EXPERIMENTAL STUDY ON HARD TURNING OF HARDENED TOOL STEEL WITH COATED CARBIDE CUTTING TOOLS

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To my beloved wife C.P.Premalatha for her support and motivation and to the god who had answered my prayers.

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ABSTRACT

Hard turning is a technique that can be used to substitute grinding in the finishing operations for hardened steel (HRC 45 and above). However, the use of this technique was limited due to high cost of the cutting inserts. The introduction of newly developed carbide cutting tools has made hard turning more widespread. This study was undertaken to investigate the performance of KC 5010 which is a physical vapor deposition (PVD) titanium aluminium nitride (TiAlN) conventional geometry insert during finish hard turning of Stavax Electro-Slag-Refining (ESR) stainless tool steel (HRC 47 - 48). Various cutting speeds: 99.41, 130 and 170 m/min, and various feed rates: 0.098, 0.125 and 0.16mm/rev were employed. Turning was done under dry cutting condition and with constant depth of cut. Cutting forces, surface roughness and chip morphology were investigated. Results of surface roughness were satisfactory. Radial force seems to be the dominant force compared to the tangential force and feed force. Continuous chips were obtained regardless of the cutting conditions employed. Saw tooth chip formation was also found under high power microscope for all the cutting condition except at low cutting speed and feed. The radial force and surface roughness models were developed using the three level full factorial design. The mathematical models developed are statistically valid and sound, particularly for Fr and surface roughness. These are verified by the confirmation run experiments and therefore can be used for prediction within the limits of the factors investigated. Based on this research, hard turning with coated carbide inserts having conventional geometry performed satisfactory.

ABSTRAK

Larik keras merupakan teknik yang boleh digunakan sebagai alternatif kepada proses pencanaian ketika pemesinan akhir keluli keras (kekerasan 45 HRC dan keatas). Walau bagaimanapun, potensi teknologi ini agak terbatas disebabkan oleh kos mata alat yang tinggi. Penghasilan mata alat karbida yang baru telah membolehkan proses larik keras dijalankan dengan lebih meluas. Kajian ini bertujuan untuk menguji prestasi mata alat karbida bergeometri konvensional KC 5010 yang disaluti titanium aluminium nitrida melalui proses deposit wap fizikal semasa larik keras kemasan keluli tahan karat "Stavax Electro-Slag-Refining" (HRC 47 - 48). Kelajuan yang berlainan iaitu 99.41, 130 dan 170 m/min dan tiga kadar uluran yang berlainan iaitu 0.098, 0.125 dan 0.16 mm/pusingan telah digunakan. Ujian larik dijalankan dalam keadaan kering dan pada kedalaman pemotongan yang tetap. Daya – daya pemotongan, kemasan permukaan serta morforlogi serpihan telah dikaji dalam kajian ini. Didapati ukuran kemasan permukaan adalah pada nilai yang memuaskan. Daya "*radial*" adalah daya yang dominan berbanding daya – daya yang lain. Serpihan terusan didapati pada semua keadaan pemotongan. Serpihan gigi gergaji diperolehi di hampir kesemua keadaan pemotongan kecuali pada kelajuan pemotongan dan uluran rendah. Kaedah '*3 level full factorial design*' telah digunakan untuk membina model matematik bagi daya "*radial*" and kemasan permukaan. Model matematik yang dibangunkan didapati sah dan kukuh secara statistik, khususnya bagi Fr dan keemasan permukaan. Ini telah disahkan oleh ujikaji pengesahan dan model matematik ini boleh digunakan dalam lingkungan kelajuan dan uluran yang telah ditetapkan. Berdasarkan kajian ini, dapat disimpulkan bahawa larik keras menggunakan mata alat karbida bersalut berfeometri konvensional adalah memuaskan.

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LIST OF SYMBOLS AND ABBREVIATIONS

A, B, ..	-	Variable used in the design of experiment
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of variance
BUE	-	Built up edge
CBN	-	Cubic Boron Nitride
CVD	-	Chemical vapour deposition
DOC	-	Depth of cut
EDAX	-	Energy dispersive analysis by X ray Spectroscopy
et al.	-	and others
ESR	-	Electro-Slag-Refining
Fc / Fx	-	Tangential / Cutting force
Fr / Fy	-	Radial force
Ft / Fz	-	Feed force
FI	-	Factor interaction
FN	-	Finishing negative
FW	-	Finishing wiper
HRC	-	Hardness Rockwell
ISO	-	International Organization for Standardization
Kr	-	Major cutting edge angle
NR	-	Nose radius
PCBN	-	Polycrystalline cubic boron nitride
PCD	-	Polycrystalline diamond
PVD	-	Physical vapour deposition
RSM	-	Response Surface Methodology
SCEA	-	Side cutting edge angle

TiAlN	-	Titanium Aluminium Nitride
TiC	-	Titanium carbide
TiN	-	Titanium Nitride
UTM	-	Universiti Teknologi Malaysia
VB_B	-	Average width of flank wear land in zone B
WC	-	Tungsten carbide
φ	-	Shear angle
f	-	Tool feed rate
Al_2O_3	-	Aluminium oxide
R_a	-	Arithmetical mean surface roughness
r_ε	-	Corner radius
α_b	-	Back rake angle
α_s	-	Side rake angle
θ_e	-	End relief angle
θ_s	-	Side relief angle

CHAPTER 1

INTRODUCTION

Machining is a versatile shaping process of major importance for component manufacturing. The importance of machining in modern automated manufacturing systems has in fact increased due to the significant increase in the production time and the need to offset the high capital investment in these modern systems. The need for improving the technological performance of machining operations as assessed by the cutting forces, power, tool life and surface finish has long been recognized to increase the economic performance of the machining operations. As such, continual improvements in the technological performance of machining operations have been sought through research and development including new and more wear resistant tool materials as well as new geometrical tool designs [1,6].

1.1 Background

Hard turning is a more economical technique that is developed to substitute grinding in the finishing operations of hardened material of HRC 45 and above.

A good surface finish can lead to longer service life and improved efficiency of the engineering component. Previously, this can only be done by secondary processes such as grinding. However, the idea today is to eliminate this step by replacing it with finish hard turning which is capable of producing a surface with similar surface roughness. Finish hard turning is a process by which hardened steels with hardness Rockwell C (HRC) 45 and above are finish turned. Such hardened steel especially stainless tool steel has wide applications in the mould and die industry. This is mainly due to the properties of the material that has good corrosion resistance, polishability, wear resistance, machinability, and stability in hardening and high surface finish. The roughness average, R_a value to be achieved in finish turning is 1.6 μm and below. This value is consistent with the requirement found on many engineering drawings.

Hard turning have several advantages over grinding. The advantages of hard turning are [1,2,3]:

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

Audy *et al.* (1995) during his experiment on machining low carbon steel using uncoated and coated carbide inserts and ceramic inserts found out that increase in Fr is influenced principally by the cutting parameters such as the feed rate and depth of cut, while variations in the cutting force components are caused mainly by the geometry of the cutting inserts tested. When inserts of the same shape but having different coatings were tested, ceramic inserts produced about 50% less force compared with carbide insert in the initial periods. In the final period, the forces were approximately 20% of those produced with a carbide insert.

Chen (2000) found out that when finish cutting of hardened steel, the radial force (F_y) became the largest among the three cutting force components and was the most sensitive to the changes of cutting edge chamfer, tool nose radius and flank wear. Although an unchamfered tool with a small nose radius generated low F_y and hence reduce the tendency to chatter, such geometry decrease the tool life.

Noordin (2004) in his study on the performance of coated carbide insert when turning AISI 1045 steel utilized response surface methodology (RSM). It was found that feed rate is the most significant factor influencing the cutting force and surface roughness. It was also found out that an increase in cutting speed and feed reduce the tool life for KT 315 and KT 9110. F_c is the dominant force for all cutting speed. High feed speed produces loose arc chips. Mathematical models developed to predict radial force produce sound results. Flank wear and catastrophic failure are the two main types of tool failure mode for KT 315 and end clearance and flank wear for KT 9110.

The response surface methodology (RSM) approach has successfully used in developing machinability models thereby avoiding the one-factor-at-a-time study [7].

Thus from these research, the cutting force was influenced by the feed rate and the radial force is higher is most of the experience conducted by other researchers.

1.2 Problem statement

Most of the cutting forces research involves the use of CBN, ceramic and PCBN tools to turn material such as carbon steel and mild steel. However the usage of carbide cutting tools to turn hardened steel in the range of HRC 47 - 48 is lacking. Carbide tools have good resistance to wear, thermal shock and corrosion. Coated carbide tools which are relatively lower in cost are seen as a possible replacement especially with the introduction of new coatings such as physical vapor deposition (PVD) titanium aluminium nitride (TiAlN).

Thus, limited research had been conducted to obtain the relation between the surface finish and the cutting force using carbide cutting tools for hardened steel of HRC 47- 48. This combination of methodology is limited in UTM thus; the results obtained would be used for comparison purpose and also to analyze previously done research involving the STAVAX and physical vapor deposition (PVD) titanium aluminium nitride (TiAlN) tools.

This study will also attempt to apply design of experiment technique to develop mathematical model for main cutting force and surface roughness when hard turning KC 5010 cutting tool on hardened stainless tool steel (STAVAX ESR) of hardness value between HRC 47 and 48.

1.3 Objectives

The objectives of this evaluation are;

1) To evaluate the performance of coated carbide cutting tools when turning hardened stainless tool steel (STAVAX ESR) at various cutting conditions in terms of cutting forces and surface finish of the turned part.
2) To develop mathematical models for the main cutting force and surface finish.
3) To study the chip morphologies at various cutting conditions.

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