the same flow rate, however, it was noticed that the increase of the tool rotational speed diminished the formation of striations and dull spots.

Previous tests (8) have shown that surface finish improves with increased electrolyte flow rates. Nevertheless, with the present results the increase of rotational speed also aids in improving surface roughness. This is accounted for by the fact

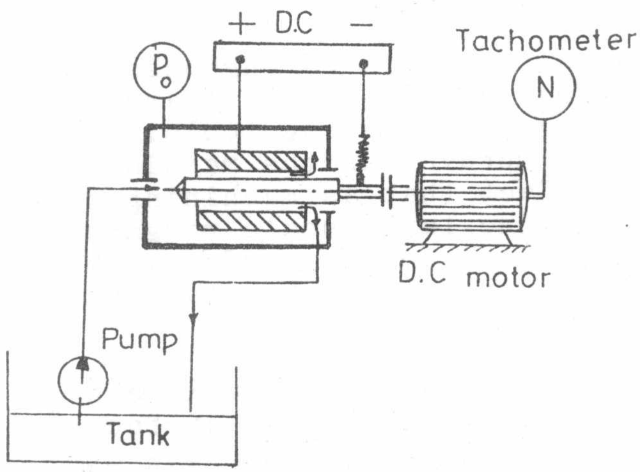

Fig.(1) Diagrammatic layout of test cell

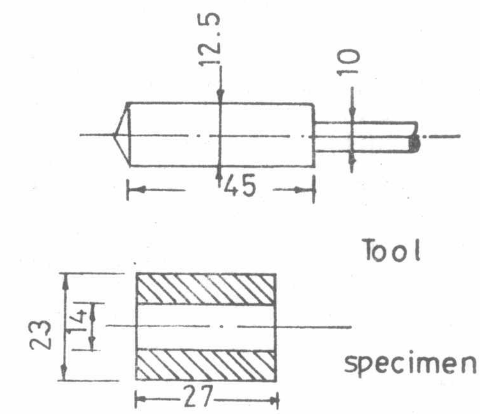

Fig.(2) Tool and specimen

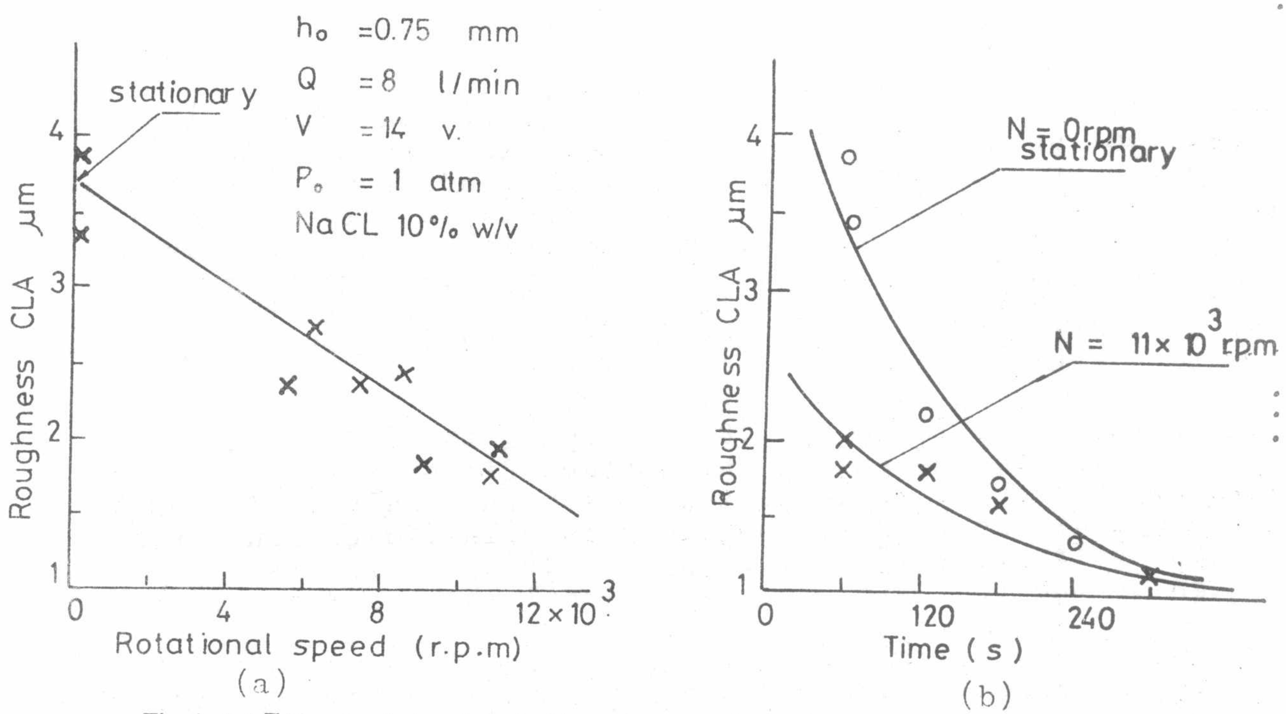

Fig.(3) Effect of tool rotational speed and machining time on surface roughness that the flow pattern in the inter-electrode zone improves as the tangential speed of the suspended particles, in the electrolyte, adjacent to the workpiece surface increases. The increase of the turning speed raises the kinetic energy of the sludge particles enhancing them greater liability to escape from the machining zone, thus reducing overcut and improving surface roughness.

The effect of the machining time on the surface roughness is indicated in the relationship of Fig. 3b. The results are shown for both cases of non-rotating and rotating tools. Both curves indicate that the roughness improves as the machining time increases. This is due to the fact that as machining proceeds and the radial gap increases, the large scale roughness is successively removed leading to final smooth surfaces. Moreover, the curves show that by increasing the tool rotational speed the roughness improves.

In order to provide the production engineer with simple and direct data regarding the control and prediction of surface roughness, empirical relations were derived relating the CLA value with the main working parameters. The empirical relationships derived in this investigation include results of the present tests in addition to results deduced from previous works after being analysed.

From Figs. 3a&b it can be deduced that the CLA value assumes an empirical relation in the form:

$$CLA = 20 / (N^{0.068} . t^{0.42})$$

The shown relation relates surface finish, CLA (μm) to the tool rotational speed N (rpm) and the machining time t (s), under the present experimental working conditions. For non-rotating tools, the surface roughness would be only related to the machining time. Such a simple relation can be used as a preliminary guide to production engineers in assessing roughness. The N and t powers in the above equation can be slightly varied under other working conditions. However, by running few tests such powers can be easily estimated.

Experimental results (17 & 18) regarding the effect of the main working parameters on the surface finish during electrochemical broaching were analysed. From the analysis it can be deduced that the surface roughness is mainly dependent on the applied voltage, tool feed rate, electrolyte flow rate and the design of the tool i.e. cross-sectional shape and tip form.

For the case of high feed rate broaching (17), where the voltage/feed rate ratio ranges between 0.2 and 4 v/mm/min, the relationship between the CLA value and the main working parameters can assume the following empirical form:

$$CLA = 1.05 \; V^{0.34} / f^{0.23}$$

for the case of broaching square holes using a sodium nitrate solution, whereas, for the case of broaching hexagonal holes the equation takes the form:

$$CLA = 1.15 \; V^{0.16} / f^{0.13}$$

where, V : applied voltage, v
f : tool feed rate, mm/min

Such relations show an asymptotic drop in the CLA value with the increase in the feed rate.

Regarding low feed rate broaching, where the V/f ratio ranges between 4 to 10 v/mm/min, the relationships between the CLA value and the working parameters assume a linear form as follows:

$$CLA = a \, (V/f) + b$$

The constants a and b vary according to the design of the tool.

Tool Shape	a	b
Hemispherical	0.158	0.57
Hemispherical with land	0.163	0.35
Conical	0.151	0.25
Conical with land	0.142	0.08

Thus for practical machining conditions the production engineer can be able to predict with sufficient accuracy the CLA value for various ECM processes by adopting the empirical approaches under the estimated working conditions. Moreover, the surface finish can be controlled through choosing the suitable main working parameters to attain a required surface finish.

Such equations cannot be directly generalized but are still limited to the experimental conditions. However, similar relationships can be obtained for any specific electrochemical machining process in the same manner.

CONCLUSIONS

The present analysis shows that ECM processes are inevitably associated with various problems which reflect on surface integrity and thus can hinder their potentiality for nowaday production techniques.

The proposed empirical approaches for predicting and controlling surface roughness are intended to aid production engineers who

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apply such processes in industry.

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