TRIBOLOGICAL PROPERTIES OF EDC COATED LAYER BY USING POWDER METALLURGY ELECTRODE

SAYIDAH NAFISAH BINTI HJ. AWANG

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SAYIDAH NAFISAH BINTI AWANG

A Thesis submitted
in fulfilment of the requirements for the master of
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DECLARATION

I declare that this master project entitled “Tribological Properties of EDC Coated Layer by Using Powder Metallurgy Electrode” is the result of my own research except as cited in the references. The master project has not been accepted for any degree and is not concurrently submittedin candidature of any other degree.

Signature :..

Name :..

Date :..

APPROVAL

I hereby declare that I have read this master project and in my opinion this master project is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Industrial Engineering)

Signature :...

Supervisor Name :...

Date :...

DEDICATION

This thesis is dedicated to my late father Hj.Awang bin Jusoh, whose wisdom and strength continue to guide me from beyond. Though you are no longer here, your teachings and love remain etched in my heart, driving me to strive for excellence in all that I do. I hope to make you proud. To my mother Hjh.Rosnah binti Seman, who has been my rock and my greatest supporter. Your boundless love, sacrifices, and unwavering faith in me have been the foundation upon which I have built my dreams. Thank you for always being there with a warm embrace and wise words of encouragement. To my loving husband Mohamad Amirudin bin Azman, whose steadfast support, patience, and love have been my anchor throughout this journey. Your faith in me and your encouragement have been instrumental in my success. Thank you for being my partner in every sense. To my two wonderful children Aara and Aariz, whose smiles and laughter bring joy to my life. You are my greatest motivation, and everything I do is for you. I hope this achievement inspires you to pursue your dreams with passion and dedication. To my siblings, who have shared in my joys and struggles. Your belief in my abilities has given me the courage to persevere. Each one of you has inspired me in your unique ways, and I am grateful for our bond that strengthens me. To my dear friends, who have been my companions on this academic journey. Your constant support, understanding, and camaraderie have been invaluable. The moments we shared, both challenging and joyful, have made this journey more meaningful and memorable. Thank you all for your love, support, and belief in me. This accomplished is as much yours as its time.

ABSTRACT

This research investigated the tribological properties of Electrical Discharge Coating (EDC) applied to mild steel using Powder Metallurgy (PM) copper electrodes. Different compaction pressures and sintering temperatures were tested to see how they affected the performance of the coating, focusing on the coefficient of friction (CoF), wear weight loss, wear scar depth, and coating layer thickness. Mild steel, a widely used industrial material, is prone to wear and corrosion, which limits its performance under severe operating conditions. The experimental setup involved using a Sodick AQ35L die-sinker EDM machine, with PM copper electrodes prepared at different compaction pressures (3, 4, and 5 tons) and sintering temperatures (450°C, 550°C, and 650°C). We conducted tribological tests using a micro pin- on-disc tribometer, maintaining a constant normal load and sliding speed. The combination results indicated that EDC coatings formed under higher sintering temperatures and optimal compaction pressures exhibited lower CoF and reduced wear scar depth compared to the uncoated mild steel substrate (P=4tons, T=550°C). The research concluded that EDC using PM copper electrodes could effectively enhance the wear resistance of mild steel, making it more suitable for applications in cutting tools, molds, and dies.

SIFAT TRIBOLOGI LAPISAN BERSALUT EDC MENGGUNAKAN ELEKTROD METALURGI SERBUK

ABSTRAK

Penyelidikan ini menyiasat sifat tribologi Salutan Pelepasan Elektrik (EDC) yang digunakan pada keluli lembut menggunakan elektrod tembaga Metalurgi Serbuk (PM). Pelbagai tekanan pemadatan dan suhu pensinteran diuji untuk melihat bagaimana ia mempengaruhi prestasi salutan, dengan fokus pada pekali geseran (CoF), kehilangan berat haus, kedalaman parut haus, dan ketebalan lapisan salutan. Keluli lembut, bahan industri yang digunakan secara meluas, terdedah kepada kehausan dan kakisan, yang mengehadkan prestasinya di bawah keadaan operasi yang teruk. Susunan eksperimen melibatkan penggunaan mesin EDM Sodick AQ35L die-sinker, dengan elektrod tembaga PM disediakan pada pelbagai tekanan pemadatan (3, 4, dan 5 tan) dan suhu pensinteran (450°C, 550°C, dan 650°C). Kami menjalankan ujian tribologi menggunakan mikro tribometer pin-on-disc, mengekalkan beban normal yang tetap dan kelajuan gelincir. Hasil kombinasi menunjukkan bahawa salutan EDC yang dibentuk di bawah suhu pensinteran yang lebih tinggi dan tekanan pemadatan yang optimum menunjukkan CoF yang lebih rendah dan kedalaman parut haus yang berkurangan berbanding dengan substrat keluli lembut yang tidak bersalut (P=4 tan, T=550°C). Penyelidikan ini menyimpulkan bahawa EDC menggunakan elektrod tembaga PMdapat meningkatkan rintangan haus keluli lembut dengan berkesan, menjadikannya lebih sesuai untuk aplikasi dalam alat pemotong, acuan, dan die.

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LIST OF ABBREVIATIONS

3D	-	Three dimensional
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of variance
ASTM	-	American Society for Testing and Materials
CoF	-	Coefficient of friction
Cu	-	Copper
DoE	-	Design of experiments
EDC	-	Electrical discharge coating
EDM	-	Electrical discharge machining
HV	-	Vickers Hardness
MPa	-	Megapascal
N	-	Newton
NiTi	-	Nickel-Titanium
PM	-	Powder metallurgy
RSM	-	Response surface methodology
SEM	-	Scanning electron microscope
TiC	-	Titanium Carbide
TWR	-	Tool wear rate
WC-Co	-	Tungsten Carbide-Cobalt

LIST OF SYMBOLS

ρ	-	Density
µ	-	Micro
°C	-	Degree celsius
F	-	Force
P	-	Pressure
V	-	Voltage

CHAPTER 1

INTRODUCTION

1.1 Research Background

Electro-discharge machining (EDM) is a spark erosion machining technology that removes metal through erosion generated by an electric spark. It is widely used for machining precise shapes in any material, regardless of hardness, provided it is an electrical conductor and cannot be machined conventionally. Die-sinking EDM has two major drawbacks: the formation of a brittle and fractured white layer on the surface over which the machining is done, and tool wear, which is generally carbide formed by the reaction between worn out electrode elements and carbon from dielectric material (Ranjan, 2014).

Electro-discharge coating (EDC) is a method that forms a white carbide layer on a workpiece after reversing the polarity and enhances numerous attributes of the workpiece. It improves the original material's hardness and abrasive wear resistance. EDC electrode materials must have basic features such as electrical and thermal conductivity, a high melting temperature, a low wear rate, and resistance to deformation during machining. Powder metallurgy (PM) compact, whether green or semi-sintered, can play a dynamic function as an EDM tool, supplying critical materials to the workpiece's surface (Kumaran & Muralidharan, 2023).

EDC is a coating technique in which a tool electrode manufactured by PM technique (powder compaction in power press at certain pressures) is used as anode and a workpiece (to be coated) is selected as cathode in EDM (polarity opposite to electrical discharge machining) and material is decomposed from the tool electrode and deposited over the work-piece surface in the presence of dielectric fluid. Among these coating processes, EDC has certain distinct advantages that distinguish it as a new coating technology. There is no requirement for a vacuum chamber or any other additional equipment with this coating procedure. Coating of various materials on various substrate materials can be accomplished using a simple EDM setup and appropriate parameter selection (Ranjan, 2014).

PM compact, which can be green or semi-sintered, is commonly used as an EDM tool in EDC to deposit needed materials on the surface of the workpiece. The qualities of PM tools can be ordered by altering the compaction pressure, sintering temperature, and constituent composition. PM electrodes were discovered to be more sensitive to fluctuations in pulse current and pulse duration, and their impact on output restrictions such as material removal rate and electrode wear was found tobe dissimilar to standard electrodes. The surface reliability of a work surface is altered by PM tools. The characteristics of PM tools can be modified by altering compaction pressure and sintering temperature. PM tool electrodes are used because they allow for larger discharge energies to be used with suspended powder particles, resulting in denser re-form layers and enhanced micro-cracking vulnerability (Kumaran & Muralidharan, 2023).

The mild steel to be used in this study is a soft material prone to rusting. Additionally, exposureto loads, pressures, and high temperatures during production makes it susceptible to wear and corrosion over time. Given that material hardness is crucial for resistance to wear from friction or erosion, this study aims to perform surface modification on mild steel using Electrical Discharge Coating (EDC) with Powder Metallurgy (PM) copper (Cu) electrodes at various compaction pressuresand sintering temperatures.

The investigation will focus on exploring the impact of compaction pressure and sintering temperature of PM electrodes on the coefficient of friction, wear weight loss, wear scar depth, and wear track morphology of the coating layer. These characteristics will be compared to the original surface of the mild steel substrate. It is anticipated that the coating layers formed by EDC with PM Cuelectrodes will exhibit superior wear resistance, which could offer advantages in the cutting tool, mold,and die sectors.

1.2 Problem Statement

Mild steel, a common material in industrial applications, is prone to wear and corrosion, which limits its performance when subjected to various operating conditions. The research of surface modification techniques is prompted by the requirement to improve wear resistance in mild steel components, which is critical for applications in cutting tools and manufacturing processes. The research focuses on overcoming this issue by combining EDC with PM electrodes, with a special emphasis on mild steel (Krastev, 2015).

Despite the potential advantages of EDC, the optimal combination of parameters, such as electrode material, compaction pressure, and sintering temperature, for achieving superior tribological properties remains unclear. This research aims to bridge this knowledge gap by investigating the tribological performance of EDC-coated layers on mild steel using PM Cu electrodes. The use of PM electrodes adds another level of complexity and variable to the coating process. Understanding the impact of parameters such as compaction pressure, and sintering temperature on the resulting tribological properties is critical for designing a complete approach for improving mild steel wear resistance.

The study aims to provide significant insights into the optimization of the EDC process for mild steel applications by methodically analyzing and measuring the influence of various parameters. The expected findings include identifying important variables controlling tribological performance, laying the groundwork for the production of more durable and reliable mild steel components in industrial environments. Addressing these issues is crucial for increasing mild steel's applicability and performance in tribologically challenging situations.

In this study, tribological tests will be conducted using a micro pin-on-disc tribometer, maintaining a constant normal load (10N) and sliding speed (5mm/s). The focus will be on assessing key tribological metrics, including the coefficient of friction, wear weight loss, wear scar depth, and wear track morphology. Comparative analyses will be performed between the coated surfaces and the original mild steel substrate. These evaluations aim to provide insights into the effectiveness of the EDC-PM Cu electrode process in enhancing wear resistance.

1.3 Research Objectives

The research objectives are outlined as follows:

i) To examine the influence of the compaction pressure of PM Cu electrode on the tribological properties of the EDC coating layer, including the coefficient of friction, wear weight loss, wear scar depth, and wear track morphology on mild steel.

ii) To investigate the impact of the sintering temperature and compaction pressure of PM Cu electrode on the tribological properties of the EDC coating layer, encompassing the coefficient of friction, wear weight loss, wear scar depth, and wear track morphology on mild steel.

1.4 Scope of Research

The main objective of this research is to modify the surface of mild steel by EDC with PM Cu electrode. The composition pressure and sintering temperature of PM Cu electrodes will be varied, and the EDC parameters will be kept constant throughout the process. The Sodick AQ35L EDM machine will be used in this research to conduct the EDC process. The materials selected for this research comprise a mild steel workpiece, a 6 mm copper electrode, and dielectric fluids. The tribological testing will be conducted using a small pin-on-disc tribometer, maintaining a constant normal load (10N) and sliding speed (5 mm/s). Subsequently, the tribological properties of the EDC coating layer, including the coefficient of friction, wear weight loss, wear scar depth, and wear track morphology, will be thoroughly investigated after the completion of the EDC process.

1.5 Significant of Study

In recent years, there has been increased interest in the EDC method because it can improve workpiece surface characteristics without requiring direct contact between the electrode and the workpiece (Jamaluddin, 2021). The EDC process is also able to be carried out without the need for any particular environmental conditions such as a vacuum or a clean room. It can be done at room temperature with a standard die-sinker EDM equipment. The importance of this research is to encourage the consideration of EDC processes with green PM electrodes.

1.6 Thesis Organization

This study's structure is separated into five chapters. The first chapter is about the introduction. This chapter clarifies the research's background, problem statement that describes the existing scenario or difficulty with mild steel qualities in the cutting tool, mold, and die business. Furthermore, Chapter 1 includes the purpose and scope. Chapter 2 contains a review of the literature. This chapter summarizes the relevant periodicals and books. Moreover, Chapter 3 meticulously outlines the methodology, including the technique, procedure, tools, and materials employed in the experiment. In Chapter 4, designated for result analysis and discussion, the presentation encompasses all acquired data and provides comprehensive explanations of the results. Ultimately, Chapter 5 summarizes the research's data analysis, results, and achievements.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a brief review of previous studies on the surface modification by EDC. Different types of EDC methods, EDC parameters, characteristics of coating and application of EDC process investigated by previous researchers were discussed in this chapter. Lastly, the review of mild steel, copper (Cu) powder metallurgy and design of experiment (DoE) were also provided at the end of this chapter.

2.1 Fundamentals of Electric Discharge Coating (EDC)

Electrical discharge coating (EDC), alternatively referred to as electrical discharge alloying (EDA), represents an extension of Electrical Discharge Machining (EDM) (Ahmed et al., 2021). It employs a die-sinker EDM to apply a coating layer onto the surface of the workpiece (Liew et al., 2020). The EDC process follows the sparking principle, which is a variation of the EDM process. This method is utilized to deposit a specific amount of material onto an irregular surface or intricate shape. EDC alters the workpiece surface to enhance its properties and performance, such as surface hardness, as well as resistance to wear and corrosion (Tyagi et al., 2021). Hence, ensuring a smooth process in EDC involves crucial considerations such as the careful selection of an appropriate electrode, powder suspension, and other machining parameters like polarity, current, pulse duration, and fluid concentration (Sahu et al., 2018).

The working principles of the EDC process constitute a surface engineering technique employed to deposit material onto a workpiece surface using a sacrificial or green compact tool electrode within an electrical discharge machine. This process utilizes a dielectric medium and involves the deposition of material onto substrates from the sacrificial electrode through spark erosion. EDC stands out as an advanced yet straightforward coating method applied primarily to conductive materials. Its advantages include excellent adhesion between the parent material and coating, high efficiency in achieving thick coatings, and the capacity to balance the composition of the coated layerby selecting appropriate tool electrode material and dielectric fluid. The process is used to alter the desired surface characteristics, enhance substrate serviceability, and protect against corrosion, thermal stress, and other adverse environmental conditions (Kumaran et al., 2023). According to Muralidharan(2023), EDC is widely utilised as an economically viable coating technology that deposits coating material on the substrate using electrical discharge procedures. The procedure uses a dielectric mediumand spark erosion to deposit material on the substrates from the sacrificial electrode.

In contrast to EDM, which is a material subtractive process, EDC operates as a material additive process. It achieves this by depositing materials onto the workpiece surface rapidly through high-current electrical pulses and the presence of dielectric fluid (Tyagi et al., 2022). Table 2.1 illustrates the distinctions between the EDM and EDC processes, taking into account their functions, polarity, and machined surfaces. The process flow chart for EDC is depicted in Figure 2.1.

Table 2.1 Differences between EDM and EDC (Beri et al., 2012; Das and Misra, 2012; Vijayakumar et al., 2016)

	Electrical discharge machining (EDM)	Electrical discharge coating (EDC)
Definition	A material removal process is employedto shape a workpiece by eliminating material until the desired form is achieved.	It is a coating process that applies a layer of material onto a workpiece tomodify its surface.
Electrode polarity	The electrode or tool can be positioned in either the positive or negative terminal, and this choice depends on the parametric conditions such as tool wear rate and material removal rate.	The electrode or tool is positioned at the anode (positive terminal), while the workpiece can be situated at the cathode (negative terminal).
Weight of workpiece after processing	Reduction occurs as a result of thematerial being removed.	An increase is observed due to the deposition of material, although insome cases, there might be a decrease attributable to crater formation.
Function	To eliminate material from the surface of the workpiece.	To improve the surface properties ofthe workpiece.