## Faculty of Manufacturing Engineering

# SURFACE INTEGRITY AND TOOL WEAR OF HARDENED HTCS-150 STEEL (52 HRC) IN MILLING WITH TiAlN COATED CARBIDE

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# SURFACE INTEGRITY AND TOOL WEAR OF HARDENED HTCS-150 STEEL (52 HRC) IN MILLING WITH TiAlN COATED CARBIDE

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# DECLARATION

I declare that this thesis entitled "Surface Integrity and Tool Wear of Hardened HTCS-150 Steel (52 HRC) in Milling with TiAlN Coated Carbide" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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# APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature :……………………………………………..

Supervisor Name : PM. Ir. Dr. Mohd Hadzley Bin Abu Bakar

Date :…………………..……………………

# DEDICATION

To my beloved mother, father, husband, parent-in-law, my family and all my supportive friends.

# ABSTRACT

Recent development in metal stamping introduced a new die namely hardened High Thermal Conductivity Steel-150 (HTC-150). Understanding the cutting parameters, surface characteristics and cutting tool wear during machining this new die would lead to efficiency in machining operation. This research concentrated on the finishing process in machining HTCS-150 hardened steel (52 HRC) using ball nose end mill TiAlN coated carbide insert. The purpose of this study is to develop the regression model and optimization focused on the relationship between the cutting parameters (cutting speed, feed rate and axial depth of cut) and the response (surface roughness and cutting tool wear) by using Box-Behnken approach under Response Surface Methodology (RSM) experimental design. In addition to model development, Analysis of Variance (ANOVA) was employed to identify significant factors that influenced the surface roughness and cutting tool wear. Further analysis of surface characteristics and cutting tool wear were observed under Scanning Electron Microscope (SEM). Experimental processes were carried out using Variaxis MAZAK CNC 5 axis milling, assisted by the Design Expert 10 analysis software. Ranges of cutting parameters selected were 120-130 m/min cutting speeds, 0.3-0.5 mm/tooth feed rates, 0.1-0.5 mm axial depth of cut and 0.01 mm constant radial depth of cut. The results show the model develop adequately represent the process with modeling validation runs within the 90% of prediction interval and their residual errors compared to the predicted values were less than 10%. The optimization results show that the lowest surface roughness achieved at 125 m/min cutting speed, 0.30 mm/tooth feed rate and 0.1 mm axial depth of cut. Combination of cutting parameters for the lowest cutting tool wear recorded as 130 m/min cutting speed, 0.4 mm/tooth feed rate and 0.1 mm axial depth of cut. The ANOVA analysis shows that for the surface roughness, most influenced cutting parameters was axial depth of cut followed by feed rate and cutting speed. Meanwhile, for cutting tool wear, feed rate and depth of cut recorded as most influenced cutting parameter followed by cutting speed. Observation using SEM observed that feed marks, scratch, adhered material, smeared material, and surface porosity were major defects on the machined surface. Analysis of wear characteristics presented abrasion, coating delamination, adhesion, formation of built-up edge and chipping were among failure mechanisms observed. The results from experimental provide useful information to obtain ultra-fine surface finish and decrease the cutting tool wear during machining HTCS based materials to minimize post processing activities.

# *ABSTRAK*

*Perkembangan terbaru dalam logam hentakkan panas memperkenalkan acuan baru iaitu Besi Berkonductiviti Haba Tinggi (HTCS-150) yang dikeraskan. Memahami parameter pemotongan, ciri-ciri permukaan dan kehausan mata alat semasa pemesinan acuan baru ini akan membawa kepada kecekapan dalam operasi pemesinan.Penyelidikan ini tertumpu pada proses pemesinan akhir dalam pemesinan HTCS-150 yang dikeraskan (52 HRC) dengan menggunakan mata alat karbida bersalut TiAlN endmill yang berbentuk separa bulatan. Objektif kajian ini adalah untuk membina model matematik dan menumpukan optimasi kepada hubungkait antara pembolehubah pemotongan (kelajuan pemotongan, kadar kemasukan dan kedalaman pemotongan) dan hasil pemesinan (kekasaran permukaan dan kadar kehausan mata alat) dengan menggunakan pendekatan Box-Behknen di bawah Response Surface Methodology (RSM). Sebagai penambahan kepada pembinaan model matematik, Analisis of varians (ANOVA) digunakan untuk mengenalpasti faktor-faktor penting yang mempengaruhi kekasaran permukaan dan kehausan mata alat. Seterusnya, analisis lanjut tentang kekasaran permukaan dan kehausan mata alat telah diperhatikan di bawah Imbasan Electron Mikroskop (SEM). Proses eksperimen dijalankan menggunakan mesin kisar menegak MAZAK 5 paksi dan perisian Design Expert 10 iaitu sebagai perisian analisis. Julat parameter pemotongan yang dipilih adalah 120-130 m/min untuk kelajuan pemesinan, 0.3-0.5 mm/mata alat untuk kadar kemasukan dan 01-0.5 mm bagi kedalaman pemotongan secara menegak, manakala kedalaman bagi pemotongan secara paksi Y (melintang) adalah tetap iaitu 0.01mm. Keputusan menunjukkan model yang dibentuk cukup untuk menggambarkan proses kajian dengan ujian pengesahan model dengan kadar 90% jarak ramalan dan baki ralat perbandingan kepada nilai ramalan adalah kurang daripda 10%. Keputusan optimisasi menunjukkan kekasaran permukaan paling rendah dicapai pada kelajuan pemotongan 125 m/min, kadar kemasukan 0.3 mm/mata alat dan kedalam pemotongan 0.1 mm. Gabungan pembolehubah permotongan untuk menghasilkan kadar kehausan mata alat paling rendah pula dicatatkan pada kelajuan pemesinan 130 m/min, kadar kemasukan 0.40 mm/mata alat dan kedalaman pemotongan 0.1 mm. Bagi kekasaran permukaan, analisis ANOVA menunjukkan pembolehubah permotongan yang paling mempengaruhi hasil kekasaran permukaan adalah kedalaman pemotongan diikuti oleh dan kadar kemasukkan dan seterusnya kelajuan pemotongan. Manakala untuk kadar kehausan mata alat, kadar kemasukan dan kedalaman permukaan dicatat sebagai pembolehubah pemotongan yang paling mempengaruhi diikuti kelajuan pemesinan. Pemerhatian dengan menggunakan SEM menunjukkan tanda kemasukan,calar, bahan tambahan, bahan pelet dan keliangan yang terdapat pada permukaan merupakan kecacatan yang utama pada permukaan yang dimesin. Hasil daripada percubaan memberikan maklumat berguna untuk mendapatkan permukaan ultra-halus dan mengurangkan alat pakai selama pemesinan bahan berdasarkan HTCS untuk meminimalkan kegiatan pemprosesan pelanjutan.*

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# LIST OF ABBREVIATIONS

HTCS - High Thermal Conductivity Steel

CADCAM - Computer-Aided Design and Manufacturing

CVD - Chemical Vapor Diffusion

HSM - High Speed Machining

CNC - Computer Numerical Control

TiAlN - Titanium Aluminum Nitride

TiN - Titanium Nitride

TiCN - Titanium Carbonitride

SEM - Scanning Electron Microscope

EDM Electro Discharge Machine

RPM - Rotation Per Minute

Al - Aluminum

$Al_2O_3$ - Aluminum Oxide

C - Carbon

Ti - Titanium

Si - Silicon

Mn - Manganese

S - Sulfur

Cr - Chromium

Cu - Copper

Sn - Tin

Mg - Magnesium

ISO - International Organization for Standardization

VB - Flank wear

BUE - Built Up Edge

BUL - Built Up Layer

DOC Depth Of Cut

RDOC - Radial Depth Of Cut

ADOC - Axial Depth Of Cut

SMSS - Sum Model of Square Sequential

RSM - Response Surface Methodology

BBD - Box-Behnken Design

PCD - Polycrystalline Diamond

HSS - High Speed Steel

PCBN - Polycrystalline Cubic Boron Nitride

AISI - America International Standard Institute

MMC - Metal Matrix Composites

ANOVA - Analysis of Variance

# LIST OF SYMBOLS

°C - Degree Celsius

µm - Micrometer

% - Percent

$a_p$ - Radial depth of cut

$a_e$ - Axial depth of cut

$F_z$ - Feed rate

Kv - Kilo volt

m/min - Meter per minute

mm - Millimeter

min - Minute

Vc - Cutting speed

W/m.k - Watts per meter kelvin

Ra - Average surface roughness

MPa - Megapascal

# LIST OF PUBLICATIONS

Journal

1. Hadzley, A. B., Anis, A. A., Farizan, M. N., Osman, M. H., Norfauzi, T., & Noorazizi, S. (2018). Analysis of Surface Integrity and Formation of Material Side Flow in Dry and Wet Machining of Aluminum Alloy. Journal of Advanced Manufacturing Technology (JAMT), 12(1 (1)), 501-512.

2. Hadzley, A. B., Azahar, W. M., Anis, A. A., Izamshah, R., Amran, M., Kasim, S., & Noorazizi, S. (2018). Development of Surface Roughness Prediction Model using Response Surface Methodology for End Milling of HTCS-150. Journal of Advanced Manufacturing Technology (JAMT), 12(1 (1)), 467-476.

# CHAPTER 1

# INTRODUCTION

## 1.1 Research background

Machining is a manufacturing process that transforms the raw material into the desired shape. The process use cutting tools to remove unwanted materials by shearing the workpiece with engaging rotating parts in opposite direction. There are three domain methods that are classified in machining operations, namely milling, drilling and turning. Other processes such as sawing, boring, broaching and shaping also considered categorised under machining operations. For each machining process, a specific machine tool is needed to facilitate the process according to the designated tasks.

One of the significant applications of machining is to manufacture die for metal stamping application. Metal stamping is a process of fabricating metal parts and forming the metal parts into an ideal shape by applying high pressure to a blank piece (Karbasian and Tekkaya, 2010). The stamping machine incorporates a special made die which provides the stamped part shape and this process also widely used and found in automotive industry as the process capable to make intricate, accurate, strong and durable parts in huge quantities. Many automotive parts are already applied using this technology, for example chassis component, roof rail, bumper, fender, and bonnets. Method that commonly used for mould and die manufacturing is end milling process. In die machining, the main challenge is the high surface of material hardness and curvy workpiece geometries that will affect and contribute to short lead times (Becze et al., 2000). At the same time, due to the quality awareness of the dies long life term, requirement for the best qualities of surface finish becomes more significant.

For manufacturer of mould and die, a great challenge occurs when they have to fulfil the necessity to have a good surface quality on complex free-form shape. The challenge could be worsened when the material being used was in hardened condition. The introduction of High Thermal Conductivity Steel-150 (HTCS-150), with hardness of 52 HRC for hot stamping application highlighted the requirement to strategically study the formulation of optimization of surface roughness and tool wear that can facilitate holistic guideline to machine this new material. In industry, specific die normally being machined in rough and finish conditions before manually polished by hands of operators. The present techniques to complete the required surface finish for mould and die component by manual polishing has a tendency to minimise the productivity and difficulty in ensuring the component accuracy. The major concern in machining hardened materials is the necessity for a fine surface roughness process due to its properties such as high wear resistance, high compressive strength and high stability in hardening.

In this study, a new developed material namely HTCS-150 hardened steel is being systematically investigated based on its machinability according to the control parameters of cutting speed, feed rate and axial depth of cut. This project aims to study the wear performance and surface integrity in machining HTCS-150 hardened steel using TiAlN coated carbide. The milling operation has been performed by using a MAZAK variaxis 5-axis CNC milling machine where the surface finishing of HTCS-150 hardened steel has been monitored at different cutting parameters, parallel with the tool wear behaviour. The understanding and correct use of the cutting tool and parameters in producing a fine surface finishing will lead to the reduction in cycle times which is achieved through the increasing level of the parameter.