EFFECT OF ELECTROLYTE TYPE ON ELECTROCHEMICAL MACHINING OF 304 STEEL

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ABSTRACT

Electrolyte type, due to the nature of its constituent ions, affects the reaction rate, the uniformity of the electric field and formation of the external layer on the workpiece surface in the machining area during the electrochemical machining process, Also it causes to creation of different dissolution behaviors of the workpiece. Therefore in this study the effect of sodium chloride, sodium nitrate, potassium chloride and hydrochloric acid electrolytes with different currents on the electrochemical machining characteristics of stainless steel 304, including material removal rate, side gap and surface roughness, has been investigated. The results showed that the formation of a passive layer during the machining with sodium nitrate electrolyte reduces the material removal rate and side gap compared with sodium chloride and potassium chloride electrolytes. According to the experimental results,by increasing the machining current, surface roughness in sodium chloride and potassium chloride electrolytes is decreased, but this amount increases in the sodium nitrate electrolyte. Also the material removal rate and side gap rise in the case of sodium chloride, sodium nitrate and potassium chloride when combined with hydrochloric acid. On the other hand, the surface roughness reduces in the combined sodium chloride and potassium chloride electrolytes, but increases in the combined sodium nitrate electrolyte.

Keywords
Electrochemical machining, electrolyte, material removal rate, side gap, surface roughness.

1. INTRODUCTION

Electrochemical machining (ECM) is based on the controlled anodic solution on the surface of the workpiece. In this process, the workpiece (anode) and the tool (cathode) are both electrically conductive and both submerged in an electrolytic cell. The conductive fluid in the process has a connecting role between the two electrodes and sweeps the process products and the thermal energy of chemical reaction away from the machining gap. High efficiency, high surface finish, no residual stress in the workpiece, no tool wear, and the possibility of manufacturing complex shapes are advantages of electrochemical machining. This process is currently widely used in aerospace, military, tool fabricating, automotive, and medical industries [1]. Due to great importance of

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achieving high material removal rate, high surface finish, and reduced side gap in the electrochemically machined workpieces, the studies in this field are growingnowadays. Thus many researches have been made to achieve machining efficiency and dimensional accuracy and reduced surface finish [2].

Tang et al. studied the effects of electrolyte current density in electrochemical machining on S-03 stainless steel with different electrolytes on machining parameters. In their study, they used Sodium Chloride, Sodium Nitrate, and a combination of them. The results of experiments showed that Sodium Chloride has the greatest current intensity efficiency among other electrolytes and the density of current intensity does not have any effect on current intensity efficiency. They also found out that as the cathode feed rate increases, the surface roughness decreases.

In a study, Jain and Morgan [3] investigated the ECM process improvement utilizing the Oxygen enriched electrolyte. They used Sodium Chloride and Oxygen enriched Sodium Chloride with various densities aselectrolytes. The results showed that as the Oxygen is added to the electrolyte, the material removal rate greatly increases since Hydroxyl ions (OH)are widely increased with respect to pure Sodium Chloride.

Tang et al. [4] studied the effects of Sodium Chloride and Sodium Nitrate electrolytes on the features of S-03 stainless steel electrochemical machining. They implemented a $L_{16}(4^5)$ Taguchi design of experiments involving voltage, cathodic feed rate, electrolyte pressure, electrolyte type, and electrolyte intensity as experiment factors at four different levels. The results of experiments showed that a compound of Sodium Nitrate (178 $^{gr}/_{lit}$) and sodium Chloride (41 $^{gr}/_{lit}$), a voltage of 20 volts, and an electrolyte pressure of 0.8 MPa in electrochemical machining of S-03 stainless steel are the optimized values foe machining features (MRR, side gap, and surface roughness).

Schubert et al [5] studied the electrochemical machining of cementite carbide with a combination of Sodium Nitrate and Ammonia with a ratio of $\frac{NH_3}{NaNO_3} = \frac{2}{2.9}$ as the electrolyte. The experiments showed that each of Cobalt and Tungsten phases has a unique electrochemical solutability behavior. They were able to reach to a homogenous solutability of the hard phase and the connecting phase (binder) using the aforementioned combination of electrolytes. They also found out that with this type of electrolyte, the machining efficiency is in relation with current density.

Bannard [6] in a research studied the effect of the surface activating additives in machining electrolytes. He used a 15% Sodium Chloride with surface activating additives in his research. The results showed that these additives increase the electrolyte flow up to 25%. He also found out that some active polymeric additives increase the solutability of the workpiece and the material removal rate. In contrast, some additives decrease the electrochemical solutability, particularly in the regions of low current density.

Thanigaivelana et al. [7] investigated the electrochemical micromachining of the stainless steel using acidic Sodium Nitrate as electrolyte. In their research they used electrolytes with various compounds and densities including 0.5 M H_2SO_4 + 25 $mol/_{lit}$ $NaNO_3$ and 25 $mol/_{lit}$ $NaNO_3$ with electrolyte flow rates of 4.5 and 6.7 $lit/_{min}$. They found that material removal rate and over cut (OC) are highly affected by electrolyte type. In comparison with pure Sodium Nitrate electrolyte, the acidic Sodium Nitrate electrolyte has higher material removal rate due to less formation of mud and less over cut due to less micro-sparks.

Hoare et al. [8] experimentally investigated the ECM machining of 1020 steel with a 1.5 molarity ofBromite Sodium ($NaBrO_3$) electrolyte. They found that due to the formation of a passive layer in a wide range of applied voltages on the workpiece surface, the dimensional and geometrical accuracy is reduced and the machined surface is highly porosed.

Mao and Hoare [9] in an empirical study investigated the anodic solutability of 1020 steel in electrolytes containing both the NO_3^- and Cl^- ions with the $\frac{Cl^-}{NO_3^-}$ ratios of 0.5,2,3,4, and 7. The results showed that the Cl^- ions are responsible for the solution of anodic layers which formed by the NO_3^- ions in iron based materials. They also found that ClO_4^- ions uniformly solve the anodic layers.

Laboda et al. [10] performed a broad research between the years 1972 to 1974 at the laboratories of GM Corporation to find an alternative electrolyte for Sodium Chloride which causes undesirable solution during ECM process. The results showed that $NaClO_3$ electrolyte has the best dimensional and geometrical control on workpiece at high removal rates and produces a good surface finish, with respect to other electrolytes.

Based on the aforementioned researches, the proper electrolyte has an important role to achieve the desired machining features in ECM process. Due to the difference between therateof solutability of the constituent elements in alloy steels like 304 stainless steel, the proper choice of the electrolyte type has great importance. So the aim of this research is to investigate the effect of Sodium Chloride, Sodium Nitrate, Potassium Chloride and the combination of them with Hydrochloridric acid with a molarity of 0.1 at different currents on machining features (MRR, side gap, and surface roughness) of 304 stainless steel.

2. 2-1 MATERIALS AND METHODS OF EXPERIMENT

In this research the commercial 304 stainless steel is used as workpiece. The constituent elements of this steel is on the weight basis as shown in table 1. The 304 stainless steel has an austenite microstructure and is resistant to corrosion and creep and has a high toughness. Table 2 shows the mechanical properties of this material. These properties have made this steel to be widely used in many different applications like energy industry, food industry, automotive parts, chemical

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industry, and aerospace applications. The conventional machining of this steel is difficult due to built-up-edge formation. To perform the experiments, the specimens with the diameter of 30mm and thickness of 10 mm were cut from a bar and their cross section surface were ground. Also a Copper tool was used for machining which some of its physical properties is shown in table 3. In order to reduce the stray current effect which reduces the undesirable solutability, the side edges of the tool was isolated by spraying an epoxy electrostatic coat. Figures 1 and 2 show the machined specimen and the tool before and after coating respectively.

Table 1 Weight percent of alloying elements in the 304 stainless steel

Element	Wight percent (%)	Element	Wight percent (%)
Al	0.024	S	0.018
C	0.046	Si	0.372
Cr	17.670	V	0.069
Cu	0.689	W	0.044
Mn	0.886	Fe	71.360

Table 2 Mechanical and physical properties of the 304 stainless steel

Parameter	Unit	Value
Ultimate tensile strength	MPa	500-700
Young's Modulus	GPa	200
Yield strength	MPa	190
Elongation (%)	%	45
Hardness	HV	$215\geq$
Density	Kg/m^3	7.9
Electrical resistance	$\mu \, \Omega \, m$	0.73
Heat transfer	w/m.k	15

Table 3 Physical properties ofcopper tool

Parameter	Unit	Value
Density	gr/cm^3	8.93
Melting point	°C	1083
Boiling point	°C	2580
Heat transfer	w/m.k	380.7
Electrical resistance	$s/m.m^2$	59.5
Hardness	N/mm^2	HB 45

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Fig. 1 Machined workpieces in experiments
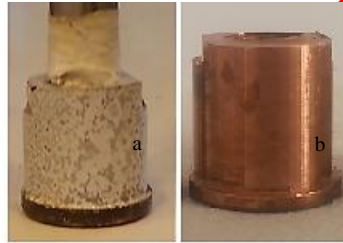
Fig.2 (a) Copper tool before coating (b) Copper tool after coating

2-2 The ECM Device

The device shown in figure 3 was designed and built to perform the experiments. This device has four different units (power supply and control unit, tool feed unit, electrolyte fluid recirculating unit, and tool and workpiece holder unit). The power supply unit has a working voltage range between 0 and 12 volts and a maximum current of 100 A. The control unit has the capability of measuring and controlling the variation of gap condition during the machining. The electrolyte fluid recirculating unit stores, feeds, and purifies the fluid and controls its temperature to a specific degree. In order to prevent the entrance of unwanted particles to the machining zone and provide a clean electrolyte, a 5μm filter was used. The heat exchange system consists of a 1500 W heater, a PT 100 heat sensor, a thermostat and a relay which used to control the electrolyte temperature. The machining process was performed in a plexiglass chamber where the workpiece was hold in with a special fixture. Figure 4 shows the schematic ECM machine and its relevant devices.

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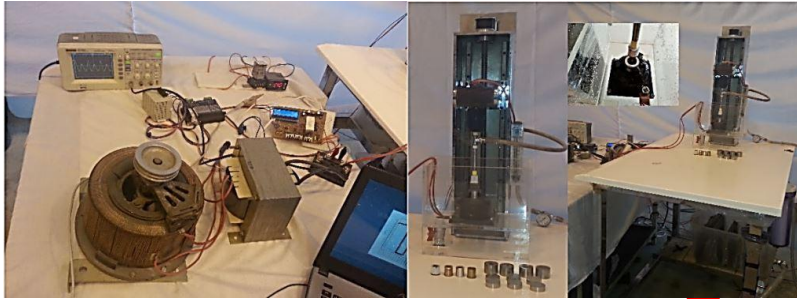## 2-3 The Method of Measuring output parameters
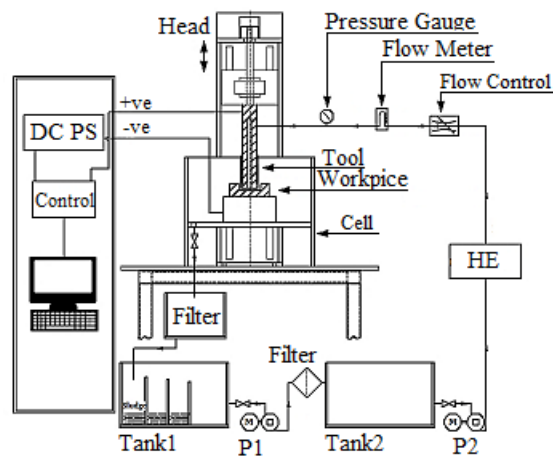

Fig. 3 Equipment for experiments

Fig. 4 Schematic diagram of ECM and its equipment

To measure the material removal rate in experiments, a Mettler Toledo balancewith the precision of 0.0001 gr was used. For this purpose the specimens was washed with purified water and dried and then weighed. So by weighing the specimens before and after the experiments, the material removal rate was calculated by the equation 1

$$MRR = \frac{M_1 - M_2}{t} \tag{1}$$

Where MRR is the material removal rate ($^{gr}/_{min}$), M_1 is the mass before machining, and M_2 is the mass after machining and t is the experiment time (min).

To measure the side gap in experiments a Starret HS 1000 profile projector was used. By this device first a magnified picture of the machined specimens was created and then by introducing some points on the side edge, the average machined diameter was calculated. The side gap is calculated by equation 2

$$Side\ gap = \frac{Dp - Dt}{2} \qquad\qquad (2)$$

Where D_p is the machined diameter (mm) and D_t is the tool diameter (mm). A MahrPerthometer M2 was used to measure the surface roughness. Since the values of the roughness were different at center, middle, and side regions, the measurement of average surface roughness (R_a) was performed at three points in center, middle, and side regions and the average value was chosen as the surface roughness.

2-4 Design of Experiments

A full factorial design with a total of 18 experiments was designed. In these experiments the Sodium Chloride (NaCl), Sodium Nitrate (NaNO$_3$), and Potassium Chlorite (KCl) electrolytes with the density of 0.1 mole at the currents of 35, 45, and 55 A were used. Table 4 shows the properties of the implemented electrolytes in the experiments. The conditions of the experiments and the levels of the variables were chose after a series of initial experiments and are briefly shown in table 5.

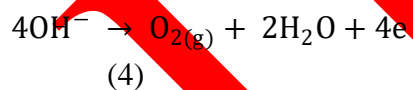**Table 4**Characteristics of the used electrolytes in experiments

Electrolyte	Sodium chloride	Sodium nitrate	Potassium chloride	Chloridric Acid
Chemical formula	NaCl	NaNO$_3$	KCl	HCl
Group	salt	salt	Salt	acid
Constitutional formula	NaCl		KCl	H─Cl
Molar mass	58.44	84.98	74.54	36.46
	126.45	121.56	149.85	426.16
	U_{Cl}=7.91×10^{-4} U_{Na+}=5.19×10^{-4}	U_{NO3-}=7.4×10^{-4} U_{Na+}=5.19×10^{-4}	U_{Cl-}=7.91×10^{-4} U_{K+}=6.1×10^{-4}	U_{Cl-}=7.91×10^{-4} U_{H+}=25.2×10^{-4}
	359	912	359	-
Density (g/cm^2)	2.17	2.257	1.984	1.18

Table 5 Conditions and parameters set in experiments

Parameter	Unit	Value
Voltage	V	10
Current density	A	35,45,55
Electrolyte current rate	L/min	3 ± 0.5
Electrolyte pressure	bar	0.5 ± 0.02
Electrolyte temperature	°C	26 ± 1
Preliminary gap	mm	0.3
Machining time	Min	5
Electrolyte type	-	NaCl,NaNO$_3$,KCl, HCl
Electrolyte density	M	0.1+1 , 1

3. DISSCUSION

Figure 5 and 6 show the material removal rates with different electrolytes and different currents. As shown in the figures, the highest material removal rates is achieved with Potassium Chloride electrolyte at the current of 55 A and the least material removal rate is achieved with Sodium Nitrate at the current of 35 A and the material removal rate with Sodium Nitrate electrolyte at all current values are less than other electrolytes and their combination with Hydroxyl acid. It seems that the reason for this is the difference between the Cl$^-$ solutability behavior of NO$_3^-$ and anions in this electrolyte. In machining with Sodium Nitrate electrolyte, part of the machining current according to equations 3 and 4 is spent to complete the formation of Oxygen gas and the passive layer (Oxide layer) on the surface of the workpiece0 according to equation 5 [2, 11].

$$2H_2O \rightarrow O_{2(g)} + 4H^+ + 4e \tag{3}$$

$$4OH^- \rightarrow O_{2(g)} + 2H_2O + 4e \tag{4}$$

$$Me + nH_2O \rightarrow MeOn + 2nH^+ + ne^- \tag{5}$$

This results in reduced machining efficiency and therefore reduced material removal rate. But in machining with Sodium Chloride and Potassium Chloride electrolytes which have Chlorineonions, Due to uncompleted formation of Oxygen gas and lack of formation of passive layer, the efficiency of machining current intensity is maximum and thus results in higher machining rate for these electrolytes with respect to Sodium Nitrate according to equation6.

$$MRRg = \eta \frac{A\,I}{Z.F}$$
          (6)

In equation 6 I is the current intensity (A), A is atomic mass (gr), I is solutability capacity, f is Faraday's constant and η is machining current efficiency.

Figures 5 and 6 also show that the material removal rates with respect to current in various electrolytes. As seen in these figures, the material removal rates in different electrolytes increase with the increase of current. The reason for this phenomena can be stated as with the increase in current, the rate of oxidation in machining zone increases and makes more stimulation of the ions from workpiece toward the electrolyte. This increases the value of material removal rate according to equations 6 and 7 [2, 11].

$$Va = \eta wj \tag{7}$$

Where in equation 7, j is current density, w is electrochemical equivalent, η is current efficiency, and V_a is machining speed.
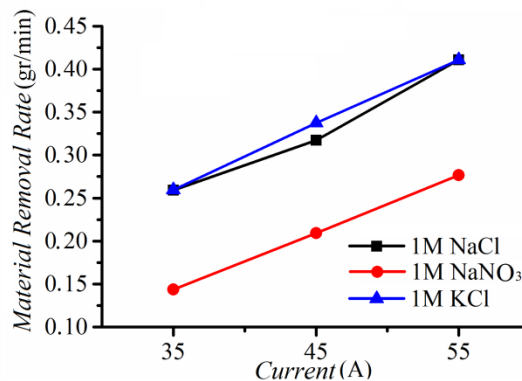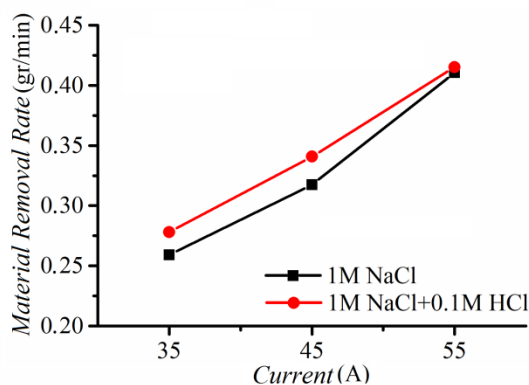

Fig. 5 Material removal rate variations to the change of current in sodium chloride, sodium nitrate and potassium chloride electrolytes at the concentration of 1 Molarity
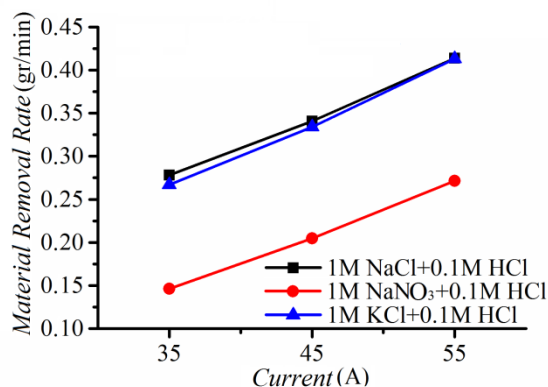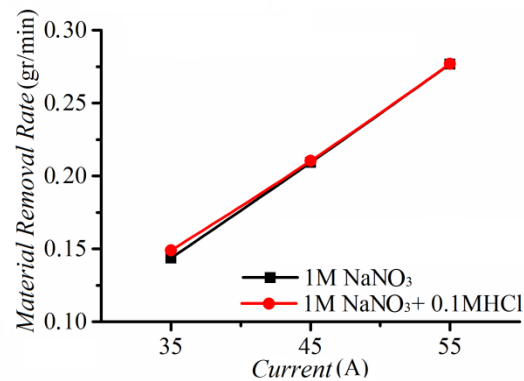
Fig. 6 Material removal rate variations to the change of current in combined sodium chloride, sodium nitrate and potassium chloride electrolytes with hydrochloric acid

Also figures 7 through 9 show the material removal rate of the combination of electrolytes with Hydrochloridric acid. As seen in the figures, addition and combination of hydrochloridric acid with other electrolytes increases the removal rate. Because adding 0.1 M HCl to Sodium chloride, Potassium Chloride, and Sodium Nitrate electrolytes with the molarity of 1, increases the density of combined electrolyte ions with respect to pure electrolyte and by increasing the electrolyte density, the number of ions involved in machining process increases which causes increased material removal rate.

Fig. 7 Material removal rate variations to the change of current in sodium chloride electrolyte and its combined electrolyte with hydrochloric acid

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Fig. 8 Material removal rate variations to the change of current in sodium nitrate electrolyte and its combined electrolyte with hydrochloric acid
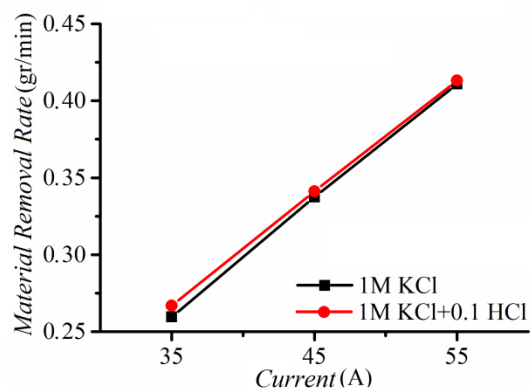
Fig. 9 Material removal rate variations to the change of current in potassium chloride electrolyte and its combined electrolyte with hydrochloric acid

**3-2 Investigating the Effect of Electrolyte Type on Side Gap at Various Currents:**

Figures 10 and 11 show the effect of electrolyte type on side gap at different currents. As shown in these figures, the smallest side gap is formed with Sodium Nitrate as electrolyte and with the current of 55 A and the largest side gap is formed with Potassium Chloride as electrolyte with the current of 35 A. Also it can be seen that the value of side gap at various current values in pure and combined Sodium Nitrate electrolytes is less than the value of side gap in pure and combined Sodium Chloride and Potassium Chloride electrolytes. It seems that the reason for this is the formation of the oxide passive layer on the surface of the workpiece and thus the reduced stray current effect in the region of side gap [4,7,14] in a way that in non-passive Sodium Chloride and Potassium Chloride electrolytes, the lack of formation of passive layer in ECM machining causes an increase in the stray current flux at the side gap zone and increases the value of side gap.

Also figures 10 and 11 show that the value of side gap with pure and combined Potassium Chloride electrolytes is more than pure and combined Sodium Chloride electrolyte at various current values.

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The reason for this can be expressed as the difference between the molar conductivity value (Λ) of Sodium Chloride and Potassium Chloride. The molar conductivity value for Potassium Chloride electrolyte ($149.85 \, cm^2/\Omega$) is more than its value for Sodium Chloride electrolyte ($126.45 \, cm^2/\Omega$).

Since these two electrolytes have Cl⁻ anion in common, this difference is caused by the high ionic stimulation (U) of K⁺ cation ($U_{K^+} = 6.1 \times 10^{-4} \, cm/v.s$) with respect to Na⁺ cation ($U_{Na^+} = 5.19 \times 10^{-4} \, cm/v.s$). The high conductivity of this electrolyte increases the value of flux in the machining zone. It seem that this increase is responsible for increase in unwanted solution and side gap.

Also as shown in figures 10 and 11, in all electrolyte types, the side gap is reduced by increasing the current. The reason for this reduction can be stated as by increasing the current, the rate of reactions at side gap increases and thus the products of the reactions also increase [12,13]. The increase of reaction products at machining gap region decreases the electrolyte conductivity at side gap region in comparison with lower current values. The low conductivity of electrolyte decreases the flux at side gap region and thus decreases the side gap size.
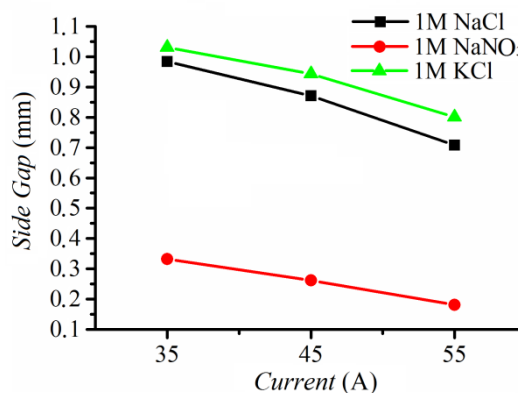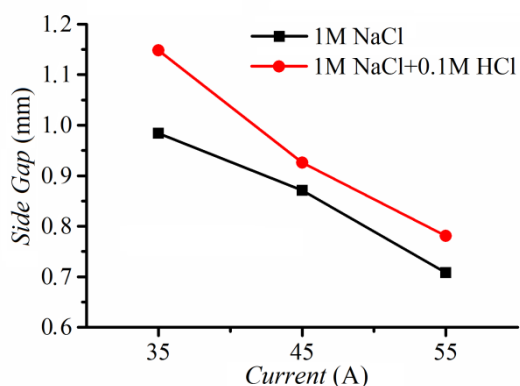

Fig. 10 Side gap variations to the change of current in sodium chloride, sodium nitrate and potassium chloride electrolytes at the concentration of 1 Molarity
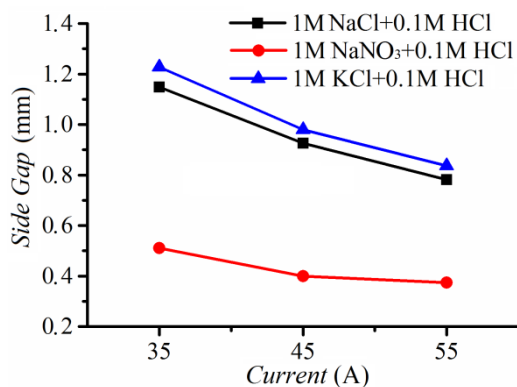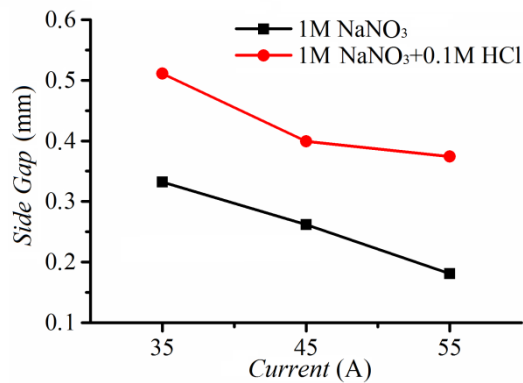
Fig. 11 Side gap variations to the change of current in combined sodium chloride, sodium nitrate and potassium chloride electrolytes with hydrochloric acid

Figures 12 through 14 show the effect of combined electrolytes of 0.1 molarity Hydrochloridric acid with Sodium Chloride, Sodium Nitrate, and Potassium Chloride electrolytes in comparison with their pure electrolytes on side gap. As shown in the figures, the addition of 0.1 molarity of hydrochloridric acid to the electrolytes increases the side gap in comparison to the pure electrolytes. Also these figures show that the percent value of increase in the side gap in the combined Sodium Nitrate electrolyte is higher than other combined electrolytes. This is due to the fact that by the addition of 0.1 molarity Hydrochloridric acid to Sodium Nitrate electrolyte, the Cl^- ions in the electrolyte due to their corrosive nature, locally remove the passive oxide layer at this region. The removal of this layer increases the stray current flux at this region and therefore increases the unwanted solution which increases the side gap.

Fig. 12 Side gap variations to the change of current in sodium chloride electrolyte and its combined electrolyte with hydrochloric acid

Fig. 13 Side gapvariations to the change of current in sodium nitrate electrolyte and its combined electrolyte with hydrochloric acid
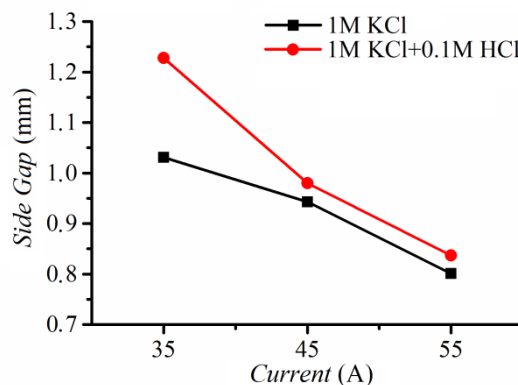
Fig. 14 Side gapvariations to the change of current in potassium chloride electrolyte and its combined electrolyte with hydrochloric acid

3-3 The Effect of Electrolyte Type on Surface Roughness at various Currents

Figures 15 and 16 show the effect of electrolyte type on surface roughness at various current values. As shown in the figures, the lowest value of the surface roughness belongs to combined electrolyte of Sodium Chloride and Hydrochloridric acid with the current of 55 A and the highest value of surface roughness belongs to Potassium Chloride electrolyte at the current of 35 A.
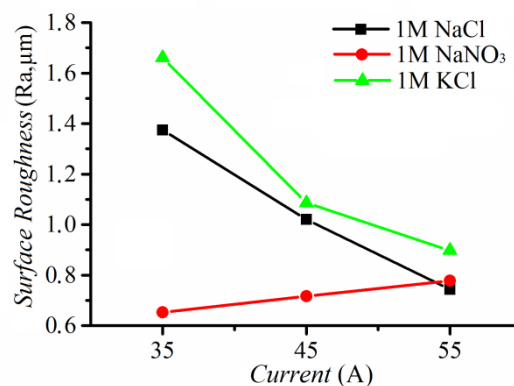
Concerning the results, it can be seen that the value of surface roughness with Sodium Chloride and Potassium Chloride and their combination with 0.1 molarity Hydrochloridric acid reduces with increase in current while with Sodium Nitrate electrolyte and its combination with 0.1 molarity Hydrochloridric acid, the surface roughness increases with increase in current. The reason for this can be expressed as during machining with Sodium Chloride and Potassium chloride electrolytes and their combination with Hydrochloridric acid, a loosely salt layer is formed on the surface of the workpiece in proportion with increase in current. This loosely salt layer more uniformly distributes

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the machining current on the surface of the workpiece at higher current intensities. The uniform distribution of machining current on the surface of the workpiece creates a homogenous solution and increases the surface finish at higher current intensities [16-18]. Equation 10 show the relationship between the intensity and the salt layer thickness with current intensity. Using the Sodium Nitrate electrolyte and its combination with 0.1 molarity Hydrochloridic acid at lower current intensities (0-5 A/cm^2) a passive layer forms on the surface of the workpiece. This layer at current intensities of 5-35 A/cm^2, in proportion with current intensities, discretely disjoins the surface of the workpiece. Increase in current intensity in this region creates a non-homogenous solution and pitting of the machined surface and increases the surface roughness.

$$i = n F D \frac{C_{sat}}{\delta} \tag{10}$$

Where i is the current intensity (A/cm^2), n is the number of exchanged electrons, F is Faraday's constant (96500), D is emissivity constant (cm^2/s), C_{sat} is the intensity of salt on the surface (M), and δ is the salty layer thickness (cm).

Also figure 15 and 16 show that the value of surface roughness for Potassium Chloride electrolyte is more than Sodium Chloride at all current intensities. It seems that the reason for this discrepancy is the difference between the electrical conductivity of these two electrolytes due to higher ionic stimulation of K^+ ion with respect to Na^+. The high electrical conductivity of electrolytes increases the electrochemical reaction rates in machining region which increases the volume of reaction products at this region [12]. The high volume of reaction products in machining zone with Sodium Chloride as electrolyte creates a less homogenous Solution with respect to Sodium Chloride due to higher precipitation of reaction products on the surface of the anode and thus increases the surface roughness of the workpiece.

Fig. 15 Surface roughnessvariations to the change of current in sodium chloride, sodium nitrate and potassium chloride electrolytes at the concentration of 1 Molarity
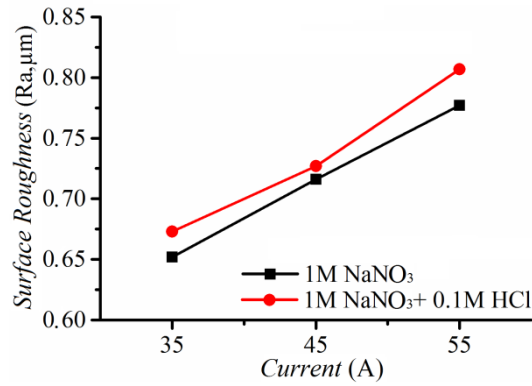
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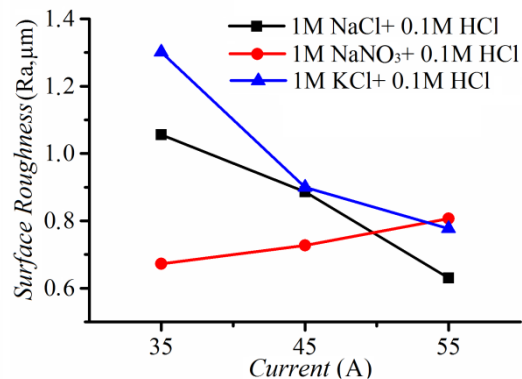
Fig. 16 Surface roughness variations to the change of current in combined sodium chloride, sodium nitrate and potassium chloride electrolytes with hydrochloric acid

Figure 17 shows the results of surface roughness measurement for Sodium Nitrate electrolyte and its combination with 0.1 molarity Hydrochloridric acid. It can be seen that the value of surface roughness increases in comparison with pure electrolyte. The reason for this phenomena is that the Cl^- ions which are created by the addition of 0.1 molarity Hydrochloridric acid to the electrolyte, locally attack the passive layer on the surface of the steel in the presence of NO_3^- ions which locally solves the passive layer. The locally solution of this layer due to non-uniform attack of Cl^- ions creates non-uniform solution condition and pitting of the workpiece with respect to pure Sodium Nitrate which increases the surface roughness in combined electrolytes [9,15].

Figures 18 and 19 show the results of surface roughness measurement for Sodium Chloride and Potassium Chloride and their combination with 0.1 molarity Hydrochloridric acid. As seen in the figures, the value of surface roughness in combined Sodium Chloride and Potassium Chloride electrolytes is less than their pure electrolytes. Its reason is the less formation of metallic Hydro oxides and their precipitation on the surface of the workpiece during the electrochemical machining and the creation more homogenous solving condition in combined electrolytes with respect to pure electrolytes such that by adding 0.1 molarity Hydrochloridric acid to Sodium Chloride and Potassium Chloride, the Hydroxyl ions react with the H^+ ions which are created by the addition of 0.1 molarity Hydrochloridric acid to the electrolyte and create water molecules. Under this condition the metallic hydroxyls formation reduce
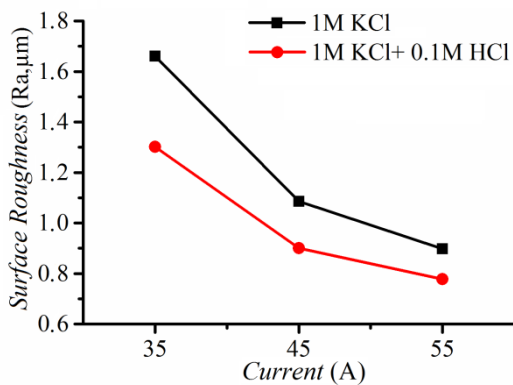
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Fig. 17 Surface roughnessvariations to the change of current in sodium nitrate electrolyte and its combined electrolyte with hydrochloric acid
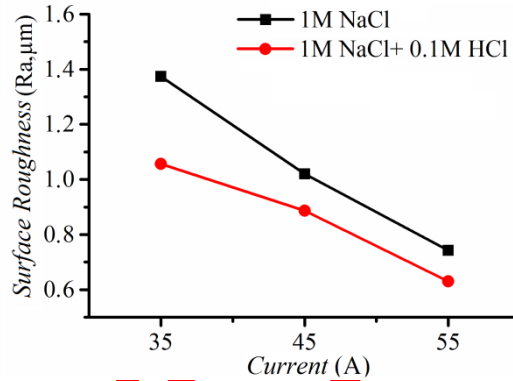
Fig. 18 Surface roughnessvariations to the change of current in sodium chloride electrolyte and its combined electrolyte with hydrochloric acid

Fig. 19 Surface roughnessvariations to the change of current in potassium chloride electrolyte and its combined electrolyte with hydrochloric acid

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4. CONCLUSION

In this research the effect of electrolyte type on material removal rate, surface roughness, and side gap was investigated. The results show that electrolyte type is an important factor in ECM process and the proper choice of electrolyte improves the machining features. The results of the research are briefly listed below:

1- In ECM machining the material removal rate in Sodium Chloride and Potassium Chloride is more than Sodium Nitrate under the same conditions.

2- The side gap in Sodium Nitrate is less than Sodium Chloride and Potassium Chloride under the same conditions and the side gap in potassium Chloride is more than Sodium Chloride.

3- In Sodium chloride and Potassium chloride electrolytes, the surface roughness increases with decrease in current but in Sodium Nitrate it increases with increase in current.

4- In Sodium chloride, the surface roughness is less than Potassium chloride under the same conditions.

5- The addition of 0.1 molarity Hydrochloridric acid to Sodium chloride and Potassium Chloride electrolytes increases the material removal rate and side gap in comparison to their pure electrolytes, Moreover, the surface roughness in combined Sodium Chloride and potassium Chloride electrolytes in comparison with their pure electrolyte decreases, but it increases with combined Sodium Nitrate as electrolyte in comparison with its pure electrolyte.

REFERENCES

[1] S. Ayyappan& K. Sivakumar, *Experimental investigation on the performance improvement of electrochemical machining process using oxygen-enriched electrolyte*, Int J AdvManufTechnol 75: pp.479–487, 2014.

[2] Lin Tang & Bo Li &Sen Yang &QiuliDuan&Baoyin Kang, *The effect of electrolyte current density on the electrochemical machining S-03 material*, Int J AdvManufTechnol 71: pp.1825–1833.2013.

[3] V. K. Jain & S. Murugan, *Investigations into the effect of cathode material on temperature distribution during electrochemical machining*, International Journal of Production Research, INT.J.PROD.RES 1986,Vol., 24, No. 2, pp.439-450,2002.

[4] Lin Tang & Yong-Feng Guo, *Experimental Study of Special Purpose Stainless Steel on Electrochemical Machining of Electrolyte Composition*, Materials and Manufacturing Processes, 28: pp.457–462, 2013.

[5] N. Schubert, M. Schneider & A. Michaelis, Electrochemical *Machining of cemented carbides, International Journal of Refractory Metals and Hard Materials* 47, pp.54-60, 2014.

[6] J. Bannard, *The use of surface-active additives in electrochemical machining electrolytes, Journal of Applied Electrochemistry* 4, pp.117-124, 1974.

[7] R.Thanigaivelana, RM.ArunachalambB.Karthikeyanc, P.Loganathan, *Electrochemical micromachining of stainless steel with acidified sodium nitrate electrolyte, The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)*,Procedia CIRP 6, pp.351 – 355, 2013.

[8] James P. Hoare, Kao-Wen Mao , Augustine J. Wallace, JR, 1972 ,*The electrochemical machining of mild steel in NaBrO3 solutions*, Corrosion Science, Vol. 13, pp. 799to803. Pergamon Press. Printed in Great Britain, 1973.

[9] Kao-Wen Mao and James P. Hoare, *Theanodicdissolutionofmildsteelinsolutionscontainingboth Cl^- and NO_3^- ions*, Corrosion Science, Vol. 13, pp. 799 to 803. Pergamon Press. Printed in Great Britain, 1973.

[10] M. A. Laboda and M. L. Mcmillan, *Electrochem. Tech.* 5, pp.340- 346 (1967).

[11] Thomas Wagner (geb. Haisch) *High rate electrochemical dissolution of ironbased alloys in NaCl and NaNO3 electrolytes*, 2002.

[12] S.K. Sorkhel and B. Bhattacharyya, Parametric *control for optimal quality of the workpiece surface in ECM*, Journal of Materials Processing Technology, 40, pp.271-286,1994.

[13] S. S. Uttarwar, Dr. I. K. Chopde, *Study of Influence of Electrochemical Process Parameters on the Material Removal Rate and Surface Roughness of SS AISI 304*, International Journal Of Computational Engineering Research (ijceronline.com) Vol. 3 Issue.3, 2013.

[14] W. Wang & D. Zhu & N.S. Qu& S.F. Huang &X.L. Fang,*Electrochemical drilling with vacuum extraction of electrolyte, Journal of Materials Processing Technology* 210, pp.238–244,2010.

[15] D.L. Pramanik and A. Chattopadhyay,*Selection of the optimum electrolyte composition and flow rate for machining a particular high alloy steel*, 1982.

[16] El-Hofy, Hassan Abdel-Gavad, *Advanced Machining processes*, 2005.

[17] T. Haisch , E. Mittemeijer , J.W. Schultze, *Electrochemical machining of the steel 100Cr6 in aqueous NaCl and NaNO3 solutions: microstructure of surface films formed by carbides*, ElectrochimicaActa 47 pp.235–241, 2001.

[18] M. Datta, *Anodic dissolution of metals at high rates*, IBM J. RES. DEVELOP. VOL. 37 NO. 2 MARCH 1993.

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