PERFORMANCE EVALUATION OF WIRE ELECTRO-DISCHARGE MACHINING ON TUNGSTEN CARBIDE

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ESPECIALLY DEDICATED TO

My beloved husband

Md Fauzee Bin Mohamad

My supportive parents

Hj. Hassan Bin Hj. Sharif
Hjh. Juwita Binti Hj. Omar

My wonderful brothers and sisters

Asmalinda Binti Hj. Hassan
Mohd Khamsyari Bin Hj. Hassan
Irwan Bin Hj. Hassan
Syed Syafiq Bin Hj. Hassan
Muhammad Hafiz Bin Hj. Hassan
Nurul Hafizah Binti Hj. Hassan

And last but not least to all my relatives and my close friends

Thank you for all the prayers, courage, confident and trust that you all gave to me. May Allah bless all people that I love and it's my honor to share this happiness with my love ones.

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ABSTRACT

This thesis presents the machining of tungsten carbide (WC-15%Co) using wire electro-discharge machining (WEDM) with brass wire diameter of 0.2 mm used as the tool electrode. The main purpose of this study was to investigate the influenced of various parameters involved in WEDM on the machining characteristics, namely, surface roughness (Ra), sparking gap (Gap), cutting speed (CS), recast layer (RL) and microcracks after undergone WEDM process. The Full Factorial Design of Experiment (DOE) approach with two-level was used to formulate the experimental layout, to analyze the effect of each parameter on the machining characteristics and to predict the optimal setting for each WEDM parameters such as pulse on (ON), pulse off (OFF), peak current (IP) and servo voltage (SV). Confirmation tests were also conducted for the optimum conditions for each machining characteristics in order to verify and compare the results from the theoretical prediction using Design Expert software and experimental confirmation tests. In this investigation, the machining operation for tungsten carbide was performed using a Sodick linear motor WEDM series AQ537L. Meanwhile, for the measurement equipments; Mitutoyo Formtracer CS-5000 was used to measure the Ra, Zeiss Axiotech High Power Optical Microscope was used to measure the Gap and lastly, the thickness of recast layer and the presence of microcracks were examined using the Scanning Electron Microscope XL40. In general, results revealed that pulse on have appeared to be the significant effect to all responses investigated. Overall, the results from the confirmation tests showed that the percentage of performance was acceptable due to all the results obtained were within the allowable values which was less than 10% of margin error.

ABSTRAK

Kajian yang dijalankan ini adalah mengenai pemesinan WEDM terhadap bahan tungsten karbida (WC-15%Co) dengan menggunakan wayar tembaga yang berdiameter 0.2 mm sebagai elektrod. Tujuan utama kajian ini adalah untuk menyiasat kesan beberapa parameter yang terlibat dalam WEDM proses terhadap kriteria pemesinan seperti kekasaran permukaan (Ra), kelajuan pemotongan (CS), jarak percikan api (Gap), ketebalan lapisan tuangan semula (RL) dan rekahan kecil selepas menjalani pemesinan WEDM. Rekabentuk ujikaji dengan pendekatan *Full Factorial* dua tahap ini digunakan bagi merekabentuk ujikaji, menganalisis kesan setiap parameter terhadap kriteria pemesinan dan untuk menjangkakan penetapan yang optimal bagi setiap parameter WEDM seperti tempoh denyutan (ON), masa rehat (OFF), arus puncak (IP) dan voltan servo (SV). Ujikaji pengesahan juga telah dijalankan untuk setiap jangkaan parameter yang optimum, bagi tujuan pengesahan dan perbandingan keputusan di antara nilai ramalan teori menggunakan perisian *Design Expert* dengan nilai yang diperolehi dari ujikaji. Dalam kajian ini, pemesinan yang dijalankan ke atas tungsten karbida dilakukan menggunakan *Sodick linear motor WEDM series AQ537L.* Sementara itu, bagi peralatan pengukuran; *Mitutoyo Formtracer CS-5000* digunakan untuk mengukur Ra, *Zeiss Axiotech High Power Optical Misroscope* pula digunakan untuk mengukur Gap dan akhir sekali, ketebalan lapisan tuangan semula dan kewujudan rekahan kecil diperiksa menggunakan *Scanning Electron Microscope XL40*. Umumnya, keputusan yang diperolehi menunjukkan, tempoh denyutan memberikan kesan yang utama terhadap kesemua respon yang dikaji. Secara keseluruhan, keputusan pengesahan ujikaji menunjukkan bahawa kesemua peratusan ralat perbezaan yang diperolehi berada di dalam lingkungan nilai yang dibenarkan iaitu peratus ralat kurang daripada 10%.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Project

Electrical discharge machining, commonly known as EDM, is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and the workpiece. There are no physical cutting forces between the tool and the workpiece involved. EDM has proved valuable especially in the machining of super-tough, electrically conductive materials such as the new space-age alloys. It can be used to produce parts with intricate shape that is impossible when using conventional cutting tools.

This machining process is continually finding further applications in the metal machining industry. It is being used extensively in the plastic industry to produce cavities of almost any shape in metal moulds. Other applications are also included such as producing critical parts for aerospace, electronics and medical industries [1-2]. Although the application of EDM is limited to the machining of electrically conductive workpiece materials, the process has the capability to cut these materials regardless of their hardness or toughness.

In this research, tungsten carbide is chosen to be the work material. Tungsten carbide (WC-Co) is an important material for tool and dies mostly because of its high hardness, strength and wear resistance over a wide range of temperature. It has high specific strength and cannot be fabricated easily by conventional machining techniques. Literature reports indicated that EDM can be successfully applied to a single-phase ceramics, cermets and ceramic-matrix composites, as far as they exhibit an electrical resistivity lower than values between 100 and 300Ω.cm [3]. Since EDM has been shown to be a versatile method for machining difficult-to-work materials and suitable in conforming WC-Co cemented carbides, therefore EDM process is chosen as a method to machine tungsten carbide in this study.

Although many studies have been conducted on EDM of tungsten carbide [1-4], investigations on the surface integrity on the tungsten carbide are still lacking. Hence, this study was attempts to investigate the effect of wire EDM parameters on the surface integrity of tungsten carbide, namely the surface finish, thickness of recast layer and over-cut of the wire electrode. The main focus in this study is on micro-crack formation. The machining parameters are the input parameters of EDM process, namely voltage, peak current, pulse duration and interval time, which is believed have great influence to EDMed surface. Classical Design of Experiment (DOE) is used to investigate the effect of machining variables and to establish the relationship of certain responses.

1.2 Problem Statement

During the EDM process, both the workpiece and the tool undergo surface modification. Many researchers [5-14] have looked at the modification of steel workpieces, but few have examined the modification of the tungsten carbide materials. The plasticity of tungsten carbide is high and in comparison with steel, its modulus of elasticity is three times greater. Its hardness is greater than that of steel, even in very extreme conditions it does not make noticeable changes at high temperature [15].

However, the problem in machining tungsten carbide with WEDM is difficulty in achieving high accuracy and high productivity with minimum surface damage. This is due to large number of variables and uncertain nature of the process. Although most of WEDM equipment nowadays has advanced process control, selecting and maintaining optimal settings is still an extremely difficult job to do [1]. The lack of machinability data on the conventional as well as advanced materials, precise gap monitoring devices and an adaptive control strategy that accounts for the time-variant and stochastic nature of the process are the main obstacles toward achieving the ultimate goal of unmanned WEDM operation [16]. Former researchers claimed that during machining tungsten carbide, the microstructure of EDMed surface varies significantly under different peak current and pulse duration [17]. It is also reported that even for the cases where optimum surface conditions are achieved, EDM of tungsten carbide usually induces cracks and relevant residual stresses within a thermally affected zone (recast layer and adjacent regions) beneath the shaped surface [18]. Accordingly, about 70% of the punches used within dies for production of high quality are made of carbide (WC-Co) material [19]. These punches usually require high dimensional accuracy and excellent surface finish that is difficult to produce using WEDM process.

Therefore, there is a need to understand the important parameters that greatly influence surface integrity when machining tungsten carbide using WEDM. As such, it is the aim of this work to investigate the correlation between the EDM machining parameters and surface integrity including micro-cracks, recast layer and surface finish. In addition, the influence of machining parameters on the spark gap during WEDM process also will be observed. The Classical Design of Experiment (DOE) technique will be employed as the methodology since this approach is powerful in providing various information of machining process.

1.3 Objective

The objectives of this research are:

1. To evaluate the performance of WEDM on tungsten carbide (WC) with respect to various responses such as surface integrity of the machined surface, sparking gap and cutting speed.
2. To establish mathematical model for all responses involved which are sparking gap, recast layer, surface finish, cutting speed and microcracks of the tungsten carbide during WEDM.
3. Full factorial method from DOE used in order to analyze and determine global solutions for optimal cutting parameters of WEDM operation.

1.4 Scope

The scope of this research consists of:

1. Machining tungsten carbide (work material) with brass wire using WEDM machine.
2. Surface integrity to be investigated includes surface finish, micro-cracks and thickness of recast layer.
3. Parameters to be studied include voltage, peak current, pulse duration and interval time.
4. Scanning Electron Microscope (SEM) will be use to evaluate the micro-cracks presence and thickness of recast layer.
5. The Classical DOE and analysis of variance (ANOVA) method will be processed using Design Expert software version 6.0.8.

1.5 Expected Results

The expected result from this study is to obtain the optimum conditions in various situations in WEDM using brass wire for machining tungsten carbide. The detail results and discussions of the effect of machining parameters on the microstructure of the machined surface such as the presence of micro-cracks and the depth of recast layer, surface roughness and spark gap of brass wire will be provided. It was hoped that the findings could be used by industry practitioners to select the most suitable cutting parameter for tungsten carbide application to realize its economic potential to the fullest. It was expected that the mathematical models that were developed could help in predicting various responses such as surface roughness, recast layer, micro-crack and spark gap for any conditions within the scope of the study conducted by the author.