# PERFORMANCE OF COATED CARBIDE TOOL IN LOW SPEED MILLING OF STAINLESS STEEL UNDER FLOOD AND MIST LUBRICATION

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**SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY**
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**2009**

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## ABSTRACT

## PERFORMANCE OF COATED CARBIDE TOOL IN LOW SPEED MILLING OF STAINLESS STEEL UNDER FLOOD AND MIST LUBRICATION

Most of the research works on the milling of stainless steel in the past were carried out at cutting speeds of higher than 100 m/min and had reported that the optimum speeds for milling steel were in the range of 100 m/min to 150 m/min. In some cases, milling at low speeds is inevitable. Some solid end-mill tools used to produce small features such as pockets and slots have a diameter of less than 2 mm. If a tool with diameter of 2 mm is used, milling cannot be performed at speeds higher than 100 m/min if the machine employs a spindle with a maximum rotational speed of less than 16,000 rpm. However, many milling machines use spindles with rotational speeds much less than this value. The aim of the work described in the dissertation is to provide an improved understanding of the performance of AlN/TiN nano-coated solid carbide ball nose end-mill tool in milling stainless steel at low speed (below 100 m/min) under conventional flood and mist lubrication condition. The tool wear behaviour and the morphology of the surface finish obtained under different lubrication conditions were examined. In particular, the effect of the hardness of the workpiece, helix angle of the cutting tool and the effectiveness of mist and flood lubrication in low-speed milling of stainless steel were investigated. The machining were carried out at the cutting speed of 50 m/min and 88 m/min, depths of cut of 0.2 mm and 0.4 mm and feeds rate of 0.04 mm/tooth, 0.01 mm/tooth and 0.004 mm/tooth. The machining tests were performed on STAVAX (modified AISI 420 stainless steel) with the hardness of 35 and 55 HRC using Okuma milling machine under conventional flood and mist lubrication conditions. Abrasion, chipping and catastrophic failure are the wear modes encountered during machining under flood lubrication condition. The abrasive wear and the likeliness of the cutting tool to chip and fail prematurely increased with an increase in the hardness of the workpiece and a reduction in the helix angle of the tool. Small quantity of natural oil sprayed in mist form was effective in reducing the tool wear and severity of abrasion wear, and preventing catastrophic failure. Throughout the entire duration of machining of 35 and 55 HRC of stainless steel under mist lubrication condition, the cutting edge of the 25° and 40° helix angle tools only suffered small-scale edge chipping and abrasive wear. The ductility of the workpiece had significant influence on the surface finish of the workpiece. In particular, it was found that in milling STAVAX with a hardness of 55 HRC, despite the tool was being subjected to a more severe wear, the surface finish was more superior than that of the workpiece with the hardness of 35 HRC.

## ABSTRAK

*Kebanyakan kerja memesin keluli yang dilaporkan sebelum ini dijalankan dengan kelajuan pemesinan yang melebihi 100 m/min dan kelajuan optima untuk mengisar keluli (milling steel) adalah antara 100 m/min hingga 150 m/min. Dalam sesetengah kes, mengisar (milling) di kelajuan rendah adalah tidak dapat dielakkan. Sesetengah pisau pengisar hujung padat (solid end-mill tool) yang digunakan untuk membuat poket, lubang dan celah yang kecil mempunyai diameter yang kurang daripada 2 mm. Jika pisau pengisar dengan diameter 2 mm digunakan, proses mengisar tidak dapat dijalankan pada kelajuan yang lebih tinggi daripada 100 m/min jika gelendong mesin mengisar itu berputar pada kelajuan maksimum yang kurang daripada 16,000 rpm. Adalah didapati bahawa banyak mesin pengisar mempunyai gelendong yang berputar dengan kelajuan yang lebih kurang daripada nilai ini. Tujuan kerja dalam disertasi ini adalah untuk memberi pertambahan pemahaman prestasi pisau pengisar karbida yang bersalut dalam mengisar keluli tahan karat pada kelajuan yang perlahan (di bawah 100 m/min) dalan keadaan pelinciran banjir dan kabus semburan (flood and mist spray). Mekanisma kehausan pisau pengisar and mofologi kekemasan permukaan di bawah situasi yang berbeza akan dikaji. Kepengaruhan kekerasan bahan kerja, sudut heliks pisau pengisar and keberkesanan pelinciran banjir and kabus semburan akan diselidik. Kerja pengisaran dijalankan pada kelajuan 50 m/min dan 88 m/min, kedalaman pemotongan 0.2 mm dan 0.4 mm, dan penyaluran bahan (feed rate) 0.04 mm/gigi, 0.01 mm/gigi, dan 0.004 mm/gigi. Ujian-ujian pengisaran dijalankan di atas bahan kerja STAVAX (keluli tahan karat yang diubahsuai AISI 420) degan kekerasan 35 dan 55 HRC dengan menggunakan mesin pengisar Okuma di dalam keadaan pelinciran banjir and kabus semburan. Lelasan (abrasion), penyerpihan (chipping) dan kegagalan (failure) adalah ciri-ciri yang ditemui semasa pemesinan di dalam keadaan pelinciran banjir. Lelasan dan kemungkinan pisau pemotong untuk menyerpih dan gagal bertambah dengan peningkatan dalam kekerasan bahan kerja dan pengurangan sudut heliks alat pemotong. Kuantiti kecil minyak semula jadi yang disembur dalam bentuk kabus adalah berkesan untuk mengurangkan kehausan pisau pengisar dan keterukan lelasan, dan mencegah kegagalan pisau pemotong. Sepanjang tempoh memesin bahan kerja 35 dan 55 HRC keluli tahan karat (HRC-SS) di dalam keadaan peliciran kabus semburan, pisau pengisar yang bersudut heliks 25° dan 40° sudut heliks hanya dikenakan penyerpihan dan lelasan yang berskala kecil. Kemuluran bahan kerja mempunyai pengaruh yang penting kepada kemasan permukaan kerja. Khususnya, adalah didapati dalam pengisaran 55 HRC-SS, walaupun kehausan pisau pengisar menjadi lebih teruk, kemasan permukaan adalah lebih baik berbanding dengan pengisaran 35 HRC-SS.*

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## TABLE OF CONTENTS

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AlCrN | Aluminium chromium nitride |
| AlN | Aluminium nitride |
| AlTiCN | Aluminium titanium carbon nitride |
| AlTiN | Aluminium titanium nitride |
| BUE | built-up edge |
| CAD | computer aid design |
| CAM | computer aid manufacturing |
| CCNG | compressed cold nitrogen gas |
| CCNGOM | compressed cold nitrogen gas and oil mist |
| CNC | computer numerical controlled |
| CrN | chromium nitride |
| CVD | chemical vapour deposition |
| DLC | diamond-like carbon |
| DOC | depth of cut |
| fcc | face centred cubic |
| HRC | Rockwell hardness "C" |
| HRC-SS | stainless steel with Rockwell hardness "C" |
| HSM | high speed milling |
| m | meter |
| m/min | meter per minute |
| mm | milimeter |
| MQL | Minimum quantity lubrication |
| NaCl | natrium chloride |

| | |
|---|---|
| PVD | physical vapour deposition |
| rpm | revolution per minute |
| SS | stainless steel |
| TiC | titanium carbon |
| TiCN | titanium carbon nitride |
| TiN | titanium nitride |
| Vol | volume |
| WOC | cross over/ width of cut |

## LIST OF EQUATIONS

## LIST OF FIGURES

## LIST OF SYMBOLS

| | |
|---|---|
| % | percentage |
| ± | plus or minus |
| Al | Aluminium |
| Cl | chlorine |
| Cr | chromium |
| *D* | diameter |
| Fe | ferrous |
| *L* | length |
| Mn | manganese |
| N | Nitride |
| *N* | revolution |
| Na | sodium |
| O | oxygen |
| *ø* | Shear angle |
| Si | Silicon |
| *T* | Tool life |
| Ti | Titanium |
| *tc* | chip thickness |
| *W* | width |
| $\alpha$ | Rake angle |
| $\beta$ | helix angle |
| *v* | Cutting speed |

**LIST OF TABLES**

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Nowadays, science and technology plays a very important role in manufacturing and production. Studies have been carried out to improve the advance technologies and manufacturing methods such as machine tool design, controller system, tool holding devices, and tooling technology which has significant impact on the quality of the products. The introduction of the computer aid design and computer aid manufacturing (CAD/CAM), such as computer numerical controlled (CNC) milling and turning (Chevrier *et al.*, 2003; Mansour & Abdalla, 2002; Toh, 2004) had a deep impact to the engineering industry.

Milling is a widely employed material removal process for different materials, and it is characterized by high material removal rate (Reddy & Rao, 2006). The major difficulties encountered in the milling process are the tool wear and surface finish. During the cutting process, tool wear is caused by the mechanical and chemical interaction between the tool, workpiece and environment (Attanasio *et al.*, 2006; Sokovic *et al.*, 2001). This includes the relative motion between tool-chip and tool-workpiece, and the chemical reactions induced between tool-coolant during the cutting process. Nevertheless, the tool wear in end-milling is also dependent on the length of the sliding contact between the tool and the workpiece. As the length of the sliding contact between the tool and the workpiece decreases in proportion to the increases of the feed rate, the tool wear is expected to be reduced (Rahman *et al.*, 2003). Tool wear affects the dimension accuracy and surface quality of the milled surface (Kumar *et al.*, 2006). Flank wear is the predominant wear in the determination of tool wear and tool life, where most of the researchers described the tool wear in term of flank wear and by measuring the flank wear. In milling, both tool wear and the surface finish are two important factors in evaluating the performance of cutting tool.

Generally there are two types of wear, i.e. mechanical wear and chemical wear (Sokovic *et al.*, 2001). Abrasive wear, chipping and fracture are examples of mechanical wear. Chemical wear is the thermo-chemical wear resulting from chemical interaction between the tool, workpiece and environment such as diffusion wear. Figure 1.1 shows the occurrence of different types of chemical and mechanical wear.

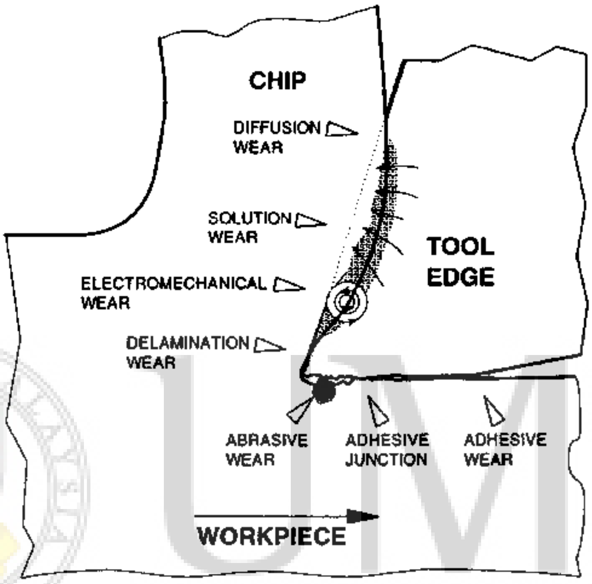


**Figure 1.1: Schematic diagram showing the location of different types of wear taking place**

Source: Sokovic *et al.*, (2001)

The milling condition depends on the cutting environment, cutting parameters, cutting tool and workpiece (Ema & Davies, 1989; Korkut & Donertas, 2007; Richetti *et al.*, 2004; Stanford *et al.*, 2007; Tsao & Hong, 2002; Tzeng, 2007). Hence, research is essential to determine the optimum cutting conditions. Recommendations from manufacturers should only be used as a guide because better cutting conditions for a specific situation can only be found through research (Richetti *et al.*, 2004). Various methods had been explored to improve the tool life and surface finish. These include the use of different cutting parameters, geometries of tool, types of cutting fluids, and coating material on the tool (Rahman *et al.*, 2003).

The cutting of metal is the major metal shaping process in the production of engineering components (Sokovic *et al.*, 2001). Steel is one of the most common materials (metal) in the world and a major component in constructions, buildings, infrastructure, tools, ships, automobiles, machines and appliances (Wikipedia, 2009). Stainless steel has good mechanical and chemical properties, and it plays an extremely important role in the engineering industry. The machining of stainless steel materials generally gives short tool life, limited metal removal rate, large cutting forces and high power consumption. These could be attributed to the high temperature strength, rapid work-hardening during machining and reactivity with the tool materials at high cutting speed (Lin, 2002). Short tool life and poor surface finish are the two main problems encounter in machining stainless steel, which generally regarded as difficult-to-machine material (Shao *et al.*, 2007).

## 1.2 Metal Cutting Process

In machining, chip formation takes place by a process of intense plastic shearing in a region known as the primary deformation zone, as shown in figure 1.2. This zone extends from the tool cutting edge to the junction between the surface of the chip and workpiece. The chip has a freshly created clean surface and, as it flows up to the tool rake face, it is subjected to very high normal stress. Under these conditions, strong adhesion occurs between the nascent chip and the tool and this chip can results an additional shear in the region of the chip adjacent to the tool face known as the secondary shear zone. In practice, the primary shear zone is often idealized as a plane, called the shear plane. The angle of the inclination of the shear plane to the direction of cutting is called the shear angle (Liew, 2004).

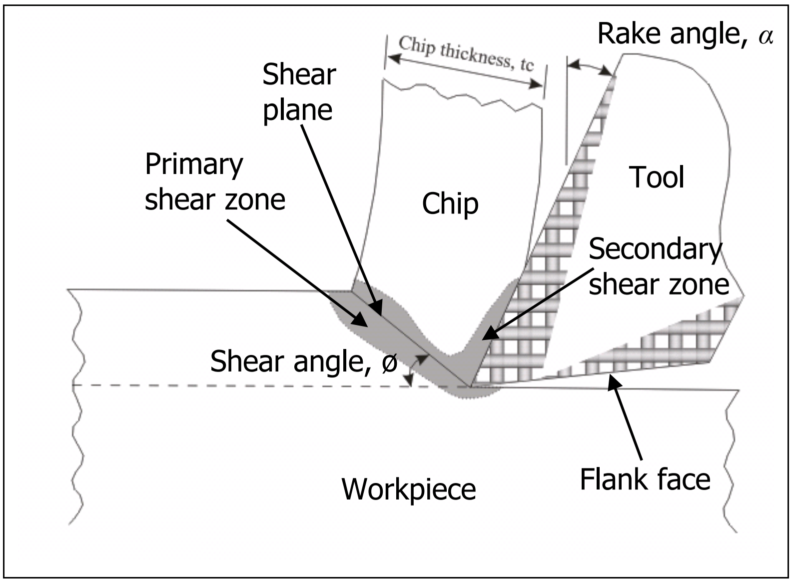


**Figure 1.2: Schematic geometry of orthogonal cutting**

Source: Liew (2004)

Over the secondary shear contact region, regions of both sticking and sliding friction occur. Over this part of the contact, the normal stress rises steeply to a maximum value at the cutting edge (figure 1.3). Deformation occurs in the lower layers of the chip material and the real contact area approaches the apparent area. The frictional stress is constant and independent of the normal stress, and equal to the bulk shear flow stress of the chip material. Over the remainder of the contact, at some distance away from the cutting edge, sliding friction occurs in which the coefficient of friction is constant. In this region, relative motion between the chip and the tool occurs at the interface between the contacting asperities (Liew, 2004).