EVALUATION OF MICRO DRY WIRE EDM OF STAINLESS STEEL ON KERF ACCURACY

BY

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ABSTRACT

Micro dry wire EDM (µDWEDM) is a process where gas is used as the dielectric fluid instead of a liquid. In this process certain modifications of wire EDM (WEDM) are needed during the machining operation to achieve stable machining. Smooth and stable machining operation as well as the kerf variation in µDWEDM process remains as critical issues. Thus, the objectives of this research are to establish a stable µDWEDM process and to develop kerf mathematical model. The investigation was performed on a stainless steel (SS304) with a tungsten wire as the electrode using integrated multi process machine tool, DT 110 (Mikrotools Inc., Singapore). This research consists of two main parts which are the process parameters selection and the mathematical modelling of kerf in µDWEDM. For the process parameters selection, types of dielectric fluid, dielectric fluid pressure, polarity, threshold voltage, wire tension, wire feed rate, wire speed, gap voltage, and capacitance were the controlled parameters. The experimentation method used in this part was a conventional experimental method, one-factor-at-a-time (OFAT). The machining length of the microchannels were measured using scanning electron microscope (SEM). Stable and smooth machining operation of µDWEDM was found to be with compressed air as the dielectric fluid, workpiece positive polarity, 24% threshold voltage, 0.0809 N wire tension, 0.2 µm/sec wire feed rate, and 0.6 rpm wire speed. The best conditions in this part were proposed as the fixed parameters while the capacitance and gap voltage as the controlled parameters for the kerf investigation. For mathematical modelling of kerf, statistical analysis based on the response surface methodology (RSM) was employed. RSM employed consists of two main designs which were first-order design; Plackett-Burman design; and second-order design; central composite design (CCD). Plackett-Burman design was utilized in order to check the validity of the process parameter selection results. The validation results showed that the proposed parameters; capacitance (10.00-0.10 nF) and gap voltage (80-110 V); were the variables that should be used as the controlled parameters for kerf investigation in µDWEDM using CCD. The results were obtained by measuring the kerf using SEM. The first-order design and the second-order design were analysed using ANOVA. The investigation of kerf was divided into two responses which were upper kerf and bottom kerf. Empirical models were developed for both of the responses. Both parameters; capacitance and gap voltage have high influence on both of the responses. The optimum parameters for both minimum upper and bottom kerf were found to be 0.1 nF capacitance, 91 V gap voltage, compressed air dielectric fluid, 0.0345 MPa dielectric fluid pressure, workpiece positive polarity, 24% threshold voltage, 0.0809 N wire tension, 0.2 µm/sec wire feed rate, and 0.6 rpm wire speed. The developed models are found to be adequate since the percentage error were relatively small (< 3%). The main innovative contribution of this research is the identification of process parameters together with their level for stable machining and formulation of mathematical model for optimum kerf.

خلاصة البحث

السلك الصغير الجاف EDM(µDWEDM) هو عملية يتم فيها استخدام الغاز كمائع عازل للكهرباء بدلاً من السائل. في هذه العملية ، هناك احتياج إلى إجراء تعديلات معينة على السلك EDM (µDWEDM) أثناء تشغيل الآلة لتحقيق عملية تشغيل مستقرة. لا تزال سَلاسة واستقرار عملية التشغيل - بالإضافة إلى تباين الkerf في عملية WDWEDM - تمثل مشكلات حرجة. وبالتالي ، فإن أهداف هذا البحث تتضمن إنشاء عملية µDWEDM مستقرة وكذلك تطوير نموذج حسابي للkerf. تم إجراء التحقيق على فولاذ لا يصدأ (SS304) بسلك تنجستن كي يعمل الكترود يًستخدم كأداة متكاملة ومتعددة العمليات، DT 110، (شركة مايكروتول بنسغافورة) .يتكون هذا البحث من جزئين رئيسيين وهي عملية اختيار العوامل والنمذجة الحسابية للkerf في µDWEDM. بالنسبة لعملية اختيار العوامل المتحكم فيها، فقد شملت العوامل الآتية: أنواع السوائل العازلة للكهرباء ، وضغط الموائع العازلة للكهرباء ، والتقاطب ، والجهد الكهربائي للعتبة ، وشد السلك ، ومعدل تغذية الأسلاك ، وسرعة الأسلاك ، وفجوة الجهد ، والسعة. الطريقة المستخدمة في هذا الجزء هي طريقة الإختبار التقليدية ، وهي عامل واحد في وقت (OFAT). تم قياس طول التشغيل الآلي للقنوات الصغيرة باستخدام المجهر الإلكتروني الماسح (SEM). تم العثور على تشغيل ميكانيكي مستقر وسلس للµDWEDM ليكون مع الهواء المضغوط كالسائل العازل للكهرباء وتقاطب إيجابية العمل ، والجهد الكهربائي للعتبة والذي يبلغ 24 ٪ ، وشد السلك الذي يبلغ 0.0809 نيوتن ، ومعدل تغذية الأسلاك والذي يبلغ 0.2 ميكرون / ثانية ، وسرعة السلك 0.6 دورة في الدقيقة. في هذا الجزء، تم اقتراح أفضل الظروف كعوامل ثابتة، في حين أن السعة والجهد الكهربائي للفجوة كانا العاملين المتحكم فيهم لتحقيق الkerf. أما بالنسبة للنمذجة الحسابية للkerf ، تم استخدام التحليل الإحصائي بال response surface methodology (RSM) والتي تتكون من تصميمين رئيسيين وهما تصميمان من الدرجة الأولى. تصميم بلاكيت بورمان (Plackett-Burman) وهو تصميم من الدرجة الثانية، و central composite design (CCD). تم استخدام تصميم بلاكيت بورمان للتحقق من صحة نتائج عملية اختيار العوامل. وأظهرت نتائج التحقق من صحة أن العوامل المقترحة وهي السعة (0.10-10.00 nF) وفجوة الجهد (80-110 فولت) كانت المتغيرات التي ينبغي استخدامها كعوامل متحكم بها لتحقيق الkerf في µDWEDM باستخدام CCD. تم الحصول على النتائج عن طريق قياس الkerf

باستخدام SEM. تم تحليل التصميم ذو الدرجة الأولى والتصميم ذو الدرجة الثانية باستخدام ANOVA، وتم تقسيم التحقيق في kerf إلى استجابتين وهما الkerf العلوي و السفلي. تم تطوير نماذج تجريبية لكل من الاستجاباتين. عامِليّ السعة وفجوة الجهد الكهربائي أظهرا تأثير كبير على كل من الإستجابات. تم العثور على العوامل المِثلى لكل من الحد الأدنى من الkerf العلوي والسفلي لتكون السعة 0.1 nF ، وفجوة الجهد الكهربائي بقوة 91 فولت ، سائل عازل للكهرباء بهواء مضغوط ، ضغط سائل عازل كهربائي 0.0345 ميجا باسكال ، قطبية إيجابية للعمل ، وجهد كهربائي للعتبة 24٪ ، شد سلكي يبلغ 0.0809 N / ثانية، ومعدل تغذية الأسلاك يبلغ 0.2 ميكروميتر في الثانية ، وسرعة الأسلاك والتي تبلغ 0.6 دورة في الدقيقة. تم التوصل إلى أن النماذج المقترحة مَقبولة لأن نسبة الخطأ كانت صغيرة نسبيًا (أقل من 3٪). تُعد المساهمة المبتكرة الرئيسية لهذا البحث هي تحديد معايير العوامل و مستواها من أجل تشغيل مستقر وصياغة نموذج حسابي لkerf أفضل.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

AC	Alternating Current
ANFIS	Neuro-Fuzzy Inference system
ANOVA	Analysis of Variance
AWJW	Abrasive Water Jet Machining
C	Carbon
CH_4	Methane
CO	Carbon Monoxide
Cr	Chromium
DC	Direct Current
DEDM	Dry Electrical Discharge Machining
DOE	Design of Experiment
DWEDM	Dry Wire Electrical Discharge Machining
EBM	Electron Beam Machining
ECM	Electro Chemical Machining
EDM	Electrical Discharge Machining
FET	Field Effect Transistor
HAVA	Hot Anode Vacuum Arcs
HAZ	Heat Affected Zone
LAM	Laser Assisted Machining
Mn	Manganese
MRR	Material Removal Rate
N	Nitrogen
Ni	Nickel
OFAT	One-Factor-at-A-Time
P	Phosphorus
Ra	Surface Finish
RC	Resistance Capacitance
RSM	Response Surface Methodology
S	Sulfur
SEM	Scanning Electron Microscope
Si	Silicon
SS304	Stainless Steel Grade 304
USM	Ultrasonic Machining
W	Tungsten
WEDM	Wire Electrical Discharge Machining
WJM	Water Jet Machining
µDEDM	Micro Dry Electrical Discharge Machining
µDWEDM	Micro Dry Wire Electrical Discharge Machining
µED	Micro Electrical Discharge

µEDM	Micro Electrical Discharge Machining
µWED	Micro Wire Electrical Discharge
µWEDM	Micro Wire Electrical Discharge Machining

LIST OF SYMBOLS

μ	Micro
Ø	Diameter
E	Discharge energy
C	Capacitance of the circuit
C_p	Lumped parasitic capacitance present in parallel to C
V	Voltage
V_b	Breakdown voltage
d	Gap distance between two electrodes
δ	Gas density
f	Uniformity coefficient
r	Radius
E_0	Limited field strength under weakly nonuniform electric field
γ	Townsend’s second ionization coefficient
α	Townsend’s first ionization coefficient
p	Gas pressure
a	Constant depend upon gas composition
b	Constant depend upon gas composition
j_{FN}	Field emission current density
A_{FN}	Constants
B_{FN}	Constants
β	Field enhancement cause by the surface irregularities
γ_{eff}	Effective secondary electron emission coefficient
K	Constant
D	Constant
B	Kerf
A	Distance of the maximum amplitude for the lateral vibration of the wire
i	Current
R	Resistance
y	Response
f	Function
k	Number of parameters
ϵ	Experimental errors
x	Value of the factors
β_0	Constant
β_i	Linear
β_j	Interaction
β_{ij}	Quadratic end coefficient

n	Number of experiments
l	Machining length
d_0	Breakdown distance between the wire electrode and the workpiece
c	Capacitance
v	Gap voltage

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Electrical discharge machining (EDM) process, a non-contact machining process is also known for its capability in machining hard and brittle conductive materials regardless of their hardness (Abbas et al., 2007; Liao et al., 2005; Yoo et al., 2014; Hoang and Yang, 2013, 2015; Debroy and Chakraborty, 2013; Yan, 2010). EDM is thermal machining where the material from the workpiece is removed by the thermal energy created by the electrical spark (Hoang and Yang, 2015; Pour et al., 2014, 2014a). A series of electrical sparks or discharges occur rapidly in a short span of time within a constant spark gap between the micro sized tool electrode and the workpiece material. In this process, the tool and the workpiece both are adequately immersed in a dielectric medium, such as, kerosene, deionised water or any other suitable fluid (Hoang and Yang, 2015; Chow et al., 2008; Chen et al., 2009).

Some of the variations of EDM process that can be altered for micro fabrication are micro EDM (µEDM), wire EDM (WEDM), and micro wire EDM (µWEDM) (Chakraborty et al., 2015; Di et al., 2009; Ali et al., 2010; Hoang and Yang 2013). WEDM and µWEDM operation have very similar material removal mechanism as the EDM process aside the fact that the former uses winding wire as an electrode (Hoang and Yang, 2015; Debroy and Chakraborty, 2013; Azhiri et al., 2014). These processes have the ability to cut intricate shapes and tapered geometries with high precision, efficiency, and stability (Hoang and Yang, 2015; Chen et al., 2015; Patil and Waghmare, 2014; Conde et al., 2018). In the following subsections;

dry EDM, kerf, and mathematical modelling which are the main focus of this research are briefly discussed.

1.1.1 Dry EDM

In EDM process, dielectric fluid plays an important role in order to flush away the debris from the machining gap. In addition, the dielectric fluid also helps to improve the efficiency of the machining operation as well as improving the quality of the machined parts. Commonly used dielectric fluids are mineral oil-based liquid or hydrocarbon oils which have the tendency to cause fire hazard and environmental problems such as the production of very toxic and non-recyclable dielectric wastes and fumes that may cause health hazard to the users (Azhiri et al., 2014; Pandey and Singh, 2010; Kunieda and Furudate, 2001; Pradeep and Dani, 2015; Dhakar and Dvivedi, 2016; Zhang et al., 2004; Banu and Ali, 2016).

In order to overcome these problems, researchers have introduced dry EDM (DEDM) (Hoang and Yang, 2013, 2015; Azhiri et al., 2014; Khatri et al., 2016; Wang et al., 2012). It is a green machining method where the electrode used is in a pipe form and gas or air flows through the pipe electrode. The air act as a replacement of liquid dielectric fluid in which it removes the debris from the gap and cools the machining surface (Mahendran and Ramasamy, 2010; Fujiki et al., 2011; Besliu et al., 2010; Paul et al., 2013; Skrabalak and Kozak, 2010). This dry technique can be applied in micro machining which include dry wire EDM (DWEDM), micro dry EDM (µDEDM), and micro dry wire EDM (µDWEDM) (Skrabalak and Kozak, 2010; Yu et al., 2005; Hoang and Yang, 2013, 2015; Azhiri et al., 2014; Wang et al., 2012).

DWEDM is a modified WEDM process where gas dielectric is used instead of liquid dielectric fluid. The high-pressured flow of gas helps to remove the debris and