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MODELLING AND OPTIMIZATION OF NANO POWDER MIXED MICRO WEDM PROCESS USING ARTIFICIAL NEURAL NETWORKS AND GENETIC ALGORITHM

BY

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ABSTRACT

Micro Wire Electro Discharge Machining (µ -WEDM) is a non-conventional machining process which is used for machining complex structural design and achieving net-shape machining. This machining method is mainly used for conductive materials. However, semiconductor materials like Silicon (Si) can not be effectively machined due to its high resistivity. For this requires some advanced technique to enhance the machining process and efficiency. One technique could be the conductive coating on the workpiece material and use of nano powder mixed dielectric fluid. So far not much research has been conducted to machine Si like materials by using nano powder mixed dielectric fluid. Moreover, there is no intelligent system available that can help the users to select optimal parameters to achieve specific machining goal. One aim at this study is to carry out nano powder assisted micro WEDM for temporarily coated Silicon samples to achieve improved surface finish with more machining efficiency. For this purpose, three different type of nano powders like Aluminium(Al), Silicon (Si) and Graphite (C) were used for machining highly doped Silicon workpiece material to observe the effect of nano powders on the machining process. Before machining the workpiece material (Si) was coated temporarily by a highly conductive material like gold (Au) metal to make the workpiece more conductive during the machining process. The research showed that by using nano powder mixed µ-WEDM process, Material Removal Rate (MRR) was improved by almost ~48% than traditional machining process. However, Spark Gap (SG) was also increased by ~28% for nano powder assisted WEDM as compared to dielectric EDM oil used machining. Further, Al powder mixed WEDM process have resulted higher MRR but less SG than any other powder. It was found that at specific condition (at 80V,13 pF, 0.2g/L powder concentration, 320 nm gold thickness) the Al nano powder mixed dielectric used machining can produce the lowest surface roughness as 26 nm. It was also observed that at lower powder concentration and specific parametric conditions C, Al can easily produce nano range surface roughness where Si powder produces comparatively worse surface roughness than other powders. Therefore, it can be concluded that average surface roughness (ASR) can be improved by maximum ~65% for nano powder assisted machining as compared to conventional WEDM. Another main purpose of this research is to establish an intelligent system that can suggest suitable parameters for nano powder assisted µ-WEDM operation (for Si machining) to achieve certain machining goal. The experimental datasets of this study are used carefully to create a successful predictive model using artificial neural network (ANN). On the basis of the established predictive model, some experiments have been further conducted to assess the validity of the model. Then ANN model has been further optimized by using genetic algorithm (GA) to get required input for optimum output results. Finally, the accuracy of the modelling has been calculated by measuring the error percentage which is less than 5-10% for the model. This infers the modelling efficiency up to 90%.

خلاصة البحث

التصنيع الآلي بالتفريغ الكهربائي وباستخدام السلك الميكروي (µ -WEDM) هو عملية غير تقليدية للتصنيع الآلي والتي تستخدم تصنيعاً ذو تصميم هيكلي معقد لتحقيق تصنيع آلي صافي الشكل. تستخدم هذه الطريقة بشكل أساسي للتصنيع الآلي في المواد الناقلة .ومع ذلك فإن المواد النصف ناقلة كالسيليكون لا يمكن تصنيعها آلياً بشكل فعال بسبب مقاومتها العالية. لذلك فهي تحتاج بعض التقنيات المتطورة لتحسين عملية التصنيع الآلي و تحسين الفعالية. إحدى هذه التقنيات هي تأمين غطاء ناقل لمادة القطع المشغولة واستخدام سائل عازل ممزوج مع المسحوق النانوي. وحتى الآن لم يتم إجراء الكثير من البحوث لتصنيع المواد المشابهة للسيليكون (Si) باستخدام السائل العازل الممزوج مع المسحوق النانوي ، وفوق ذلك ، لا يتوفر نظام ذكي يستطيع مساعدة المستخدمين لتحديد العوامل المتغيرة المثالية لتحقيق الهدف المخصص للتصنيع. أحد الأهداف الأساسية لهذه الدراسة هو إجراء التصنيع الآلي بالتفريغ الكهربائي وباستخدام السلك الميكروي وبمساعدة المسحوق النانوي على عينات السيليكون المطلي بشكل مؤقت لتحسين صقل الأسطح مع زيادة الفعالية .ولتحقيق هذا الغرض ، تم استخدام ثلاثة أنواع مختلفة من المساحيق النانوية كالألمنيوم (Al) ، والسيليكون (Si) والجرافيت (C) لتصنيع مواد القطع المشغولة و المعالجة بشكل كبير بمادة السيليكون ولمراقبة تأثير تلك المساحيق النانوية على عملية التصنيع. تم تغليف مادة القطع (السيليكون) قبل التصنيع مؤقتاً بمادة عالية الناقلية كمعدن الذهب (Au) لجعل القطع أكثرناقلية خلال عملية التصنيع. يعرض هذا البحث ذلك باستخدام التصنيع الآلي بالتفريغ الكهربائي وباستخدام السلك الميكروي وبمزج المسحوق النانوي. تم تحسين معدل إزالة المادة MRR بمقدار تقريبي 48% مقارنة بطرق التصنيع التقليدية، ومع ذلك فإن Spark Gap (SG) زادت بحوالي 28٪ بوجود المسحوق النانوي بالمقارنة مع وجود الزيت العازل. بالإضافة إلى ذلك، عملية مزج مسحوق الألمنيوم في التصنيع الآلي بالتفريغ الكهربائي وباستخدام السلك أدت إلى أزيادة ال MRR ونقصان ال SG بالمقارنة مع المساحيق الأخرى. كما تم اثبات أن العازل الممزوج بمسحوق الألمنيوم النانوي في عملية التصنيع وفي شروط خاصة (80V، 13 pF، تركيزالمسحوق 0.2g/L ، سماكة الذهب 320 nm) يؤدي إلى انقاص خشونة السطح ل 26 nm . كما وجد أن المسحوق ذو التركيز الأقل وذو الشروط الخاصة لقيم العوامل المتغيرة كالجرافيت و الألمنيوم يمكن أن ينتج بسهولة معدل خشونة سطح بمجال نانوي. في حين أن مسحوق الـ Si ينتج معدل خشونة سطح أسوأ مقارنة بالمساحيق الأخرى. وفي الخلاصة يمكن إستنتاج أن متوسط خشونة السطح يمكن تحسينها بحد أقصى يصل إلى 65% تقريباً باستخدام المسحوق النانوي المساعد في عملية التصنيع مقارنة بالطرق التقليدية. والهدف الرئيسي الآخر من هذا البحث هو انشاء نظام ذكي يستطيع اقتراح عوامل متغيرة لعملية µ-WEDM المدعومة بالمسحوق النانوي (التصنيع الآلي للسيليكون) من أجل تحقيق الهدف المحدد للتصنيع. تم استخدام بيانات التجارب في هذه الدراسة بدقة لإيجاد نموذج تنبؤي ناجح باستخدام الشبكة العصبية الاصطناعية (ANN) . بالاعتماد على هذا النموذج التنبؤي المنشأ ، أجريت بعض التجارب الإضافية لتقييم صلاحية هذا النموذج. بعد ذلك تمّت أمثلة نموذج الشبكة العصبية الإصطناعية بإستخدام الخوارزمية الجينية (GA) لتأمين المدخلات المطلوبة للحصول على نتائج مخرجات مثالية. وفي النهاية، تم حساب دقة النمذجة عن طريق قياس نسبة الخطأ والتي كانت أقل من (5-10)% للنموذج. وهذا يدل على أن كفاءة النموذج يمكن أن تصل الى 90%.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechatronics Engineering).

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DECLARATION

I hereby declare that this dissertation 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 SYMBOLS

Al	Aluminum
Au	Gold
Ar	Argon
Al_2O_3	Aluminum oxide
C	Carbon
Cr	Chromium
C	Capacitance
Cu	Copper
E	Energy
F	Farad
Ge	Germanium
g/cm^3	Gram per centimeter cube
g/mL	Gram per millileter
g/L	Gram per Liter
I_p	Pulse current
min	Minute
μm	Micro-meter
μJ	Micro Joule
μF	Micro-Farad
mm	Millimeter
MoS_2	Molybdenum disulfide
mA	Milliampere

mm^3/min	Millimeter cube per minute
mm/s	Millimeter per second
N	Newton
nF	Nano-Farad
nm	Nano-meter
nJ	Nano joule
nos/min	Number of short circuit per minute
Pa	Pascal
pF	Pico-Farad
R_a	Average surface roughness
R_{max}	Maximum surface roughness
Si	Silicon
SiC	Silicon Carbide
T_{on}	Pulse on time
T_{off}	Pulse off time
Ti	Titanium
TiC	Titanium Carbide
V	Voltage
+ve	Positive charge
–ve	Negative charge
Ώ-cm	Ohm centimeter
"	Inches

LIST OF ABBREVIATIONS

ABC	Artificial bee colony
AJM	Abrasive Jet Machining
ASR	Average Surface roughness
ANN	Artificial Neural Network
ANN-GA	Artificial neural network-Genetic algorithm
BPN/BPNN	Back propagation neural network
CNC	Computer numerical control
CT	Coating Thickness
CNT	Carbon nano tube
EDS	Electro discharge Spectroscopy
EDM	Electro discharge machining
EDX	Electro energy dispersive x-ray analysis
ECM	Electro-chemical Machining
EWR	Electrode wear rate
FESEM	Field Emission Scanning Electron Microscope
GA	Genetic Algorithm
i.e	(id est) that is
LMBP	Levenberg-Marquardt Back propagation algorithm
MEMS	Micro electro mechanical system
μ-EDM	Micro-electro discharge machining
μ-WEDM	Micro-wire electro discharge machining
μ-WEDG	Micro wire electro discharge grinding

MRR	Material removal rate
MSE	Mean square error
MLP	Multi-layer perceptron
NP	No powder
NPM	Nano powder mixed
NPMEDM	Nano powder mixed EDM
NPM µ-WEDM	Nano powder mixed µ-WEDM
PC	Powder concentration
PMEDM	Powder mixed EDM
RSM	Response surface methodology
RBFN	Radial basis function neural network
R^2	Correlation coefficient
SEM	Scanning Electron Microscopy
SR	Surface Roughness
SG	Spark Gap
SD	Standard Deviation
TWR	Tool wear ratio
USM	Ultrasonic Machining
WEDM	Wire electro discharge machining

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

In recent years, electrical discharge machining (EDM) and micro wire electrical discharge machining (µ-WEDM) have been considered as a potential machining technique to meet various industrial and diverse engineering requirements due to their excellent characteristics and advantages. The material eroding process of EDM and Micro WEDM are identical, however, their functional characteristics differ from each other. The µ-WEDM process is a well-established special type variant of conventional EDM process. In the µ-WEDM process, electrical discharges are generated between a flexible metallic wire and work-piece material to erode materials from the work-piece without causing direct contact between them (Ho, Newman, Rahimifard, & Allen, 2004).

This WEDM process is widely used to machine electrically conductive and semi-conductive materials like Silicon(Si), Germanium (Ge) owing to its physical nature and feasibilities. The Silicon is the most common engineering material in MEMS-based fabrication and electronic industry. Having excellent physical properties, polished silicon mirrors has large demands in sensors and optical industries as well. Takino et al. first introduced WEDM technology (Takino et al., 2004, 2005) which could be an effective way for various contours to fabricate the complex 2D or 3D shaped Silicon mirrors. However, Silicon has some physical properties like high surface resistance than bulk body resistance which makes it difficult to machine by the µ-WEDM process.

Therefore, machining of Silicon like materials is becoming very challenging and no more extensive works have been carried out in this prospect.

To overcome such challenges to machine Si like materials, many works have been carried out with different techniques to achieve the finest surface finish of Silicon work-piece with better machining stability. Reynaerts et al. (Reynaerts & Van Brussel, 1997) proposed the conductive polishing on the p-type Silicon as positive and electrode as negative and vice versa for n-type material in EDM operation to enhance the machining stability and accuracy. Song et al. (Song, Meeusen, Reynaerts, & Van Brussel, 2000) studied the consequences of µ-EDM on highly doped p-type Si wafer. Recently, Saleh et al. (Saleh, Rasheed, & Muthalif, 2015) experimented the influences of temporary Gold (Au) coating on Silicon wafer for micro-EDM and micro-WEDM treatment. It was found that at a very low discharge energy (~<451.25 nJ), the micro-WEDM of pure silicon was impossible without gold coating. Further, the machining stability by this temporary gold coating process was significantly improved.

The powder mixed EDM/WEDM is another approach to signify the machining stability and accuracy. In the last era, powder mixed EDM has drawn a lot of attention to the researchers because of its proficiencies to enhance process capabilities over traditional machining process (Kansal, Singh, & Kumar, 2007). It was found that powder assisted dielectric affects the spark gap along with the discharging process which influences the performance of the machining process significantly.

In recent years, Tan et al. (Tan, Yeo, & Tan, 2008) examined the effect of nano powder assisted machining by micro-EDM and found an improvement in the machined surface. In addition, Jahan et al. (M. Jahan, Anwar, Wong, & Rahman, 2009; M. P. Jahan, Rahman, & San Wong, 2011) showed that by using different concentrations of graphite nano powder mixed dielectric oil it could be possible to get surface roughness