# EFFECT OF CHROMIUM (Cr) PARTICLE SIZE AND SPAN-20 SURFACTANT ON AISI D2 HARDENED STEEL USING ELECTRICAL DISCHARGE MACHINING

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*"This research is dedicated to my family especially to my mother, Maliah Shafie and my father, Jamil Hosni Bakar, and to my beloved husband, Mohd Zaini bin Azizan and my daughter, Nur Raisha Adeeba binti Mohd Zaini."*

*Thank you for the support, encouragement and prayer.*

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# ABSTRACT

Existing manufacturing industries are facing challenges from modern advanced materials such as composite, super alloys, and hardened steels, which are hard and difficult to machine and process. Since it is not suitable to use conventional machining of the hard material, non-conventional machining such as electrical discharge machining (EDM) is one of the ideal techniques in dealing with these materials. However, the limitations of EDM will cause lower productivity and poor surface quality. Therefore, Powder Mixed Electrical Discharge Machining (PMEDM) has emerged as one of the advanced and innovative technique to eliminate the some of the disadvantages of EDM method. The fine powder particles are added into the tank then the spark gap is filled up with these additives particles. These electrically conductive powder particles reduce the insulating strength of dielectric fluid and increase the spark gap distance between tool electrode and workpiece, which due to this EDM process becomes more stable, thereby improving the EDM efficiency and quality of the machined surface. This research emphasizes the machining of AISI D2 hardened steel with EDM through adding both of micro and nano chromium powder mixed and span-20 surfactant using copper tool electrode. Then, machining productivity (i.e material removal rate (MRR), electrode wear rate (EWR) and surface roughness (Ra) and surface characteristics were investigated in terms of surface morphology, surface topography, recast layer thickness (RL) and microhardness. It was indicated that the addition of micro-nano chromium powder and span-20 surfactant to the dielectric notably enhanced the machining efficiency and better surface quality. The highest improvement 35~46 % of MRR, 29~69 % of Ra and 42~54 % of RL were attained at combination of micro-nano chromium powder and span-20 surfactant, respectively. There is no significant effect on EWR. For this purpose, full factorial $3^2$ design of experiments (DOE) was chosen which consists of three levels of PMEDM parameters of chromium powder concentrations (Cp) and Span-20 surfactant concentrations (Cs) for both micro and nano chromium powder. Response Surface Methodology (RSM) was utilized for responses optimization and Central Composite Design (CCD) was applied in designing the experiments to evaluate the

effects of PMEDM parameters to three responses, MRR, EWR and Ra. Thus, this is clarify that the potential of addition of Cr powder and span-20 surfactant into dielectric fluid ability to gives a notable potential to be utilized as one of innovative technique, improving efficiency and better surface quality.

## ABSTRAK

Industri pembuatan sedia ada menghadapi cabaran dari bahan-bahan canggih ini. komposit, aloi super, dan keluli yang keras, yang sukar dan sukar untuk mesin. Oleh kerana tidak sesuai menggunakan pemesinan konvensional bahan keras, pemesinan bukan konvensional seperti Pemesinan discaj elektrik (EDM) adalah salah satu teknik yang ideal dalam menangani bahan-bahan ini. Walaubagaimanapun, kelemahan EDM akan menyebabkan produktiviti yang lebih rendah dan kualiti permukaan yang kurang baik. Oleh itu, Percampuran serbuk pemesinan discaj elektrik (PMEDM) telah muncul sebagai salah satu teknik maju dan inovatif untuk menghapuskan beberapa kelemahan kaedah EDM. Zarah serbuk halus dimasukkan ke dalam tangki maka jurang percikan diisi dengan zarah tambahan ini. Ini zarah serbuk konduktif elektrik mengurangkan kekuatan penebat cecair dielektrik dan meningkatkan jarak jurang percikan antara alat elektrod dan bahan kerja, yang disebabkan oleh proses EDM ini menjadi lebih stabil, dengan itu meningkatkan kecekapan dan kualiti EDM permukaan mesin. Penyelidikan ini menekankan pemesinan keluli AISI D2 yang keras dengan EDM dengan menambahkan kedua-dua serbuk kromium mikro dan nano campuran dan span-20 surfaktan menggunakan elektrod alat tembaga. Kemudian, produktiviti pemesinan (kadar penyingkiran bahan (MRR), kadar kehausan elektrod (EWR) dan kekasaran permukaan (Ra)) dan sifat permukaan disiasat dari segi permukaan morfologi, permukaan topografi, ketebalan lapisan recast (RL) dan mikrohardness. Ia telah menunjukkan bahawa penambahan serbuk kromium mikro-nano dan surfaktan span-20 ke dielektrik dengan ketara meningkatkan kecekapan pemesinan dan kualiti permukaan yang lebih baik. Peningkatan tertinggi MRR 35~46 %, Ra 29~69 % dan RL 42~54 % dicapai dengan kombinasi serbuk kromium mikro-nano dan span-20 surfaktan. Untuk tujuan ini, dipilih sepenuhnya faktorial $3^2$ reka bentuk eksperimen (DOE) yang terdiri daripada tiga tahap parameter PMEDM konsentrasi serbuk kromium (Cp) dan Span-20 konsentrasi surfaktan (Cs) untuk serbuk kromium mikro dan nano. *Response Surface Methodology* (RSM) telah digunakan untuk pengoptimuman respons dan Reka Bentuk Komposit Sentral (CCD) telah digunakan untuk merekabentuk eksperimen untuk

menilai kesan parameter PMEDM kepada tiga respon, MRR, EWR dan Ra. Oleh itu, ini menjelaskan bahawa potensi penambahan buburan Cr dan span-20 surfaktan ke dalam keupayaan cecair dielektrik untuk memberikan potensi yang ketara untuk digunakan sebagai teknik inovatif, meningkatkan kecekapan dan kualiti permukaan yang lebih baik.

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| | | |
|---|---|---|
| % | - | Percentage |
| μCr | - | Micro chromium powder |
| μs | - | Micro seconds |
| A | - | Amphere |
| AISI | - | American Iron and Steel Institute |
| Al | - | Aluminium |
| ANOVA | - | Analysis of variance |
| $a_p$ | - | Depth of cut |
| ASTM | - | American Society for Testing and Material |
| CCD | - | Central composite design |
| Cp | - | Powder concentrations |
| Cr | - | chromium |
| Cs | - | Surfactant concentrations |
| Cu | - | Copper |
| DOE | - | Design of experiments |
| EDAX | - | Energy dispersive X-ray spectroscopy |
| EDM | - | Electrical Discharge Machining |
| EWR | - | Electrode wear rate |
| FeSEM | - | Field Emission Scanning Electron Microscope |
| g/L | - | Gram/litre |
| $G_P$ | - | Gas explosive for no powder |
| $G_P$* | - | Gas explosive for adding powder |
| Gr | - | Graphite |
| HAZ | - | Heat Affected Zone |
| HP | - | Horse power |

| | | |
|---|---|---|
| HRC | - | Unit of hardness |
| HV | - | Unit of Vickers hardness tester |
| Ip | - | Peak current |
| kg | - | kilogram |
| MH | - | Microhardness |
| mm | - | Milimeter |
| MRR | - | Material removal rate |
| nCr | - | Nano chromium powder |
| $P_D$ | - | Powder density for no powder |
| $P_D$* | - | Powder density for adding powder |
| PMEDM | - | Powder Mixed Electrical Discharge Machining |
| PVC | - | Polyvinyl chloride |
| Ra | - | Surface roughness |
| RL | - | Recast layer |
| RSM | - | Response surface methodology |
| SEM | - | Scanning Electron Microscope |
| $S_G$ | - | Gap size for no powder |
| $S_G$* | - | Gap size for adding powder |
| Si | - | Silicon |
| SiC | - | Silicon carbide |
| Ton | - | Pulse on time |
| $\varepsilon_0$ | - | Permittivity in free space |
| $\varepsilon_r$ | - | Relative permittivity |

# CHAPTER 1

# INTRODUCTION

Machining hardened steel is currently receiving increasing attention to fulfill the requirement of industry in developing numerous applications due to its unique metallurgical properties. Hardened steel are not only harder, tougher, less heat sensitive and more resistant to corrosion but also more difficult-to-machine. During the last few years, numerous studies had been conducted to improve the machinability of this kind of materials and to explore and develop new techniques to minimize machining costs while maintaining the quality requirements of the machined parts. Electrical discharge machining (EDM), a thermal process, which involves the formation of a plasma channel between the tool and workpiece, is basically used to machine such difficult-to-machine and high strength and temperature resistant alloys. These materials are generally used in the die and mould making industries (Tai & Lu, 2009).

EDM process is widely accepted by the industries and a lot of research is undergoing for further improvement in this process. This technique has been developed in the late 1940's by the two Russian scientists, and till today, is still on the developing stage. The outstanding capabilities of this technique include the ability to machine high-hardness conductive materials and produce complex geometrical shapes, it involves a simple tool-making process and eliminates the mechanical stress and chatter phenomena. Despite the advantages, it has a low machining efficiency and poor surface quality limit EDM applications (Kansal et al., 2005). Adding powder to dielectric, namely powder mixed electrical discharge machining (PMEDM), is an innovative technique to eliminate the some of the disadvantages of conventional EDM method and enhanced EDM capability (Ho & Newman, 2003; Nanimina et al., 2014; Zhao et al., 2002).

In this process, various types of powders like aluminum, chromium, tungsten, graphite and copper etc. are mixed into the dielectric fluid (i.e. kerosene oil, transformer oil or EDM oil). The fine powder particles are added into the dielectric. These electrically conductive powder particles reduce the insulating strength of dielectric fluid and increase the spark gap distance between the tool electrode and workpiece, which due to this EDM process becomes more stable, thereby improving the EDM efficiency and quality of the machined surface. The EDM performance, tool-electrode life, and quality of the machined component depend greatly on the additive type, size, concentration, and properties. However, assessing the powder concentration uniformity and amount of debris after filtration and through the process is a problem, which caused powder agglomeration and deposition in the machining tank. In order to avoid powder aggregation and deposition, and to ensure homogeneous suspension of particles in the dielectric fluid, the addition of surfactant to powder mixed dielectric was proposed to increase powder homogeneity in the liquid to prevent powder deposition at the bottom of the tank.

## 1.1 Background of Study

PMEDM is a technique initially developed in the early eighties for achieving better performances compared to conventional EDM. Many researchers studied process performance characteristics such as surface finish and material removal rate in relation to process parameters. Figure 1.1 indicated the trend of the key research studies on PMEDM from the past years. Thirty-five years ago, Jeswani (1981) introduced the addition of impurities (Gr powder) to dielectric to enhance machining performance. In 1995, Ming and He (1995) observed that adding conductive and inorganic oxide particles to dielectric led to higher MRR, lower EWR and superior surface quality. The indistinct stage of this technology continued until 1998 when Wong et al. (1998) compared the utilization of various powder materials in dielectric. They explicitly disclosed the influence of powder properties on the performance parameters of EDM.

Their research revealed the great potential of adding powder to dielectric for machining performance improvement, which led to an increase in the number of research works on PMEDM in subsequent years. The cognition phase of PMEDM technology can be considered from 1998 to 2008. In this period, Gr, Al, Si or SiC were used as additives to improve EDM performance. Since 2008, PMEDM investigations have become even more attractive, because the cognition phase indicated that adding suitable powder to dielectric increases the dielectric's electrical conductivity and subsequently the spark frequency, which leads to superior machining characteristic. The increasing trend of PMEDM studies since 2008 is evident with a higher variety of powder materials employed and is expected to continue in the coming years. In addition, utilizing nano-size powder has recently become popular, since smaller particles seem to yield better performance in terms of higher MRR, lower EWR and better surface finish.

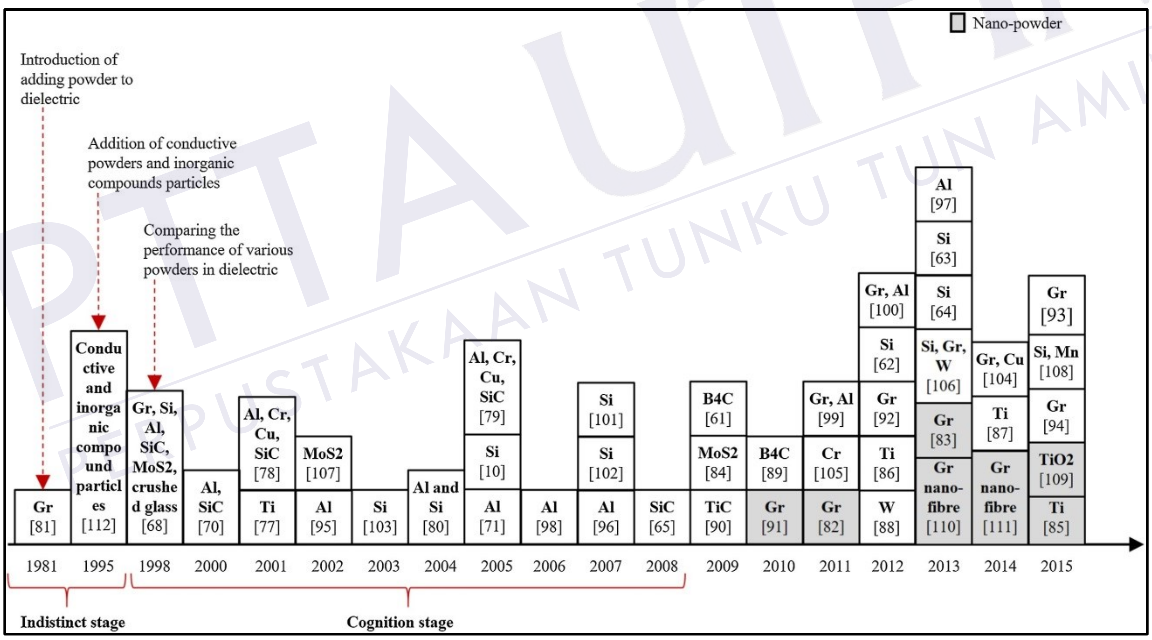


Figure 1.1: Distribution of collected research studies on PMEDM from 1982 to 2015 (Marashi et al., 2016).

A reasonably new development in this direction is to use some additive powders mixed in the dielectric fluid of EDM to obtain the requirement of minimum surface damage, increased machining rates, and enhance surface properties. This new hybrid machining process is called powder mixed electric discharge machining (PMEDM) process.

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