A STUDY ON THE PERFORMANCE OF BURNISHING PROCESS WITH DRY, MINIMAL QUANTITY LUBRICATION (MQL) AND SUPERCRITICAL CARBON DIOXIDE ($SCCO_2$) CRYOGENIC COOLING

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To my beloved mother and father,

To my beloved wife,

To my lovely daughters,

To my brothers and sisters,

To all who know and support me.

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ABSTRACT

Burnishing is an important post-machining technique used to change surface roughness, microstructure, and mechanical characteristics. Proper cooling methods are required to improve product quality. One of the preferred cooling methods for the burnishing technique is cryogenic cooling. The cryogenic cooling system, has received less attention particularly in relation to the burnishing process. $SCCO_2$ is employed as a cooling or cryogenic gas rather than a dry, small-quantity lubricant. The burnishing technique is used to improve a component's surface integrity, which is critical in the medical, aerospace and nuclear industries. It necessitates the use of proper cooling and lubricating systems most commonly flood cooling. The flood cooling method is unsafe to the working environment of burnishing process. As new cooling method that combines MQL and supercritical carbon dioxide ($SCCO_2$) cryogenic cooling. Carbide burnishing tools with diameters of 10mm and 16mm and edge radius of 1 and 2 mm were used to burnish SS400 carbon steel. Dry and MQL cooling techniques were also used to assess performance under different cooling circumstances. $SCCO_2$+MQL performance on the workpiece was demonstrated and all experiments meet the objectives. Smaller diameter for frictional stir burnishing is enhanced the tool wear progression, microhardness and surface roughness. The increasing quantity of lubricant that results from the $SCCO_2$+MQL condition helps to reduce friction and cutting temperature, which in turn slows the course of tool wear and increases the tool's lifespan.

ABSTRAK

Burnishing merupakan teknik pasca pemesinan yang digunakan untuk mengubahsuai kekasaran permukaan, struktur mikro, dan sifat-sifat mekanikal sesuatu komponen kejuruteraan. Kaedah penyejukan yang sesuai diperlukan untuk meningkatkan kualiti produk. Teknik *burnishing* digunakan untuk meningkatkan integriti permukaan komponen, yang penting dalam industri perubatan, aeroangkasa dan nuklear. Salah satu kaedah penyejukan yang diutamakan dalam konteks proses *burnishing* ialah penyejukan kriogenik. Kajian literatur yang telah dibuat mendapati bahawa sistem penyejukan kriogenik dalam proses *burnishing* kurang mendapat perhatian. Ia digunakan sebagai gas beku atau kriogenik dan bukannya pelincir kering kuantiti kecil (*minimal quantity lubrication* - MQL). Penyejukan kriogenik yang berkesan adalah dengan menggabungkan sistem penyejukan dan pelincir berbanding kaedah penyejukan banjir (*flood cooling*). Kaedah penyejukan banjir tidak selamat digunakan terutamanya kepada proses *burnishing*. Untuk itu, projek ini memperkenalkan kaedah penyejukan baharu dengan menggabungkan teknik MQL dan karbon dioksida superkritikal ($SCCO_2$). Mata alat *burnishing* jenis karbida berdiameter 10mm dan 16mm serta jejari tepi 1 dan 2 mm telah dipilih dalam kajian ini. Ia telah digunakan untuk melakukan proses *burnishing* keatas keluli karbon SS400. Teknik penyejukan kering dan MQL juga digunakan untuk membandingkan prestasi terhadap penyejukan kriogenik. Penyejukan kriogenik $SCCO_2$+MQL telah mencatatkan prestasi yang amat memberangsangkan dan mencapai objektif yang telah ditetapkan. Dengan bantuan pelincir bagi teknik penyejukan $SCCO_2$+MQL secara tidak langsung mempengaruhi pretasi *burnishing*. Hasil keputusan menunjukkan bahawa ia mampu untuk mengurangkan geseran dan kadar pembentukan haba. Dengan itu, kadar kehausan mata alat dapat dipertingkatkan dan mengurangkan kesan terhadap sifat-sifat mekanikal bahan kerja.

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LIST OF SYMBOLS AND ABBREVIATIONS

S	-	Spindle speed
f	-	Feed rate
a	-	Depth of indentation
D	-	Diameter
R	-	Radius
MQL	-	Minimum Quantity Lubricant
$SCCO_2$	-	Supercritical Carbon Dioxide
CO_2	-	Carbon Dioxide
RSM	-	Response Surface Methodology
AISI	-	American Iron and Steel Institute
ECS	-	Electrochemical Smoothing
RB	-	Roller Burnishing
µ	-	Micro
FDD	-	Fatigue Design Diagram
DoP	-	Depth of Penetration
λc	-	Cut-off Length
SPD	-	Severe Plastic Deformation
WWII	-	World War II
LPB	-	Low plasticity burnishing

HRC	-	Hardness Rockwell C
SCC	-	Stress Corrosion Cracking
HTCS	-	High Thermal Conductivity Steel
FOD	-	Foreign Object Damage
Ti-6Al-4V	-	Alpha-Beta Titanium Alloy
SS400	-	Carbon Steel
DRX	-	Dynamic Recrystallization
FSB	-	Frictional Stir Burnishing
LN_2	-	Liquid Nitrogen
MWF	-	Metalworking fluid
MPa	-	Megapascal

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Burnishing is a chip-free machining procedure that alters the surface integrity of the workpiece through intense plastic deformation (SPD). Cryogenic cooling is utilised during the burnishing procedure, the surface of the burnished workpiece rapidly cools, resulting in surface change. Following machining, the burnishing process increases the dimensional accuracy, surface quality, and shape of the object. Additionally, it increases surface hardness and reduces polishing time. It is a more hygienic form of finishing than honing or other abrasive processes. Burnishing can also eliminate slower and more costly finishing techniques and secondary operations such as grinding, honing, and lapping. In general, burnishing is conducted dry, meaning no lubricant is employed.

As previously stated by Supekar *et al*. (2012), The negative effects of thermal softening on the machined workpiece can be reduced via cryogenic machining, which in turn increases the workpiece's hardness throughout the depth of the burnished layer. Surface enhancement, which dates back thousands of years, is widely recognised as one of the most essential strategies for increasing product performance by improving surface qualities such as surface hardness. This is because surface enhancement dates back thousands of years. Since the beginning of the twentieth century, progress has been made in surface enhancement techniques such as thermal, thermochemical, and mechanical processes.

The demand for near-dry, dry and cryogenic machining requires the application of sustainable machining. These processes are regarded as significant, long-term ways of machining. Flood coolant was previously a common technology, but it has negative environmental, health, and economic repercussions. On the other hand, a novel technology cooling system was launched and displayed outstanding performance, ensuring environmental and issues regarding the health of humans for the future generation of environmentally friendly manufacturing (Mahalil *et al*.,2019).

The minimum quantity lubrication (MQL) system provides cooling that is comparable to conventional techniques. It can be utilised in the machining process, allowing for a substantial reduction in fluid disposal costs and contributing to ecologically responsible production (Mahalil *et al.*,2019; Rachmat *et al.*,2019).

1.2 Background of Study

In manufacturing industries, the increase in cutting temperature during machining affects the product's surface finish. Since the use of coolant in metal cutting is less effective than cryogenic machining in lowering the temperature rise at the tool-workpiece contact, cryogenic machining is preferred. Blending cooling and lubrication technologies is the key to achieving a solution to these issues, which is the solution to these problems. The use of $SCCO_2$ in mixed with MQL proved to be an effective lubrication and cooling technique for the milling process. This allowed for a smoother cutting motion than was possible under normal cooling circumstances (Yuan, *et al.,* 2018).

Due to their decreased cutting fluid consumption, minimum quantity lubrication (MQL), cryogenic machining and dry machining are believed to be viable alternatives to flood machining. Furthermore, the improved surface integrity features of MQL and cryogenic machining improve the functionality of machined components. Cryogenic machining adds to an environmentally benign process by generating non-hazardous, non-toxic operations as well as functionally superior products with enhanced surface integrity (Rachmat *et al.*, 2019).

For machining that is both safe for the environment and efficient, liquid nitrogen is the gas that is most usually utilised because it is so readily available. In 1919, carbon dioxide was first utilised in machining processes as a coolant. This marked the beginning of the usage of liquefied gases as coolants in machining operations. During World War II, scientists made the discovery that metals that had been frozen at very low temperatures had a stronger resilience to wear. This led to the creation of the current cryogenic hardening technique (Jawahir *et al*., 2016).

Burnishing is one of the processes that can be used to generate the desired surface and subsurface properties while working with metal. In the 1920s, the axels of Ford T cars in the United States were the first to have the burnishing process applied to them. In the 1930s, the method was applied to train axels. To increase surface attributes such as surface polish and workpiece hardness, a cold working technique known as burnishing can be utilised. This method involves the plastic deformation of a surface layer. It is essentially a small-scale forming process during which strain hardening is generated to improve surface and hardness with a mirror-like surface polish and significant compressive residual stress in the outer surface. As a result, the fatigue life of the no-chip method is increased (Caudill *et al.*, 2014a; Devaraya *et al*., 2016).

Plastic deformation is a material displacement that can be generated by roller or ball burnishing. This occurs the tool pushes the materials at the surface from peaks and valleys under normal force against the surface over the yield point of the materials. The surface layer is subjected to generated compressive residual stresses, which increase fatigue performance and lower the risk of stress corrosion cracking (SCC). On the other side, tensile stresses reduce the fatigue life of a material and increase the likelihood of surface cracking. Earlier machining techniques like turning and grinding, for example, can result in the production of tensile tensions (Konefal *et al*., 2013; Yang, 2012; Pu *et al*., 2012).

Low plasticity burnishing (LPB) creates deep compressive residual stresses, hence reducing fatigue damages such as foreign object damage (FOD), fretting, and stress corrosion cracking (SCC). Moreover, the burnishing process converts tensile residual stresses in the surface zone to compressive residual stresses. Steels, titanium alloys, aluminium alloys, cobalt-chromium alloys, magnesium alloys and brass are often utilised for burnishing. Crankshafts, axles inner, bogies also outer bearing races and other automotive components are made of soft and hard materials (up to 65 HRC). The medical, aerospace and nuclear industries have increased their use of burnishing in recent years (Scheel *et al*.,2013).

1.3 Problem Statement

It is stated that cryogenic burnishing provides superior results in terms of surface integrity compared to flood-cooled and dry burnishing. Cryogenic cooling systems that make use of liquid nitrogen are expensive, and the liquid itself must be handled with extreme caution. Cryogenic cooling systems that make use of carbon dioxide are more cost-effective than those that make use of liquid nitrogen. In addition, these systems are safe to use, are not flammable, are easily accessible, and can be recycled.

In the process of ball burnishing, the utilisation of cryogenic carbon dioxide not only safeguards the environment and the health of humans, but it also has a beneficial effect on the economic climate of manufacturing industries. Concerns about the environment, on the other hand, have helped drive an increase in demand for environmentally friendly items. As a direct consequence of this, a variety of machining settings, such as near dry machining and dry, have been implemented to solve the problem of cutting fluid. About the burnishing procedure, there is still a lack of comprehension regarding the utilisation of cryogenic cooling. It is necessary to do research on the effects of using cryogenic cooling methods in place of other methods to increase the performance of the burnishing process. It is necessary to have a more effective cooling method that evaluates table performance in comparison to MQL and the usual cryogenic method. The $SCCO_2$+MQL technique has been proposed and must be evaluated.

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APPENDIX

LISTS OF PUBLICATIONS

i. Rachmat, H., Mahalil, K., Mohid, Z., & Rahim, E. A. (2019). Comparison between Dry, MQL, and cryogenic cooling technique on surface integrity of burnished surface. *International Journal of Integrated Engineering*, *11*(5), 35–41.

ii. Rachmat, H., Abd Rahim, E., Mohid, Z., Mahalil, K., Akmal Kasah Feisal Kasah, A., & Nadzri, A. (2019). Effect of Burnishing Tool Radius and Coolant Technique on Burnishing Performance. Journal of Physics: Conference Series, 1150(2019)012047.

iii. Rachmat, H., Rahim, E. A., Mohid, Z., Mahalil, K., Kasah, A. A. K. F., & Nadzri, A. (2019). Effect of Burnishing Tool Diameter and Coolant Strategies on Burnishing-Performance. Journal of Physics: Conference Series, 1150(2019) 012070.

iv. Mahalil, K., Rahim, E. A., & Mohid, Z. (2019). Performance Evaluation of Sustainable Coolant Techniques on Burnishing Process. IOP Conference Series: Materials Science and Engineering, 494(1).