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EXPERIMENTAL DETERMINATION OF THE PARAMETERS AFFECTING THE SURFACE QUALITY OF ELECTROCHEMICAL MACHINING PROCESSES

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ABSTRACT

An experimental study was made to investigate the role of cell voltage, electrolysing current, tool feed rate and additives to electrolyte, in the quality of drilled specimens, with respect to hole over-size, hole conicity and surface finish. Tests were carried with the objective of finding the operating conditions of electrochemical drilling (ECD) which can lead to good accuracy and dimensional control of the products. The results are also compared with the available literature data. Finally the effects of various parameters are discussed in some detail.

INTRODUCTION

In a previous work [1] an experimental investigation of the effect of process parameters on productivity and rate of metal removal during electrochemical machining of low carbon steels was reported. In the present work some factors affecting the quality of the drilled surfaces are discussed. Emphasis is made on accuracy and dimensional control.

EFFECT OF TOOL FEED RATE

The effect of tool feed rate on ECD process with respect to hole oversize, hole conicity, and surface roughness is investigated.

1. Effect of Tool Feed Rate on the Hole Oversize

Fig.1, shows a falling tendency for the hole oversize as a function of the tool feed rate at different gap voltages. This falling tendency of the oversize with the feed rate can be explained by the reduced time of the side machinig when higher feed rates are used.

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Obviously, a higher metal removal rate is obtained with high tool feed rates. Thus, the precipitation rate of anode product on the hole inner surface is increased. This precipitate forms a protective film, which prevents excessive side machining through a progressively increasing resistance. The latter will control the flow of side currents in the side gap, resulting in smaller hole oversize.

2. Effect of Tool Feed Rate on the Hole Conicity

As expected, the hole conicity decreases as the tool feed rate increases. This behaviour is shown in Fig.2. As the tool feed rate increases the side machining effect decreases due to the reduced time, during which side machining occurs.

Hopenfeld and Cole [2] showed that the gap becomes covergent in the downstream direction. The conicity may be reduced greatly if side tool insulation is used. Moreover, hole conicity was found to greatly depend on the tool shape.

3. Effect of Tool Feed Rate on the Surface Roughness

Fig.3, shows the variation of the centreline average(C.L.A.)of the roughness as a function of tool feed rate at different gap voltages. The curves show that at a given gap voltage the C.L.A differes with the variations in feed rate. At the low feed rates of 0.55 to 1 mm/min., better values of C.L.A. were obtained with a gap voltage of 22V. At high feed rates of 2 to 2.45 mm/min., values of C.L.A. are almost the same at different gap voltages. Higher values of surface roughness were observed at a gap voltage of 20 V.

At a tool feed rate range of 1-2 mm/min., good surface roughness was obtained at various gap voltages. At low tool feed rate, the forward gap may not be stable due to the variation in the metal removal rate and the tool feed rate. Therefore, the gap resistance varies continuously with time. In this case poor surface finish was obtained due to periodic dissolution of metal. But, on increasing tool feed rate, the forward gap decreases and the resistance to current flow also decreases. Therefore, current increases until it is sufficient to remove material at exactly the same rate of tool advancement.

Therefore, good surface finish is associated with relatively high metal removal rates as determined by voltage, feed rate, and by keeping a constant inter-electrodes gap for a given cathode configuration.

EFFECT OF ELECTROLYSING CURRENT

The effect of the electrolysing current on ECD process with respect to hole oversize, hole conicity and surface roughness was investigated.

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1. Effect of Electrolysing Current on the Hole Oversize

The side gap results from side machining effects, which mainly depends upon the local current density distribution on the workpiece surface. The current passing across any finite distance between tool and workpiece may also result in a side gap. It follows by definition that cylindrical cavities can not be produced by the electrolytic method.

Fig.4, shows the relation between hole oversize and electrolysing current, at a working voltage of 20-32 V. This figure illustrates that hole oversize decreases with the increase in the electrolysing current at different gap voltages. At low electrolysing currents, the least hole oversize was obtained at a gap voltage of 25V.

At high electrolysing currents, smaller hole oversize were obtained with a gap voltage of 32V. This is attributed to the accumulation of gas bubbles and electrolyte salts in the side wall of the anode and the cathode, accordingly a marked decrease in the conductivity between gap sides develops and thereby machining rate was reduced.

2. Effect of Electrolysing Current on the Hole Conicity

As shown in Fig.5, the hole conicity decreases as the electrolysing current increases. The rate of conicity decreases depends on the gap voltage. At working gap voltages of 20-32V,the variation in hole conicity with the electrolysing current follows a linear relationship.

The hole conicity was observed to decrease at low voltages on decreasing the electrolysing current. In this case, the effect of gas bubbles evolution is very small. Thus, a large fraction of the current passes through the frontal gap, which reduces the side machining effect.

In addition, at higher electrolysing current and high gap voltages, it was found that the hole conicity has also improved. This behaviour can be interpreted as follows: anode products and gas bubbles accumulate on the side gap surface, thus creating a high resistance and controlling the flow of the electrolysing current at right angles to tool feed direction.

3. Effect of Electrolysing Current on the Surface Roughness

The hole surface roughness, in an axial direction was, measured and results are presented at different values of current in Fig.6. This Figure shows that: there is a significant variation in the magnitude of surface roughness as a function of the electrolysing current. At relatively low electrolysing currents and a gap voltage of 22V, a surface roughness value of about 1.5 μm C.L.A. was obtained.

In general, better surface roughnesses were obtained at moderate values of the electrolysing current (150-250A) at various gap voltages.

At high voltages of 25 to 32V, changes in conductivity due to gas generation and oxide film formation on the electrodes surface are compensated by a corresponding change in the inter-electrode gap width with increased tool feed rate, so that the steady-state current density does not vary locally along the electrode length.

However, if such equilibrium is not achieved within the machining time required for electrochemical smoothing to a certain degree, than local variations in conductivity along the electrode length, and hence in current density and in surface finish, may, therefore, be expected.

Also, the chloride ions will penetrate into the film causing its failure. The areas of penetration permit greater local current to flow than elsewhere over the electrode surface, where the film is unbroken. The atoms are removed in a random fashion,which will lead to a poor surface finish.

EFFECT OF ADDING H_2O_2 TO THE SOLUTION

The effect of adding H_2O_2 as an oxidizing agent to the electrolysing cell was investigated with respect to hole oversize, hole conicity, and surface roughness.

1. Effect of Electrolysing Current on the Hole Oversize

The relation between hole oversize and electrolysing current is shown in Fig.7. The general trend of behaviour is decrease of the hole oversize as the electrolysing current increases. However the hole oversize values are higher when H_2O_2 is added and increases at higher concentrations. This effect holds at low electrolysing currents up to 290A. Thus, in this range of electrolysing current values, the addition of peroxide is disadvantageous, as the frontal gap is affected by the accumulation of gaseous oxygen.

On the other hand, oxidation of ferrous compounds forms a protective film on the frontal anode surface, thus increasing the resistivity. Current passage in the radial direction is more enhanced in the peroxide-free electrolyte. In the vicinity of 290 A, similar hole oversizes are obtained, i.e. addition of peroxide is insignificant. But, when this electrolysing current value is exeeded, the role of peroxide appears to result in lower values of hole oversize, and hence, it is advantageous to the process with respect to oversize. The higher is the peroxide concentration, the better becomes the hole oversize value. Oxygen released by decomposition of H_2O_2 dampens as well as disturbs the polarization effects and

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consequently facilitates the passage of current in the same direction of the tool feed. Hence, less current passes radially, thus improving the hole oversize.

2. Effect of Electrolysing Current on the Hole Conicity

Whether H_2O_2 is absent or added to NaCl electrolyte the hole conicity decreases linearly with the increase in electrolysing current. Figure 8, shows the same trend as discussed in the case of the effect of electrolysing current on the hole oversize.

It seems that, oxygen released from peroxide has a stronger effect by resisting current flow through the frontal gap than up-setting and/or removing polarization in the axial direction.

3. Effect of Electrolysing Current on the Surface Roughness

At low electrolysing current (100-200A), better surface roughness was obtained with peroxide-free NaCl solution see Fig.9. This reverse effect may be due to non-uniform flow of electrolysing current in the gap caused by the presence of O_2 bubbles liberated from H_2O_2 decomposition.

As electrolysing current increases from 200 to 275 A the surface roughness decreases on adding H_2O_2 and vice versa. This may be attributed to the oxidizing effect of oxygen upon ferrous ions to form oxide films controlling the metal dissolution and the uniform distribution of electrolysing current on the anode surface.

At higher electrolysing current (exceeding 275A) and in the presence of H_2O_2, the surface roughness increases with increase of electrolysing current at different H_2O_2 concentrations. This may be due to high metal removal rates caused by the increase in electrolysing current, which tends to remove the atoms randomly.

In addition, the surface roughness decreases with the decrease in H_2O_2 concentration at low electrolysing currents. It seems that excess oxygen bubbles formed in high peroxide concentration causes non-uniformity in solution conductivity.

EFFECT OF TOOL FEED RATE IN THE PRESENCE OF HYDROGEN PEROXIDE.

The variation of the tool feed rate in the presence of H_2O_2 was investigated to determine its effect on ECD process with respect to hole oversize, hole conicity and surface roughness.

1. Effect of Tool Feed Rate on the Hole Oversize

Whether with or without H_2O_2 addition, a falling tendency for hole oversize with increased feed rates in NaCl electrolysing baths is noticed. This is clearly seen from Fig.10. Such a tendency results from reducing the chance for side machining by decreasing time of electrolysis at higher feed rates.

At low values of tool feed rates, NaCl gives lower hole oversize in the absence of H_2O_2 . Thus, the presence of H_2O_2 adversly affects the hole oversize. Increasing the amount of H_2O_2 enhances the magnitude of hole oversize. The depolarization effect of liberated oxygen increases the flow of current in the side gap. On the other hand, the ferrous salts oxidised by liberated oxygen to ferric, will deposit on the frontal gap, thus increasing the resistance of current flow.

It is also noticed that the rate of decrease in hole oversize with tool feed rate is more pronounced in the presence of H_2O_2; Presence of 0.1% peroxide in the electrolysing bath at 2.2 mm/min. feed rate gives the same result as with NaCl alone.

At 2.5 mm/min. tool feed rate, equal results of hole oversize are more or less obtained. Beyond this limit, addition of peroxide improves the hole oversize. Low concentrations of H_2O_2 (of about 0.1%) give superior results of low hole oversize. It can be deduced that supersaturation in the side gap with ferric precipitates increases the resistivity and leads to a weaker attack on the workpiece side.

Consequently, addition of very small amounts of H_2O_2 to the NaCl electrolyte decreases the hole oversize at high tool feed rates. This leads to saving machining time and increasing the productivity at a lower cost.

2. Effect of Tool Feed Rate on the Hole Conicity

The behaviour of hole conicity with feed rate is analogous to that of the hole oversize as discussed above. These relations are shown in Fig.11.

At low tool feed rates up to 2 mm/min. the hole conicity is lower in the absence of H_2O_2. The more peroxide added, the larger becomes the hole conicity. This tendency shows the effect of depolarization brought about by the action of liberated oxygen on the polarizing hydrogen bubble layer. The result is that more current passes through the side gap causing metal dissolution.

Moreover, the release of oxygen bubbles by decomposition of H_2O_2 disturbs the hydrogen polarizing film if not completely remove it.

On the other hand, the effect of chloride ions on elecrode surfaces may apply in the same concept as explained by Hoar [3]

He postulated that chloride ions are so effective for penetrating and dissolving the film of iron oxides that the iron surface in solutions of chloride ions is not passivated by a protective oxide film.

On the contrary, it is observed that, at higher tool feed rates exceeding 2 mm/min. the hole conicity decreases with H_2O_2 addition. The oxygen gas bubbles, diffusing in the electrolyte solution, oxidise ferrous compounds and form a depletion layer on the side surface and thereby increase the resistivity.

On the other hand, the presence of oxygen in the chloride bath may fulfill the necessary requirements to produce the passive film, necessary for dimensional control in the side gap, as mentioned by Hoar [4]. Therefore, it is advantageous to use controlled incremental additions of H_2O_2 to the electrolyte solution at high tool feed rates.

3. Effect of Tool Feed Rate on the Surface Roughness

Fig.12, shows the effect of addition of H_2O_2 to NaCl solution on surface roughness at different tool feed rates. It is clear that, the relations between surface roughness and tool feed rates are non-linear, either in NaCl solution alone or when H_2O_2 is added.

At low tool feed rates of 0.55 to 1.25 mm/min. a relatively poor surface finishing was obtained in conjunction with H_2O_2 addition. Absence of H_2O_2 gave better surface in this region. The surface roughness increases with the increase in the concentration of H_2O_2 and decreases with increased tool feed rate. This is due to the non-uniform conductance in the gap as caused by the presence of O_2 released from H_2O_2. Accumulation of oxygen in the frontal gap is expected to increase with the decrease in tool feed rate. In such a case, ions transfer in the side gap may be more effective.

At tool feed rates of 1.25 to 2.5 mm/min. the surface roughness becomes better by the addition of H_2O_2 to NaCl but the behaviour is unstable. This may be due to depolarization effect of O_2 atoms on hydrogen accumulated at the cathode surface leading to a uniform dissolution of metal.

Moreover, as the tool feed rate increases over 2.5 mm/min.the surface roughness increases again. This is due to an intensive oxidation of Fe^{2+} to Fe^{3+} , at which surface defects appear. Mileham et al [5] showed that, machining with Fe^{2+} results in slightly lower values of surface roughness.

DISCUSSIONS

At high tool feed rate of 1.75-2.45 mm/min. the hole oversize and hole conicity decrease with gap voltage increase. This is due to the accumulation of gas bubbles on the side surface of the cathode, and the precipitation of anode products on the side wall of the anode, and both effects reduce the passage of current in the radial direction, which inhibits side dissolution of metal.

On the other hand, at different values of tool feed rates, the best surface finish was obtained at a gap voltage of 22 volts. This is due to the presence of the anodic film which can affect the surface finish at lower gap voltages. Also, boiling and gas evolution, in addition to electrolyte salt precipitation at higher values of gap voltage, lead to uneven distribution of current density over the anode surface and this results in a random dissolution across the anode. The presence of cavitation bubbles within the machining gap may also cause machining to be terminated, since these bubbles form non-conducting regions. Moreover, cavitation has been suggested as a cause for some rough, striated finishes in ECD.

In the case of low feed rate, at different gap voltages, the rate of anodic dissolution is not stable, as a result of the non-stable gap thickness. When the tool approaches the workpiece and the gap thickness decreases, high rates of dissolution takes place resulting in spontaneous gap increase. The tool takes some time to approach again during which lag dissolution temporarily weakens. Advancement of the tool enhances current passage with consequent dissolution.

The higher the electrolysing current, the more will be the anode product in the electrolyte boundary layer near the anode surface and thus, the rate of anode product precipitation on the hole inner surface will increase. This precipitate forms a protecting film, which prevents excessive side machining due its resistance, thus leading to the control of the flow of side currents in the side gap. The latter result gives smaller hole oversize and hole conicity. This oversize and conicity can be reduced by insulating the side walls of the cathode with a non-conducting resin or with a plastic sleeve or by means of a ceramic coated material.

At different gap voltages, better surface finish was obtained at moderate values of electrolysing current of 150-250A. This is due to the fact that the gas bubbles are less pronounced at this values. But, at lower values of electrolysing current, the machining depends on metal surface, which is constituted of grains of an electrode potential difference from that of the surrounding material. If the grain has a lower electrode potential, its dissolution will proceed first, leaving a recess on the surface. Also, at higher electrolysing currents the machining is accompanied by pitting of the surface. The latter effect can be attributed to the onset of gas evolution at the anode surface, and to rupture of the anodic layer by the gas.

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On the other hand, as the tool feed rate increases, the electrolysing current and metal removal rate is increased. This may be due to the decrease of the frontal gap which leads to increase in conductivity and flow speed.

In addition, at higher feed rates (smaller gap and greater flow speed) hydrogen is liberated starting from the lower corner of the side gap, where the severe deflection of the electrolyte stream around the tool results in the formation of a brokenaway zone with considerable drop in hydrostatic pressure, andthus, the conductivity of side gap is decisively reduced,and accordingly the side machining is reduced. This would result in smaller hole oversize and hole conicity at higher feed rate.

Good surface roughness was obtained at a tool feed rate of 1-2 mm/min. This may be due to material removal at exactly the same rate of tool advancement. But, at low tool feed rates, the forward gap may not be stable due to the variation in the metal removal rate. Therefore, the gap resistance varies continuously with time. Thus, poor surface finish was obtained due to periodic dissolution of metal at low tool feed rates.

The general trend of behaviour is the decreas of the hole oversize and hole conicity as the electrolysing current increases. The decrease is more steep when peroxide is added and the rate of decrease is steeper at higher percentage of H_2O_2. At low electrolysing current up to 290A, H_2O_2 addition causes an increase in hole oversize and hole conicity. This may be due to the generation of the hydrogen bubbles being less pronounced at these values. Therefore, the frontal gap is affected by the accumulation of gaseous oxygen which leads to increasing the resistivity. Thus, the current passage in the radial direction is more enhanced in the peroxide free electrolyte.

The decreases in hole oversize and hole conicity is progressive with higher electrolysing current values beyond 290A, in presence of peroxide, especially at higher concentrations. Therefore, the addition of peroxide is preferable at high electrolysing current.

Better surface roughness was obtained with peroxide free NaCl solution. This reverse effect may be due to non-uniform electrylysing current caused by the presence of O_2 bubbles liberated from H_2O_2 decomposition which removes the atoms randomly.

Moreover, a falling tendency for hole oversize and hole conicity with increased feed rate results from reducing the chance for side machining by decreasing the time of electrolysis. The presence of H_2O_2 adversly affects the hole oversize and hole conicity. Increasing the amount of H_2O_2 enhances the magnitude of hole oversize and hole conicity. This may be due to the depolarization effect of liberated oxygen which leads to more current passage through the side gap causing metal dissolution.

Finally, a relatively poor surface finish was obtained in conjuction with H_2O_2 addition. This may be due to the decomposition of H_2O_2 which is more affected by temperature, flow rate, impurities and electrolysing current. Therefore, the decomposition is not stable, which leads to irregularities in flow of electrolysing currents. It is obvious that dissolution takes place in a random manner over the metal surface and atoms are removed in a non-uniform fashion.

CONCLUSIONS

A systematic study of different parameters governing the ECD of hardened steel in NaCl electrolyte is presented. Addition of hydrogen peroxide as an oxygen-releasing chemical was attempted and proved to be advantageous in the range of high feed rates. Emphasis was made on quality of the generated surface.

The tool feed and metal removal rates were found to increase with the electrolysing current, Also, increase of electrolysing current was found to decrease the hole oversize and conicity. Moderate values of electrolysing current in the range of 150-250A gave better surface roughness.

Similarly, the higher the tool feed rate is the higher were the electrolysing current and metal removal rate. However, the hole oversize and conicity were decreased. At tool feed rates of 1-2 mm/min. a good surface roughness was obtained at various gap voltages.

Better hole oversize and conicity were obtained at higher electrolysing current. Furthermore, the higher the hydrogen peroxide concentration is the better the oversize and the conicity obtained.

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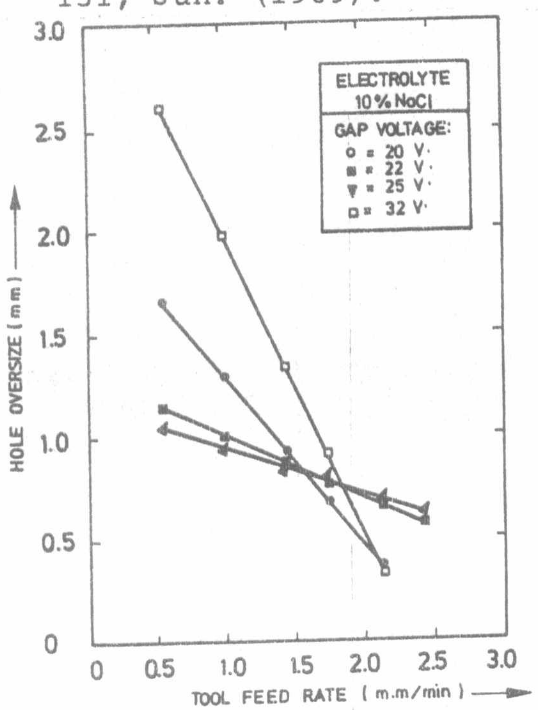

Fig. 1 Effect of tool feed rate on the hole over size at different gap voltages.

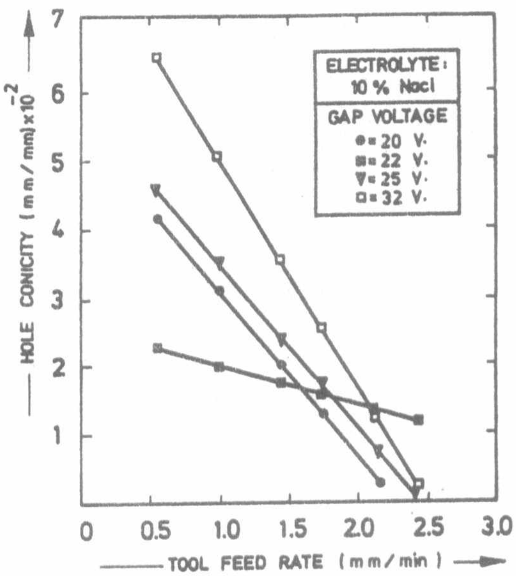

Fig. 2 Effect of tool feed rate on the hole conicity at different gap voltages.

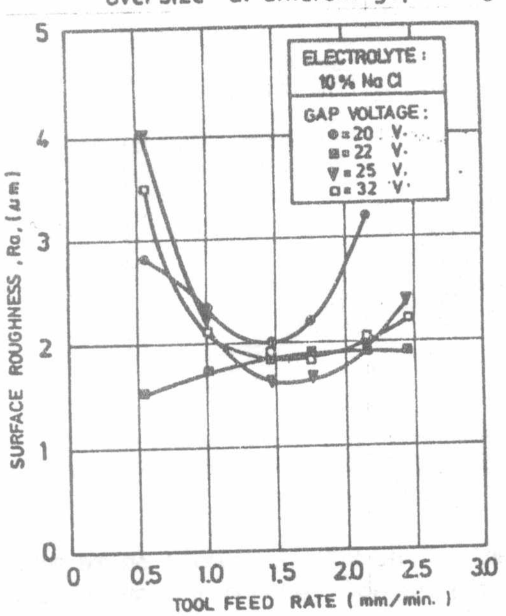

Fig. 3 Effect of tool feed rate on the surface roughness at different gap voltages.

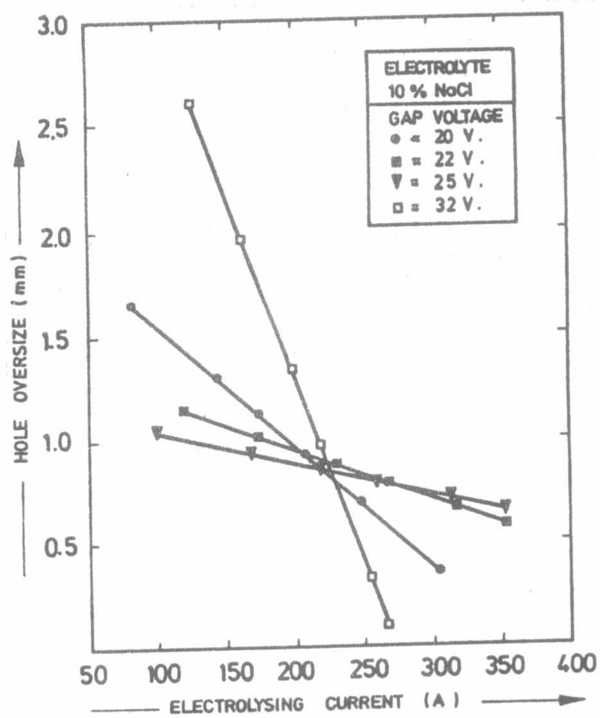

Fig. 4 Effect of electrolysing current on the hole oversize at different gap voltages.

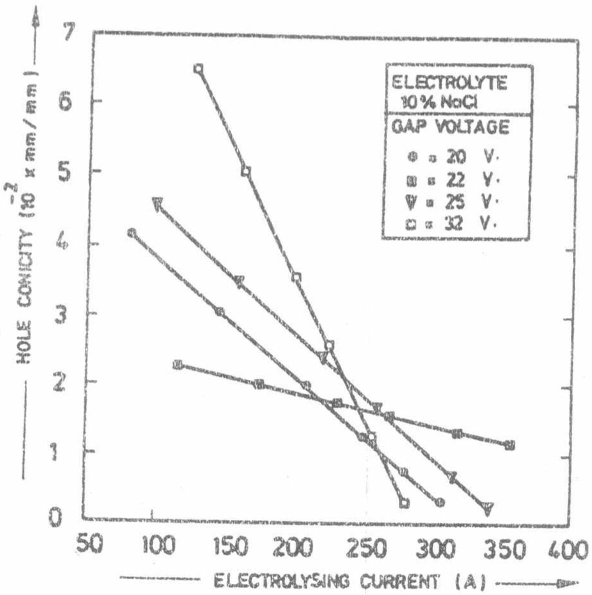

Fig. 5 Effect of electrolysing current on the hole conicity at different gap voltages.

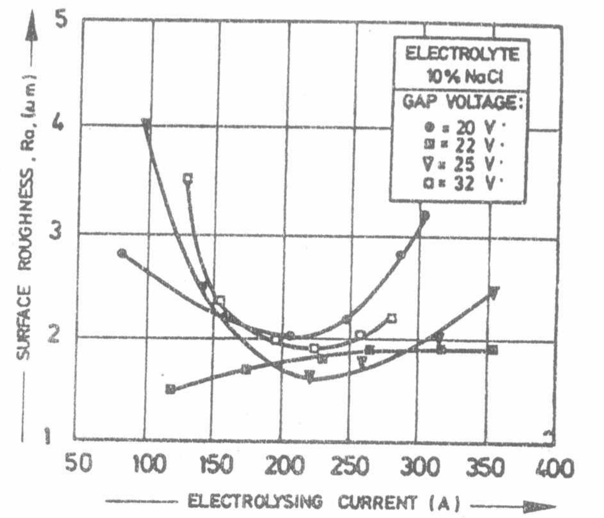

Fig. 6 Effect of electrolysing current on the surface roughness at different gap voltages.

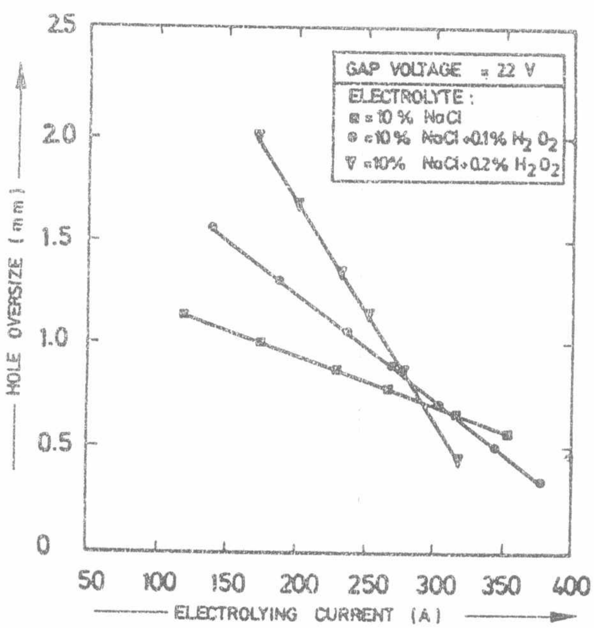

Fig. 7 Effect of electrolysing current on the hole oversize in NaCl solution with and without H_2O_2 addition.

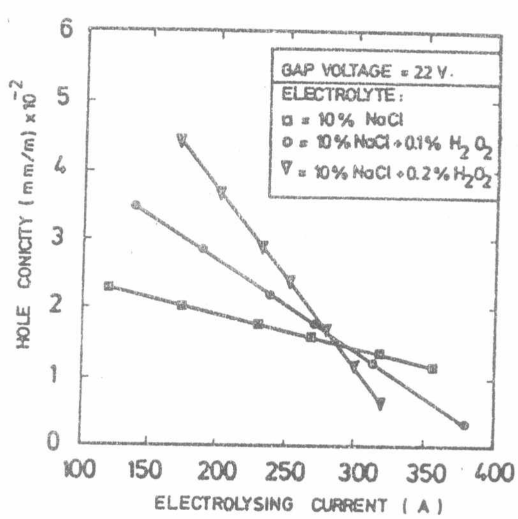

Fig. 8 Effect of electrolysing current on the hole conicity in NaCl solution with and without H_2O_2 addition.

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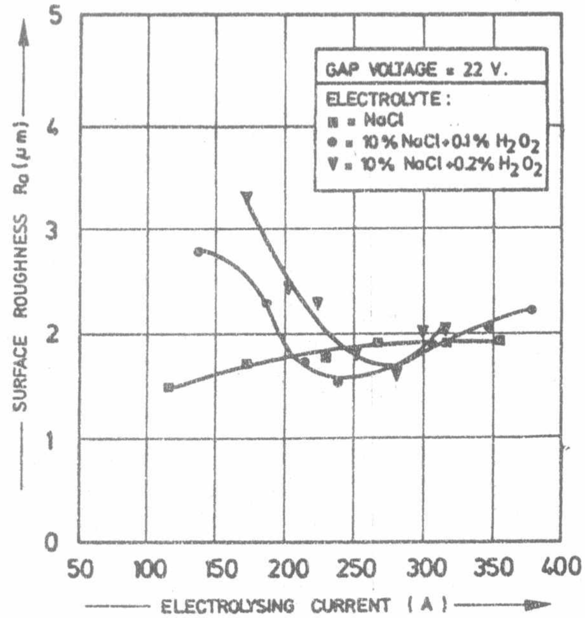

Fig. 9 Effect of electrolysing current on the surface roughness in NaCl solution with and without H_2O_2 addition .

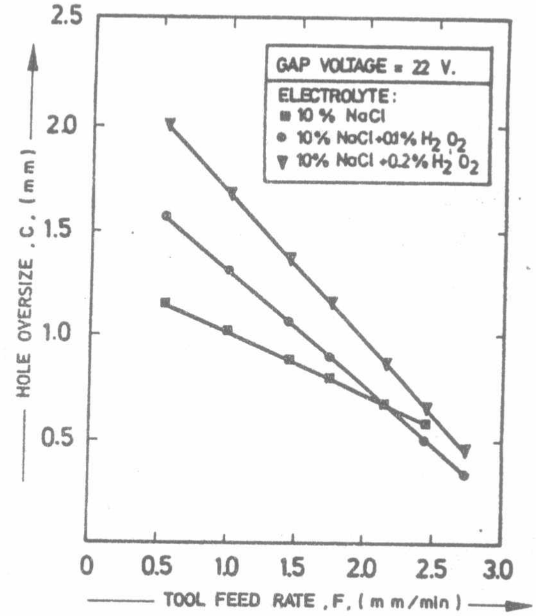

Fig. 10 Effect of tool feed rate on the hole oversize in NaCl solution with and without H_2O_2 addition .

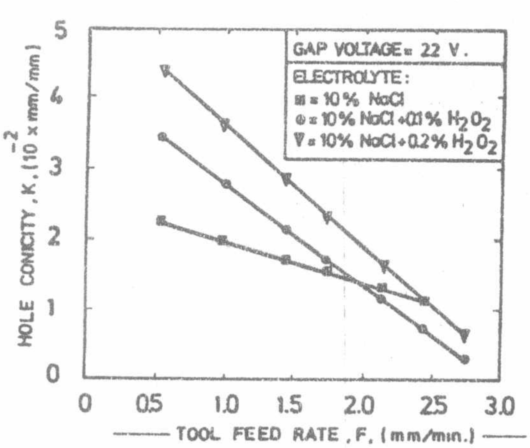

Fig. 11 Effect of tool feed rate on the hole conicity in NaCl solution with and without H_2O_2 addition .

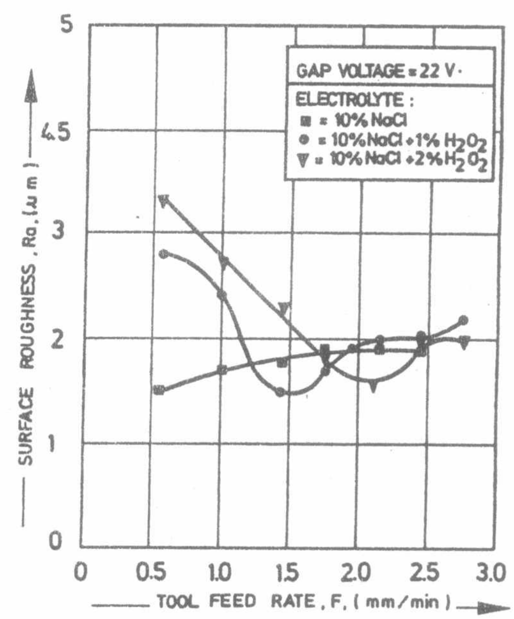

Fig. 12 Effect of tool feed rate on the surface roughness in NaCl solution with and without H_2O_2 addition .