TOOL WEAR AND TOOL LIFE PERFORMANCE OF TiAlN COATED CARBIDE CUTTING TOOLS WHEN TURNING XW 42 HARDENED TOOL STEEL

EFFENDY

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To my beloved parents, brothers, and sisters

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ABSTRACT

Hard turning is an alternative technique that can be used for finishing operations of hardened material (HRC 45 and above). CBN and ceramic tools are widely used for finish hard turning (54-55 HRC), but these tools are associated with significantly higher cost. This study was undertaken to investigate the performance of KC 5010 FP when turning XW 42 hardened tool steel (54-55 HRC). Tool performance, tool failure modes and wear mechanisms were investigated under various cutting conditions (V=100, 123, and 150 m/min, f=0.08, 0.1, and 0.125 mm/rev). Tool failure modes were also investigated, and flank wear, crater wear, and catastrophic failure are found to be occurring on the tool while flank wear is the main wear form found on tool. The wear mechanisms responsible for the wear formation are abrasion and adhesion. Mathematical models for tool life and surface roughness were developed using experimental design technique. Tool life and surface roughness models can be used for coated carbide tool KC 5010 FP for finishing hardened tool steel XW 42 (HRC 54-55) under cutting the condition investigated.

ABSTRAK

Larik keras merupakan satu teknik alternatif yang dapat digunakan untuk pemesinan kemasan keluli keras (HRC 45 ke atas). Mata alat boron nitrida kiub dan seramik digunakan secara meluas untuk larikan kemasan keluli keras (54-55 HRC), akan tetapi seramik dan boron nitrida kiub sering dikaitkan dengan kos mata alat yang tinggi. Kajian ini dilakukan untuk mengkaji prestasi mata alat karbida yang disalut KC 5010 FP di dalam proses larik keras keluli keras gred XW 42 yang mempunyai kekerasan 54-55 HRC. Maklumat mengenai prestasi mata alat, mod kegagalan dan mekanisme kahausan ditentukan untuk pelbagai keadaan pemotongan (V=100, 123, and 150 m/min, f=0.08, 0.1, and 0.125 mm/rev). Hasil kajian menunjukkan kehausan rusuk, *crater wear* dan kegagalan katastropik adalah adalah mod kegagalan yang berlaku pada mata alat. Mekanisme yang mengakibatkan kehausan mata alat ialah *abrasion* dan *adhesion.* Model matematik untuk jangka hayat dan kualiti permukaan dijana menggunakan teknik reka bentuk ujikaji. Model jangka hayat dan kualiti permukaan sah digunakan untuk mata alat karbida yang disalut KC 5010 FP semasa pemotongan keluli keras XW 42 (54-55 HRC) dibawah keadaan pemotongan yang telah dikaji.

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LIST OF SYMBOLS AND ABBREVIATIONS

AISI	-	American iron and steel institute
ANOVA	-	Analysis of variance
b	-	Shank width
BL	-	Length of groove backwall wear
BUE	-	Built-up-edge
BW	-	Width of groove backwall wear
C	-	Constant in tool life equation
CBN	-	Cubic boron nitride
CVD	-	Chemical vapor deposition
d	-	Depth of cut
et al.	-	and others
EDAX	-	Energy dispersive analysis by X-ray spectroscopy
ESR	-	Electro-Slag-Refining
f	-	Tool feed rate
FP	-	Finishing positive
FW	-	Finishing wiper
h	-	Shank height
HRC	-	Hardness Rockwell C
HSS	-	High speed steel
HTMF	-	Hard turning with minimal fluid
ISO	-	International Organization for Standardization
KB	-	Crater width
KI	-	Crater index

KM	-	Crater center distance
KT	-	Depth of the crater or depth of groove backwall wear
l	-	Tool length
MT-CVD	-	Medium temperature chemical vapor deposition
n	-	Slope of the tool life curve
N	-	Nose wear
PCBN	-	Polycrystalline cubic boron nitride
PCD	-	Polycrystalline diamond
PVD	-	Physical vapor deposition
r	-	Tool nose radius
SAE	-	Society of automotive engineers
SD	-	Depth of secondary face wear
SEM	-	Scanning electron microscope
SW	-	Width of secondary face wear
T	-	Tool life
TiAlN	-	Titanium aluminium nitride
TiC	-	Titanium carbide
TiCN	-	Titanium carbon nitride
TiN	-	Titanium nitride
V	-	Cutting speed
Al_2O_3	-	Aluminium oxide
C_e	-	End cutting edge angle
C_s	-	Side cutting edge angle
CH_4	-	Methane
F_c	-	Cutting force
F_r	-	Radial force
F_t	-	Thrust force
MoS_2	-	Molybdenum disulfide
NL_1	-	Notch wear length on main cutting edge
NL_2	-	Notch wear length on secondary cutting edge
NW_1	-	Notch wear width on main cutting edge

NW_2	-	Notch wear width on secondary cutting edge
R_a	-	Arithmetical mean surface roughness
R_t	-	Peak-to-valley height of the surface profile
Si_3N_4	-	Silicon nitride
TCl_4	-	Titanium chloride
VB_B	-	Average width of flank wear land in zone B
$VB_{B\ max}$	-	Maximum width of the flank wear in zone B
VB_C	-	Average width of flank wear land in zone C
$VB_{C\ max}$	-	Maximum width of the flank wear in zone C
α_b	-	Back rake angle
α_s	-	Side rake angle
θ_e	-	End relief angle
θ_s	-	Side relief angle

CHAPTER I

INTRODUCTION

1.1 Background

Steel is most commonly used in manufacturing. There are numerous products made from a wide variety of steel. Over past the few years, demand for steel is continuously increasing although other engineering materials such as non ferrous material and plastic are extensively developed and used. The reason for this is because steel can be used in most engineering applications, economical, and the most importantly it has a huge range of mechanical and physical properties. Steel components are often hardened in certain application areas in order to increase wear resistance. Hardened steel is obtained by heat-treating steel material (which involves quenching and tempering).

Hardened steel has been increasingly used in industrial and automotive applications such as gear, bearing, tool, and die. Requirements on surface finish and dimensional accuracy of hardened steel can be achieved by finishing operation and finishing hardened steel are usually made by traditional machining such as grinding. However, grinding operations are not economical because they are time consuming, limited to the range of geometry, and require coolant.

The process of turning hardened steel with hardness value above 45 HRC is known as hard turning. Nowadays, hard turning can be an alternative technique for replacing grinding process when finishing hardened steel. Since hard turning reduces machining time, highly geometry flexible, and requires no coolant, it not only save the cost but also reduces environmental pollution, and as there are no coolant to be dispose.

As finish hard turning is increasingly used in industrial applications, there is a need for further research in order to reduce the machining cost and improving productivity. CBN and ceramic tools are widely used for machining of various hard materials such as high speed tool steel, die steel, and bearing steel (Poulachon *et al*., 2005).

Lima *et al*. (2005) observes PCBN and ceramic are used for turning hardened steel AISI 4340 (42-58 HRC). In the case of 50 HRC steel, high wear rates were observed in PCBN tool and wear increased smoothly as cutting time elapsed. When, turning 58 HRC steel, wear rate in ceramic tool increase with cutting time however, a drastic increase in tool wear is observed when turning at high speed. Wear rate of both tool increases probably because of the presence of hard carbide particles.

Malshe *et al*. (2005) conducted the study on machining hardened steel AISI 4340 (50-52 HRC) with CBN-TiN coated tool. They were able to produced a machined surface roughness comparable to surface finishing process such as mechanical grinding, and that indicate that the coating could be complementary to CBN tool in finish hard turning.

Another researcher Kumar *et al*. (2006) reported using coated carbide ceramic tool when machining martensitic stainless steel 410 (60 HRC) and hardened EN steel (45 HRC). Tool wear increases with the increased in cutting speed and wear is higher when machining martensitic stainless steel than on machining hardened steel, this is because martensitic stainless steel more harder than hardened steel.

Noordin *et al*. (2006) used coated carbide tools when machining martensitic stainless tool steel, Stavax ESR (43-45 HRC). From the experiments conducted, it was found that cutting speed and feed have an effect on tool wear and tool life. The longest tool life was attainable when cutting at low cutting speed and feed rate. The result suggests that dry turning of hardened steel can be performed using coated carbide cutting tools at suitable selected cutting condition.

Tang (2006) found that both conventional and wiper geometry TiA1N coated carbide tools performed satisfactorily during finish hard turning of Stavax ESR stainless tool steel (47-48 HRC) and the wiper geometry inserts were capable of producing better surface finish than conventional inserts. Besides, he concluded that TiA1N coated carbide tool is suitable for dry machining of hardened stainless tool steel with excellent crater resistance due to its high hot hardness, chemical stability, and thermal conductivity.

The development of tool material was also followed by the development in coating technology where coating technology can improve properties of the tool. For instance, coated carbide tools have better properties than uncoated carbide tools such as more wear resistance, adequate fracture toughness, and good thermal stability.

In machining investigations, response surface methodology (RSM) is used quite extensively. Noordin *et al*. (2004) has used RSM to study the performance of coated carbide tool when turning AISI 1045. RSM is a collection of mathematical and statical techniques that are useful for the modeling and analysis of problems in which a respond of interest is influenced by several variables and the objective is to optimize this respond (Montgomery, 1997)

1.2 Problem statement

Increasing demand on hard turning applications open new requirement on low cost operation. Most of the hard turning studies involve hardness value in the range of 45-65 HRC and they are using CBN and ceramic as cutting tools, but these tools are associated with significantly higher cost. Hard turning using coated carbide tools have been conducted using workpiece material up to a hardness value of 47-48 HRC while studies involving hardness above 47-48 HRC is still lacking. With the development of coating tool materials and coating technology there is a need to investigate the possibility of turning hardened steel 54-55 HRC using coated carbide tools particularly for jobs involving small amount of material removal rate and small quantity. Moreover, the use coated carbide in hard turning applications are still limited and much unexplored. Therefore, this study will evaluate the performance of TiA1N coated carbide for hard turning 54-55 HRC applications.

1.3 Aim and objective

The aim of this study is to evaluate the performance of TiA1N wiper coated carbide cutting tool during hard turning of tool steel XW 42 grade (54-55 HRC). The objectives this study is:

1. To evaluate the performance of coated carbide cutting tool (tool life, tool wear, and surface roughness) when turning hardened tool steel.
2. To apply experimental design technique in developing mathematical model for tool life and surface roughness.
3. Proposing the suitable cutting conditions that will result in optimum tool life and surface finish

1.4 Scope of study

The scope of this study is:

- TiA1N conventional coated carbide cutting tool will be used when conducting the experiment.
- Cutting will be performed in dry condition
- XW 42 hardened tool steel which 54-55 HRC will be used as the workpiece material.
- Analysis will be on tool life, tool wear mechanism, and surface roughness when machining the workpiece.

1.5 Significance of the study

This study is expected to contribute towards the understanding of coated carbide tool performance in hard turning application. It is hoped that coated carbide tool can be alternative tool material for finish turning of hardened steel of 54 – 55 HRC particularly for small amount of material removal rate as coated carbide tools have an advantage of low cost when compared to CBN and ceramic.

1.6 Organization of thesis

This report is divided into six chapters. Chapter 1 will provide introduction and objectives of the project. Literature review and discussion on hard turning are presented in Chapter 2. Research methodology is discussed in Chapter 3 while Chapter 4 will discuss on experimental result. Chapter 5 is reserved for analysis of experiment. Finally, conclusion and recommendations are presented in Chapter 6.