PERFORMANCE EVALUATION OF COATED CERAMIC CUTTING TOOLS WITH T-LAND EDGE PREPARATION WHEN TURNING HARDENED TOOL STEEL

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To my beloved mother and father

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ABSTRACT

Hard turning is a technology that can be used in the finishing operations for hardened steel (45 HRC and above).The development ceramic and CBN cutting tool has made hard turning possible. This project was undertaken to investigate the performance of KY 4400 ceramic cutting tool with T-land edge preparation when turning XW 42 grade hardened steel (54-55 HRC) under various cutting speeds: 115, 145 and 183 m/min, and various feed rates: 0.098, 0.125 and 0.16mm/rev. Information on tool life, material removal rate and surface roughness were obtained, evaluated and compared with wiper and conventional inserts. The tool life and material removal rate of T-land is higher compared to wiper and conventional inserts. However, in terms of surface roughness, wiper inserts are able to generate better surface finish compared to T-land and conventional inserts. The tool failure mode and wear mechanism were also investigated. The wear mechanisms responsible for the wear formation were abrasion and diffusion. Flank wear and crater wear were the main wear observed during the turning of XW 42 grade hardened steel 54-55 HRC using KY 4400 ceramic cutting tool. At the cutting speed of 183 m/min and feed rate of 0.16 mm/rev catastrophic failure occurred. At other cutting conditions investigated, the failure mode was due to flank wear. The tool life and surface roughness models were developed using 3 level factorial design. Analysis done showed that both mathematical models for tool life and surface roughness can be used to predict the machining response with the limits of cutting conditions investigated.

ABSTRAK

Larik keras merupakan teknologi yang boleh digunakan untuk pemesinan akhir keluli keras (kekerasan 45 HRC dan keatas). Penghasilan mata alat seramik dan Boron Nitrida Kiub telah membolehkan proses larik keras dijalankan. Projek ini dilakukan untuk mengkaji prestasi mata alat seramik KY 4400 di dalam proses larik keras keatas keluli keras gred XW 42 yang mempunyai kekerasan 54-55 HRC menggunakan kelajuan pemotongan berbeza: 115, 145 dan 183 m/min dan kadar uluran berbeza: 0.098, 0.125 dan 0.16 mm/rev. Maklumat mengenai jangka hayat mata alat, produkiviti dan kualiti permukaan benda kerja diambil, dianalisa dan perbandingan dibuat dengan mata alat seramik wiper dan konvensional. Mata alat T-land mempunyai jangka hayat dan produktiviti yang lebih tinggi dibandingkan dengan mata alat konvensional dan wiper. Mata alat wiper pula berupaya menghasilkan kualiti permukaan benda kerja yang lebih baik dari mata alat T-land dan konvensional. Jenis jenis kehausan mata alat serta mekanisma kehausan mata alat turut dikaji. Didalam kajian ini *abrasion* dan *diffusion* adalah punca kehausan mata alat. *Flank wear* dan *crater wear* adalah jenis kehausan yang didapati semasa pemotongan keluli keras gred 54-55 HRC menggunakan mata alat seramik KY 4400. Pemotongan yang dilakukan pada kelajuan 183 m/min dan kadar uluran 0.16 mm/rev telah menyebabkan *catastrophic failure* berlaku. Pada parameter pemotongan yang lain, *flank wear* adalah penyebab kehausan mata alat. Model jangka hayat dan kualiti permukaan benda kerja dijana menggunakan 3 level factorial design. Analisa yang dilakukan telah mengesahkan yang kedua dua matematik model sah digunakan untuk meramal *machining response* dibawah parameter pemotongan tertentu.

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LIST OF SYMBOLS AND ABBREVIATIONS

VB	-	Flank wear
VC or VBc	-	Secondary groove wear
VN or VB_N	-	Primary groove
HRC	-	Hardness Rockwell
CBN	-	Cubic Boron Nitride
RSM	-	Response Surface Methodology
AISI	-	American Iron and Steel Institute
BUE	-	Built up edge
ISO	-	International Organization for Standardization
et al.	-	and others
KB	-	Crater width
KI	-	Crater Index
KM	-	Crater center distance
KT	-	Depth of crater
CVD	-	Chemical vapour deposition
PVD	-	Physical vapour deposition
PCBN	-	Polycrystalline cubic boron nitride
PCD	-	Polycrystalline diamond
φ	-	Shear angle
EDAX	-	Energy dispersive analysis by X ray Spectroscopy
TiN	-	Titanium Nitride

CHAPTER 1

INTRODUCTION

Machining is a material removal process that is used to produce a required shape from a workpiece material blank. Hard turning is a method that can be used to remove unwanted material from hardened steel in order to get its required shape. Precised part can be produced by hard turning without having the workpiece to undergo secondary process such as grinding and lapping. The application of hard turning is further enhanced with the use of new materials for making cutting tools such as cubic boron nitride (CBN) and ceramics [1]. As a result of this, more research is being done on the evaluation of these cutting tools made from different material for use in hard turning process.

1.1.Background

Hardened steel is widely used in manufacturing components such as gear, bearing, tools and die [1, 2]. Its properties of high wear resistance, good corrosion resistance and high surface finish have resulted in this material to be used in producing the components mentioned. Grinding has traditionally being used to finish machine hardened steel. The technique has some weaknesses: it is time consuming and only limited range of geometries can be produced.

The development of advanced cutting tool materials has led to the improvement in the cutting process of hardened steel. CBN and ceramic cutting tools can be used for turning process hardened steel. The process of turning hardened steel of 45 HRC and above is known as hard turning.

Hard turning has several advantages over grinding. The advantages of hard turning are [1]:

- The ability to produce complex geometry in one set up;
- Quality of surface finish produced by hard turning is equivalent to that obtained by grinding;
- Machining can be done without coolant and therefore the process is environmentally friendly;
- The cutting process requires less power and
- The cost of hard turning is cheaper

CBN and ceramic are widely being used in hard turning. Liu *et al.* [3] has conducted experiment on hard turning of bearing steel using PCBN tool BN 500.
From the experiment conducted, Liu found that PCBN tool wears at high cutting speed due to the increase in temperature during machining. This resulted in an increased wear rate of the tool because of the heat generated during machining at high speed. At high speed machining, the increase in temperature was due to more heat generated as a result of high strain rate that occur at shear zone.

Luo *et al.* [4] on the other hand made comparison between CBN tool (TiC and Al_2O_3 bond), ceramic tool (Al_2O_3 and TiC), and carbide tool P10 when turning hardened steel AISI 4340 ranging from 35 to 55 HRC. From the experiment conducted, it was found that carbide P10 tool was not suitable for cutting steel with high hardness because of the occurrence of rapid wear or fracture as a result of high force and cutting temperature. The main wear mechanism when machining AISI 4340 steel using CBN tool was abrasion while adhesion and abrasion were the wear mechanisms when ceramic tool was used during the experiment. The wear rate of ceramic and CBN cutting tools differs for the different hardness range of hardened steel.

Thiele *et al.* [5] conducted the study on the effect of hone radius when machining AISI 51200 steel bar of hardness 45, 52 and 60 HRC using CBN tool. The surface roughness increased when higher nose radius was used when turning hardened steel. Another important finding was that the cutting geometry influenced the axial and radial cutting force.

The response surface methodology (RSM) is a method of developing machinability models. Liu *et al.* [3] has used RSM to study the effect of depth of cut, feed rate and cutting speed when hard turning hardened bearing steel using PCBN tool.

1.2.Problem statement

Ceramic is being used as the material for cutting tool in hard turning. This is due to its ability to remove material at high rate, long tool life and its suitability for machining hard materials.

Most of the investigation done on hard turning was on hardened steel between 40-50 HRC and 60 HRC using ceramic cutting tool. However, the studies on hardened steel 54-55 HRC using ceramic cutting tool with T land edge preparation are lacking. There have been studies on conventional and wiper insert on hardened steel 54-55 HRC. Since there are applications of hardened steel 54-55 HRC in the industry, this study will evaluate the performance of a ceramic cutting tool with T land edge preparation and its performance will be compared with conventional and wiper insert. This study will also attempt to apply experimental design technique to develop mathematical model for tool life and surface roughness when hard turning KY 4400 cutting tool on XW42 tool steel of hardness 54-55 HRC.

1.3.Objectives

The aim of this work is to evaluate the performance of ceramic cutting tool KY 4400 when turning XW42 grade steel with hardness of 54-55 HRC. The objectives of this project are:

1) To evaluate the performance of the ceramic cutting tool with T land edge preparation in terms of tool life, material removal rate, tool wear mechanism and surface roughness when hard turning is done at different speed and feed rate
2) To develop empirical machinability model for tool life and surface roughness by using Experimental Design Techniques.

1.4.Scope

This project is carried out within the following scopes which are:

1) Experiment was done using KY 4400 cutting tool
2) XW42 tool steel of hardness of 54-55 HRC was used as workpiece material for this project.
3) Analysis will be on tool life, material removal rate, tool wear mechanism and surface roughness to the machined workpiece.
4) Performance comparison of the tools with various edge preparations will be made.

1.5.Significance of the study

This study is expected to provide the following outcomes:

1) Better understanding of ceramic cutting tools KY 4400 in terms of its performance and hard turning application
2) Able to evaluate the effectiveness of turning using KY 4400 for grade XW 42 steel.

1.6 Organization of thesis

This report is divided into several chapters. Chapter 1 will provide introduction and objectives of the project. Literature review on hard turning and discussion is presented in Chapter 2. Experimental techniques are discussed in Chapter 3 while Chapter 4 will discuss on design of experiment. Chapter 5 is reserved for result and analysis of experiment. The development of mathematical model for predicting tool life and surface roughness is presented in Chapter 6. Finally, conclusion and recommendations are presented in Chapter 7.