Electrochemical micromachining of stainless steel with acidified sodium nitrate electrolyte

R.Thanigaivelan\textsuperscript{a}, RM.Arunachalam\textsuperscript{b}, B.Karthikeyan\textsuperscript{c}, P.Loganathan\textsuperscript{c}

\textsuperscript{a}Professor & Head, \textsuperscript{b}Graduate students, Department of Mechanical Engineering, Muthayammal Engineering College, Rasipuram, \textsuperscript{c}Assistant Professor, Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, Sultanate of Oman

* Corresponding author. Tel.: +91 944 303 0935; Email address: tvelan10@gmail.com.

Abstract

This paper describes Electrochemical Micromachining (EMM) of stainless steel with acidified sodium nitrate. The sulphuric acid of 0.05m/L is added to the standard electrolyte namely sodium nitrate to solubilise the by-products. The foremost characteristics of EMM are researched through scheme of experiments involving various parameters, such as machining voltage, pulse on time and electrolyte concentration. The performance of acidified sodium nitrate and sodium nitrate on EMM are compared. Based on the study, the machining rate and overcut are significantly improved using acidified sodium nitrate as an electrolyte.

Keywords: Acidified sodium nitrate; Electrolyte; Overcut; Machining rate.

1. Introduction

Since the increase in the demand for micro components/products, micromachining technology has gained an important place in the fabrication of miniaturized products [2]. Among the micro electrical manufacturing technologies, EMM is one of the promising technologies that are gaining importance for its advantages such as stress-free, with good surface finish and the ability to machine complex structures in metallic materials, regardless of their hardness, high strength, or heat-resistant [5]. Researchers have already initiated the research in electrochemical micromachining. Recently, a significant breakthrough in micro ECM was presented by Ryu (2009) and micro ECM has been a key subject to the related researchers. Using environmentally friendly electrolyte of citric acid, they have made micro holes of 60μm in diameter with the depth of 50μm and 90μm in diameter with the depth of 100μm. Bao Huaqian et al. (2008) machined trilateral and square cavities and holes as well as a group of English alphabets on a stainless steel plate using pure water as an electrolyte. Ye Yang et al. (2011) have fabricated micro pins and micro holes using everyday mineral water as an electrolyte. Sharma et al. (2002) machined holes in inconel super alloy that is used for turbine blades with acidified neutral salt electrolyte to minimize sludge formation in the Inter Electrode Gap (IEG). They obtained a good and uniform hole with an aspect ratio of 11. Lee et al. (2002) have applied two electrolytes, aqueous sodium nitrate and aqueous sodium chloride. The study reveals that the former electrolyte has better machinability than the latter. Mithu et al. (2011) have used less toxic and dilute electrolyte, 0.2 M HCl for microholes fabrication. The acidic electrolyte allowed refreshing electrolyte in the machining area easily, due to the reason that acid electrolyte usually
produced by-product much less than common salt electrolytes. Dhobe et al. (2011) have used sodium bromide electrolyte for machining of titanium, since simple chloride and nitrate electrolyte require higher potential difference to break down passive film. The use of sodium bromide improves the MRR and corrosion resistance.

It is apparent from the above discussion that electrolyte type is one of the factors which affect the machining rate and accuracy. Generally, salt electrolytes such as sodium chlorate (NaClO₃), sodium chloride (NaCl) and sodium nitrate (NaNO₃) are used in ECM and these electrolytes are known to produce a large amount of sludge as by-products [7]. The threat of sludge either restricting or clogging the flow of electrolyte limits the minimum diameter of the hole that can be drilled. This research aims to alleviate the problem of sludge formation by using acidified sodium nitrate as an electrolyte, so that the accuracy as well as the machining rate can be improved.

2. Proposed use of Acidified sodium nitrate

During ECM, there will be reactions occurring at the electrodes. For electrochemical micromachining of stainless steel, acidified sodium nitrate electrolyte is prepared by mixing 0.05 mol/L H₂SO₄ to the standard electrolyte (NaNO₃). The electrolyte and water undergoes ionic dissociation as shown below when potential difference is applied.

\[
NaNO₃ \leftrightarrow Na^+ + NO₃^- \quad (1)
\]

\[
H₂O \leftrightarrow H^+ + (OH)^- \quad (2)
\]

As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the work piece. Thus the hydrogen ions will take away electrons from the cathode (tool) and liberates hydrogen gas.

\[
2H^+ + 2e^- = H₂ \quad (3)
\]

Similarly, the iron atoms will come out of the anode (work piece) as:

\[
Fe = Fe^{++} + 2e^- \quad (4)
\]

Within the electrolyte, iron ions would combine with nitrate ions and hydrogen sulphate to form iron nitrate and iron hydrogen sulphate.

\[
NaNO₃ + H₂SO₄ \rightarrow HNO₃ + Na^+HSO₄^- \quad (5)
\]

The displacement reaction of sulphuric acid dissolve the salts of HNO₃ in this manner the work piece gets gradually machined. The addition of sulphuric acid to standard electrolyte solubilises the by-products which are not reduced in quantity but they are rendered soluble rather than insoluble.

3. Experimental setup

A photograph of the experimental setup is shown in Figure 1. It consists of one program-controlled Z axis, electrolyte tank and flow unit, a pulsed power supply source and controller for machining, and tool (cathode) and workpiece (anode) fixtures. The positions of cathode can be adjusted by giving appropriate signals to stepper motors with the help of a microcontroller. The minimum movement of the three stepper motor is 2μm per step. Desired interelectrode gap (IEG) is maintained by giving feed to the motor by Z-axis controller. A perspex electrolyte container with filter and pump is mounted on the machine base.

Experiments were carried out on the developed EMM system to demonstrate the influence of the major process parameters, such as machining voltage, pulse on time and electrolyte concentration on machining rate and overcut. Experimental results are plotted to show the influence of different process parameters on machining rate and overcut. Experiments of EMM on a stainless plate with the thickness of 200 μm were carried out with 160 μm conical tip shape tool electrode. Sodium nitrate (NaNO₃) and Acidified sodium nitrate (0.05mole of H₂SO₄ +NaNO₃) of varying concentration is used as the electrolyte. The power supply with constant pulse frequency of 50 Hz is considered for the experiments. The time taken for through hole machining is considered
for calculating the Machining Rate (MR). The machined hole diameter is measured using the optical microscope. The digital micrometer is used to measure the electrode diameter for calculating the Overcut (OC). Each experiment is repeated twice.

4. Results and Discussion

4.1. Effect of Machining Voltage on Machining Rate and Overcut

Figure 2 shows the relationship between the machining voltage, machining rate and overcut for sodium nitrate electrolyte and acidified sodium nitrate electrolyte. In general, the machining rate and overcut increases with machining voltage. With increase in machining voltage, current density increases. Faraday’s law states that the material removal rate is proportional to the machining current. When sodium nitrate is used as an electrolyte they produce large amount of sludge as by-products. These by products hinder the normal dissolution of material from the workpiece and results in lower machining rate. Compared to sodium nitrate the acidified sodium nitrate electrolyte usually produces much less by-product, which is important for a steady machining process in such a small IEG gap resulting in higher machining rate. The machining rate is found to be linear for the voltage range of 7-9V. This may again be attributed to the use of acidified sodium nitrate electrolyte that produces less by-products.

From the figure 2 it’s evident that overcut for acidified electrolyte is found to be lesser compared to sodium nitrate electrolyte.

![Figure 4](image4.png)

**Figure 4. Effect of Pulse on time on Machining Rate and Overcut**

In general the machining rate and overcut increases with pulse on time. Increase in pulse on time implies that more time has been allowed to machine the workpiece for a set duration, because only during pulse on time material removal takes place. Normally, the dissolution efficiency does not rapidly increase at higher pulse on time due to the generation of larger by products that reduce the material removed. However, it has been observed that the dissolution efficiency is higher when acidified sodium nitrate electrolyte is used. The use of acidified electrolyte prevents the formation of precipitates that clog or restrict the electrolyte flow path. Figure 4 shows that machining rate increase rapidly at the range of pulse on time 15-17.5ms. The lesser sludge formation and proper flushing of dissolution products enhances the machinability of the workpiece, hence machining rate increases.

It is clear from the SEM micrograph of the machined hole that the overcut for acidified sodium nitrate electrolyte is lesser compared to the NaNO₃ electrolyte.
range of 15-17.5 ms, overcut increases rapidly for sodium nitrate electrolyte and this may be attributed to the generation of microsparks and non localization effect of current due to the sludge formation.

4.3 Effect of Electrolyte Concentration on Machining Rate and Overcut

Figure 5 shows the effect of electrolyte concentration on machining rate and overcut. As the concentration of the electrolyte increases the number of ions associated in the machining process increases, resulting in higher machining rate. The MR for acidified sodium nitrate is higher compared to sodium nitrate. The dissolution rate at higher concentration i.e, 20-25 mole/l for sodium nitrate electrolyte is less compared to acidified sodium nitrate electrolyte. At higher concentration, the larger numbers of ions are involved in the machining process and lesser sludge formations aid the rapid dissolution efficiency. On comparing overcut the acidified sodium nitrate electrolyte produces lesser overcut. The overcut is linear at high electrolyte concentration in the range of (20-25 mole/l). The reason is that the lesser sludge formation reduces the occurrence of short circuit between the tool and the workpiece. The reduction of short circuit reduces the microspark. This effect in turn reduces the overcut.

5. Conclusion

The influence of the machining voltage, pulse on time and electrolyte concentration on the machining rate and overcut for the different electrolyte type like sodium nitrate and acidified sodium electrolyte have been investigated experimentally. Based on the studies conducted, the following conclusions are made:

1. The machining rate and overcut are significantly influenced by the electrolyte type.
2. The acidified electrolyte is found to produce higher machining rate and lower overcut compared to sodium nitrate electrolyte.
3. The dissolution rate is higher for acidified sodium nitrate compared to sodium nitrate electrolyte at higher pulse on time i.e, 15-17.5 ms. The overcut gradually increases with pulse on time
4. The dissolution rate for sodium nitrate electrolyte at higher concentration i.e 20-25 mole/1 is less compared to acidified sodium nitrate electrolyte. The overcut is linear at higher electrolyte concentration.
5. Based on the conducted studies, when accurate micro holes need to be produced on 304 Stainless Steel, acidified sodium nitrate electrolyte is recommended because of their higher machining rate and lesser overcut.

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6. Reference


