LEM21

The 4th International Conference on Leading Edge Manufacturing in 21st Century

November 7-9, 2007, Fukuoka, Japan

Venue: Fukuoka International Congress Center

Sponsored by the Japan Society of Mechanical Engineers (JSME),

Organized by the Manufacturing and Machine Tool Division and the Manufacturing Systems Division

Welcome

[Return to top page]

WELCOME MESSAGE FROM GENERAL CHAIR OF LEM21

Welcome to Fukuoka, Japan for the 4th International Conference on Leading Edge Manufacturing in the 21st Century, entitled LEM21-Fukuoka, organized and sponsored by both the Manufacturing and Machine Tool Division, and the Manufacturing System Division of the Japan Society of Mechanical Engineers (JSME).

The city of Fukuoka is located geographically in Kyushu island, the southern part of Japan. The conference site, the Fukuoka International Congress Center, is located in the seaside of the Fukuoka city. Fukuoka city is very near to Korea, China, Taiwan and Southeastern Asia, so Fukuoka is called "the gateway to Asia". From 7th to 11th century Fukuoka, whose old name was Hakata, has been open to Korea and China regarding the trade and culture. Afterward Kyushu island has been, for a long time, a base of heavy industry, like iron & steel, ship, porcelain industry, robot industry, and so on. Recently, Kyushu island is becoming the hub of the production of semiconductor, flat panel display, automobile and clear distilled liquor (shochu) in Japan.

The previous conferences were held in Tokyo in 1997, in Niigata in 2003 and in Nagoya in 2005 with great success, sponsored by JSME. This conference will provide an interdisciplinary forum for the exchange of information on the leading edge research and development in manufacturing

The program of the conference includes one keynote speech and thirteen organized sessions. A keynote speech will focus on high performance superabrasive grinding. More than 190 selected papers will be delivered in seven rooms. A welcome party and banquet, and short tours as well as the industrial panel exhibition will be held.

On this occasion, we would like to focus on the potential of engineering, from the manufacturing point of view, for enhancing our life quality and simultaneously caring for the environment of the earth. As we all know we must cope with the rapidly changing technology development and at the same time, we can not neglect the issue on environment degradation. We would like you to enjoy this conference through lively and active participation in various events and exciting discussions about future manufacturing technologies and systems for the sustainable growth and development of the world.

I would like to express my deepest thanks to all members of the Organizing Committee, Program Committee and Kyushu Committee for their cooperation in preparing the Program and the Proceedings. I also would like to express my sincere thanks to the Fukuoka Convention & Visitors Bureau for their financial support.

Finally, I offer my best wishes to all the participants and I hope you have a wonderful and meaningful stay in this city of Fukuoka and Kyushu island.

Thank you very much !

Professor Hiromichi Onikura
Chair of LEM21-Fukuoka Organizing Committee
Kyushu University

[Return to top page]

Committees

[Return to top page]

Committees

Organizing Committee

Hiromichi ONIKURA, Kyushu University, General Chair

Masaomi TSUTSUMI, Tokyo University of Agriculture and Technology, Vice General Co-Chair

Akimitsu NAGAE, Yamazaki Mazak Corp, Vice General Co-Chair

Yoshio MIZUGAKI, Kyushu Institute of Technology, Vice General Co-Chair and Chair of Program Committee

Jun'ichi TAMAKI, Kitami Institute of Technology, Chair of Finance Committee

Takuya SENBA, Fukuoka Institute of Technology, Chair of Kyushu Committee

Yuji FURUKAWA, Tokyo University of Agriculture and Technology, Past General Chair and honorable advisor

Yoshiharu NAMBA, Chubu University, Past General Chair

Takashi NAKAMURA, Nagoya Institute of Technology, Past General Secretary

Masami MASUDA, Niigata University, Past General Secretary

Toshiyuki OBIKAWA, The University of Tokyo, Past General Secretary

Yoshimi TAKEUCHI, Osaka University, Past Co-Chair

Masahiro ANZAI, RIKEN

Eiichi AOYAMA, Doshisha University

Hideki AOYAMA, Keio University

Tojiro AOYAMA, Keio University

Koichi MORISHIGE, University of Electro-Communications

Noboru MORITA, Toyama University

Nobuyuki MORONUKI, Tokyo Metropolitan University

Hitoshi OHMORI, RIKEN

Etsuji OHMURA, Osaka University

Osamu OHNISHI, Kyushu University

Akira OKADA, Okayama University

Koichi OKUDA, University of Hyogo

Hiroyuki SASAHARA, Tokyo University of Agriculture and Technology

Kazuyuki SASAJIMA, Tokyo Institute of Technology

Masahiko SATO, Tottori University

Shinji SHIMIZU, Sophia University

Hidenori SHINNO, Tokyo Institute of Technology

Tadahiko SHINSHI, Tokyo Institute of Technology

Keiichi SHIRASE, Kobe University

Nobuhiro SUGIMURA, Osaka Prefecture University

Hirofumi SUZUKI, Kobe University

Hiroshi Suzuki, Kyushu Institute of Technology

Yasuhiro TAKAYA, Osaka University

Kiwamu ASHIDA, AIST

Wei GAO, Tohoku University

Shinya HAYAKAWA, Nagoya Institute of Technology

Yoshio ICHIDA, Utsunomiya University

Yukitoshi IHARA, Osaka Institute of Technology

Toyoshiro INAMURA, Nagoya Institute of Technology

Hiroyasu IWABE, Niigata University

Akio KATSUKI, Kyushu University

Tadao KAWAI, Osaka City University

Koichi KIKKAWA, Kyushu Institute of Technology

SungLim KO, Konkuk University

Eiji KONDO, Kagoshima University

Tsunemoto KURIYAGAWA, Tohoku University

Muneharu KUTSUNA, Nagoya University

Hwa-Soo LEE, Nihon University

Atsushi MATSUBARA, Kyoto University

Takashi MATSUMURA, Tokyo Denki University

Yosuke TAKEUCHI, Toto LTD.

Takeshi TANAKA, Ritsumeikan University

Hisataka TANAKA, Tottori University

Jun TANIGUCHI, Tokyo University of Science

Naoki TOUGE, Noritake Super Abrasive Co. Ltd

Takashi UEDA, Kanazawa University

Yasushi UMEDA, Osaka University

Noritsugu UMEHARA, Nagoya University

Yoshiyuki UNO, Okayama University

Shin'ichi WARISAWA, The University of Tokyo

Takao YAKOU, Yokohama National University

Hitomi YAMAGUCHI, University of Florida

Jiwang YAN, Tohoku University

Takanori YAZAWA, Nagasaki University

Shaohui YIN Hunan University

Nobuhito YOSHIHARA, Tohoku University

Libo ZHOU, Ibaraki University

International Program Committee

Yoshio MIZUGAKI, Kyushu Institute of Technology, Vice General Co-Chair and Chair of Program Committee

Koichi KIKKAWA, Kyushu Institute of Technology

Mutsumi TOUGE, Kumamoto University

Kyushu Committee

Takuya SENBA, Fukuoka Institute of Technology

Hiroshi SUZUKI, Kyushu Institute of Technology

Hiroyuki NARAHARA, Kyushu Institute of
Chair of Kyushu Committee Technology

Yasuhiko OGIYA, Nagasaki University

Takanori YAZAWA, Nagasaki University

Osamu OHNISHI, Kyushu University

Kohji AKASHI, Ariake Technical College

Koichi KIKKAWA, Kyushu Institute of Technology

Yoshihiro KOHNO, Kagoshima Technical College

Eiji KONDO, Kagoshima University

Makoto KURUSU, Sasebo Technical College

Yoshio MIZUGAKI, Kyushu Institute of Technology

Kisaburo NAGANO, Kurume Technical College

Tsutomu NAKANISHI, Miyazaki University

Hiromichi ONIKURA, Kyushu University

Hoa QIU, Kyushu Sangyo University

Shigehiko SAKAMOTO, Kumamoto University

Toshio SUZUKI, Fukuoka University

Hisanori TERAI, Kitakyushu Technical College

Mutsumi TOUGE, Kumamoto University

Yoshihiro TSUDA, Oita University

Heiji YASUI, Kumamoto University

Hidehiro YOSHINO, Saga University

Junji WATANABE, Kumamoto University

International Advisory Committee

Yusuf ALTINTAS, The University of British Columbia, Canada

Gerry BYRNE, University College Dublin, Ireland

Thomas H. C. CHILDS, University of Leeds, UK

Han DING, Shanghai Jiao Tong University, China

David DORNFELD, University of California Berkeley, USA

Guo Yon FENG, Harbin Institute of Technology, China

Dongming GUO, Dalian University of Technology, China

Tian HUANG, Tianjin University, China

Ichiro INASAKI, Keio University, Japan

Renke KANG, Dalian University of Technology, China

Jianbin LUO, Tsinghua University, China

Ioan MARINESCU, The University of Toledo, USA

Toshimichi MORIWAKI, Kobe University, Japan

Andrew Y. C. NEE, National University of Singapore, Singapore

Mustafizur RAHMAN, National University of Singapore, Singapore

JiaMing SHYU, Chien Kuo Institute of Technology, Taiwan

Alexander H. SLOCUM, Massachusetts Institute of Technology, USA

Hendrik Van BRUSSEL, Katholieke Universiteit Leuven, Belgium

V. C. VENKATESH, Univeriti Teknogi Malaysia, Malaysia

Huayong YANG, Zhejiang University,

Fritz KLOCKE, RWTH Aachen, Germany

Ranga KOMANDURI, Oklahoma State University, USA

Jang Mo LEE, Seoul National University, Korea

China

Guoxiong ZHANG, Tianjin University, China

Youzhen ZHANG, Nanjing University of Aeronautics & Astronautics, China

[Return to top page] [Top of this page]

Program (The first day)

[Return to top page]

November. 7, 2007

Keynote paper

High Performance Superabrasive Grinding
David STEPHENSON and Paul COMLEY

Room A

-Milling-

7A [101]	**Surface Integrity in Ball Nose End Milling** *Noriyuki KORETA, Hiroyuki SAKAI, Hiroaki EZAKI and Noriaki NAGAYOSI*
7A [102]	**Dynamic Characteristics of Small Diameter End Mill** *Takashi MATSUMURA, Yasuaki MIYAHARA and Takenori ONO*
7A [103]	**Modeling for Surface Roughness in End-Milling of Titanium Alloy Ti-6Al-4V Using Uncoated WC-Co and PCD Inserts** *Turnad L. GINTA, A.K.M. Nurul AMIN, A.N. Mustafizul KARIM and M. H. ISHTIYAQ*
7A [104]	**Experimental Investigations on Surface Roughness during End Milling of AISI H13 Hardened Tool Steel** *A.M.K. HAFIZ, A.K.M.N. AMIN, M.A. LAJIS*
7A [105]	**Tool Path Generation for the Formation of a Geometric Surface Pattern on a Curved Surface by Patch Division Milling** *Hiroshi MATSUDA, Hiroyuki SASAHARA, Masaaki FUKUDA and Masaomi TSUTSUMI*
7A [106]	**Break**

-Difficult to cut materials-

7A [107]	**Effect of Edge Geometry on PVD-TiN Coated Carbide Tools when Face Milling Titanium Alloy, Ti-6246** *Safian SHARIF, Erween Abd. RAHIM, Amrifan Saladin MOHRUNI, Ashraf JAWAID*
7A [108]	**Prediction of Surface Roughness in Hard Milling of AISI D2 Tool Steel** *M.A. LAJIS, A.N. Mustafizul KARIM, A.K.M. Nurul AMIN, A.M.K. HAFIZ*
7A [109]	**Finish machining of Inconel 718 by circular vibration planing - an alternative for ball end milling** *Nandita HETTIARACHCHI, Toshimichi MORIWAKI, Toshiro SHIBASAKA and Keiichi NAKAMOTO*
7A [110]	**High Speed Drilling Ti6Al4V** *Kamaruddin KAMDANI, Erween Abd. RAHIM and Safian SHARIF*

7A [111] **Break**

7A [112] **Break**

[Top of this page]

Room B

-Chemical grinding-

7B [201] **Research on Chemo-Mechanical-Grinding (CMG) of large size silica glass substrate**
Takeshi SHIINA, Libo ZHOU, Zhongjun QIU, Takeyuki YAMAMOTO, Jun SHIMIZU and Hiroshi EDA

7B [202] **Development of High Performance Wheels for Chemo-Mechanical-Grinding**
Yoshiaki Tashiro, Masaaki Kenmochi, Bahman Soitani, Tatsuya Tsuruga, Libo Zhou, Jun Shimizu and Hiroshi Eda

7B [203] **Chemical Mechanical Polishing for Oxygen Free Copper with Manganese Oxide Abrasives**
Ryunosuke SATO, Yoshio ICHIDA, Yoshitaka MORIMOTO and Kenji SHIMIZU

7B [204] **PCD Dressers for Chemical Mechanical Planarization with Unform polishing**
Hiroshi ISHIZUKA, James C. SUNG and Michael SUNG

7B [205] **Break**

-Polishing and etching-

7B [206] **Intelligent Polishing of Free Form Surface by Grinding Center**
Yoshihiro KITA, Kiku IKOKU and Xiaojun WU

7B [207] **Investigation on Reactive Ion Etching CVD Diamond Film**
Choung-Lii Chao, Wen-Chen Chou, Ta-Tung Chen and Chung-Woei Chao

7B [208] **A Polishing System assisted by Ultrasonic Vibration Suppresses Loading of Felt-buff**
Masahiko MIZUI, Yoshio MIZUGAKI, Koichi KIKKAWA and Keisuke KAMIJO

7B [209] **Break**

-Grinding method-1-

7B [210] **Grinding of C/C-SiC Composite**
Tetsuya TASHIRO and Junsuke FUJIWARA

7B [211] **Proposal of Optimum Grinding Cycles for Removal of Surface Damaged Layers**
Takazo YAMADA, Hwa-Soo LEE and Hayato TSUYUKI

7B [212] **Effect of Coolant Flow Rate on Surface Topography When Precision Grinding Silicon Using Mounted Diamond Pins**
M. KONNEH, S.IZMAN, A. R. ALAO, AFZERI, M. MUHAMAD and M. ROZAIDI

[Top of this page]

Room C

-Control and application of industrial robot-

7C [301] CAD/CAM-based Position/Force Control for a Ball-end Abrasive Tool and Its Application to an Industrial Robot
Fusaomi NAGATA, Tetsuo HASE, Zenku HAGA, Masaaki OMOTO and Keigo WATANABE

7C [302] Method for Determining the Power-saved Driving Motion of Manipulators by Heuristic Algorithms (In Case of CP Control)
Michihiro HAYASHI, Hiroshi TACHIYA, Naoki ASAKAWA and Yutaka MATSUBARA

7C [303] Automatic Tool Path Generation for Robot Integrated Surface Sculpturing System
Jiang ZHU, Ryo SUZUKI, Tomohisa TANAKA and Yoshio SAITO

7C [304] **Break**

-Adaptive control and process control-

7C [305] An Adaptive Control of Ultraprecision Machining with an In-Process Micro-sensor
Mamoru HAYASHI, Hayato YOSHIOKA, Hidenori SHINNO

7C [306] Motion Control Techniques of Rotary Table for 5-axis Machining Centers
Ryuta SATO, Daisuke ENDO and Masaomi TSUTSUMI

7C [307] A Long-term Control Scheme of Cutting Forces to Regulate Tool Life in End Milling Processes
Soichi IBARAKI, Takuya SHIMIZU and Atsushi MATSUBARA

7C [308] **Break**

-Nanomachining, brittle material processing-

7C [309] Consistent Processing and Measurement Procedure on Micro Cutting
Tetsuya NARUSE, Kazu ANDOU, Yutaka KAMEYAMA, Masayoshi MIZUTANI, Yoshihiro UEHARA, Kazutoshi KATAHIRA, Weimin LIN, Chikako SASAKI and Hitoshi OHMORI

7C [310] Study on Nanomachining Process of Si Wafer using an Atomic Force Microscope
Jun SHIMIZU, Takashi TSUMURA, Yumetaka SUEHISA, Libo ZHOU, Hiroshi EDA

7C [311] **Break**

7C [312] **Break**

[Top of this page]

Room D

-Measurement technology, mechanical measurement and instrumentation-

7D [401] A Novel Interpolation method for Quadrature Encoder
LIU Yong, HAO Shang-hui , HAO Ming-hui and Li De

7D [402] A study on the Model of 3D-coordinate Measuring Machine Error Compensation Based on Finite Element Simulation
Jizhu Liu, Shuanghui Hao, Minghui Hao and Baoyu Song

7D [403] Development of Cutting Torque Measurement Technique for Milling Process with Small Diameter End Mill
Tadao KAWAI and Yuichi MIZUTANI

7D [404] Sensing Technology of Micro Tool Edge Position by Using the Total Internal Reflection of Laser
Masaaki. NAKAZAWA, Yasuhiro. KAKINUMA and Tojiro. AOYAMA

7D [405] **Break**

-Precision positioning table (nano positioning table)-

7D [406] High Precision Positioning Control for Table Drive System using PID Controller with Nonlinear Friction Compensator
Kazuhiro TSURUTA, Kazuya SATO, Takashi FUJIMOTO and Nobuhiro USHIMI

7D [407] A Newly Developed Compact Nano-Positioning Table System Using Squeeze Bearing
Toshimichi GOKAN, Hayato YOSHIIOKA and Hidenori SHINNO

7D [408] Vertical Nano-Positioning System with Gravity Compensator
Motohiro TAKAHASHI, Hayato YOSHIOKA and Hidenori SHINNO

7D [409] **Break**

-High speed machining (positioning)-

7D [410] NURBS Interpolator for Improved High Speed Machining using Minimum Time Method
Dong-Mok LEE, Sekar MOHAN and Seung-Han YANG

7D [411] High-speed Electrical Discharge Machining with a 5-DOF Controlled Maglev Actuator
Xiaoyou ZHANG, Tadahiko SHINSHI, Akira SHIMOKOHBE, Yoshihito IMAI, Hidetaka MIYAKE and Takayuki NAKAGAWA

7D [412] **Break**

[Top of this page]

Room E

-Tool development, tool measurement-

7E [501] Fabrication of Micro Compound Tools and Their Application in Drilling
Muhammad Aziz, Osamu OHNISHI, Hiromichi ONIKURA, Nuraslina Sharkawi and Weichen KUO

7E [502] Grooving Performances of Developed Micro Diamond Grinding Tool by Electroless Composite Plating on Hard and Brittle Materials
Ahmad SHARIFUDDIN, Hiromichi ONIKURA, Osamu OHNISHI and Heung-Kil PARK

7E [503] Fabrication of Micro Diamond Tools by Electroless Composite Plating and Micro Grinding
Heung-Kil PARK, Hiromichi ONIKURA, Osamu OHNISHI and Ahmad SHARIFUDDIN

7E [504] **Tool Tip Temperatures in End Milling Application of Infrared Radiation Pyrometer with Optical Fibers**
Masahiko SATO and Hisataka TANAKA

7E [505] **Break**

-Probing, form measurement-

7E [506] **A Novel Touch Probe Triggered by Harmonic Generation**
TAKAHASHI Satoshi, MIZUMOTO Hiroshi, ARII Shiroh and YABUYA Makoto

7E [507] **A High-speed Profile Measurement System for Scroll Compressors**
Akinori INADA and Wei GAO

7E [508] **An Application of Michelson Laser Interferometer for Roundness Measurements**
Chana Raksiri and Thitipoom Dorkyor

7E [509] **Break**

-Nanomachining, brittle material processing-

7E [510] **Nano-surface Generation of Glass Using Low-pressure Super-finishing with Fine-grit Stones**
Sachiko OGAWA, Eiichi AOYAMA, Toshiki HIROGAKI, Yoshiaki ONCHI

7E [511] **The Damaged Layers of Silicon Wafer Thinning by PCD Shaver**
P.L. Tso, C.H. Chen and C. Y. Shih

7E [512] **Break**

[Top of this page]

Room F

-Measurement and reverse engineering-

7F [601] **Software and Electronic Based on-line Shafts External Diameter Measurement System**
M.A. Rahbary

7F [602] **Considerations of Reverse Engineering through CAD/CAM of a Lure**
Sande GAO, Atsushi KATO, Xiaochu TANG, Xue CHEN and Jing LI

7F [603] **Development of a Design System For Reverse Engineering Using the Photometric Stereo Method**
Masayuki FUKURA, Eiichi AOYAMA, Toshiki HIROGAKI, Keiji OGAWA and Hiromichi NOBE

7F [604] **Break**

-Cutting Condition-

7F [605] **Development of Basic System to Construct Database of Machining Know-how**
Yusuke UCHIDA and Hideki AOYAMA

7F [606] **Optimization of Pin Type Fixture Configurations**
Afzeri, M. Konneh, A.G.E. Sutjipto and Yulfian A.

7F [607] **Basic Study on Development of System to Determine Machining Conditions for Minimizing Energy Consumed in Machine Tool**
Yuki ARAKAWA and Hideki AOYAMA

7F [608] **Break**

-Machining Quality-

7F [609] **Machining Error Compensation Based on 3D Surface Model Modified by Measured Accuracy**
Go ABE, Masatoshi ARITOSHI, Tomoki TOMITA and Keiichi SHIRASE

7F [610] **Quality Control of Tooth Contact of Gear using Infrared Ray Imagery**
Takahiro IIDA, Yasuhiro UENISHI, Toshiki HIROGAKI and Eiichi AOYAMA

7F [611] **Break**

7F [612] **Break**

[Top of this page]

[Return to top page] [Top of this page]

Copyright

Copyright Information

Proceedings of the LEM21
International Conference on Leading Edge Manufacturing in 21st Century
November 6-9, 2007, Fukuoka, Japan

Published on November 5, 2007

The author is responsible for the paper presented at the meeting of the JSME (hereinafter "Society"). The Society shall not be responsible for any statement or opinion given by or to the author regarding the paper.

A license for reproduction and distribution of the paper will be granted to be the Author by the JSME provided a copyright notice is included in each copy.

The Society permits to print and photocopy a single individual copy of these papers only for personal use in research or educational purpose.

The Japan Society of Mechanical Engineers
Shinanomachi Rengakan Bldg.
Shinanomachi 35, Shinjuku-ku
Tokyo 160-0016 Japan
Phone: 81-3-5360-3500
Fax: 81-3-5360-3508
E-mail: wwwadmin@jsme.or.jp

Adobe Reader

[Return to top page]

Effect of Edge Geometry on PVD-TiN Coated Carbide Tools when Face Milling Titanium Alloy, Ti-6246

Safian SHARIF[1], Erween Abd. RAHIM[2], Amrifan Saladin MOHRUNI[1] and Ashraf JAWAID[3]
[1]Faculty of Mech. Engg, Universiti Teknologi Malaysia (email: safian@fkm.utm.my)
[2]Faculty of Mech. and Manuf. Engg, Universiti Tun Hussein Onn, Malaysia
[3]School of Engg., Coventry University, United Kingdom

Abstract

This paper presents the investigation on the effect of edge geometry of PVD-TiN coated carbide inserts on the cutting performance and wear characteristics during face milling of titanium alloy, Ti-6246. Two similar PVD-TiN coated inserts with different edge geometry were tested at various cutting speeds with a feed of 0.1 mm/tooth. Results showed that edge geometry had a significant effect and sharp insert was observed to outperform chamfered (T-land) insert at all conditions. Excessive chipping and flaking at the cutting edge were the dominant failure modes on both tools under most conditions. In addition to adhesion, attrition and diffusion wear mechanisms, thermal cracks and plastic deformation were also observed on both tools.

Keywords: Tool wear, Carbide tools, PVD coatings, Face milling, Titanium alloys

1. Introduction

Increasing trend in using titanium alloys in aerospace, chemical and petroleum industries are mainly due to their attractive properties such as strength to weight ratio, low density, superior corrosion resistance and compatibility with composite materials [1, 2]. However many researchers have classified titanium and its alloys as “difficult to cut materials” due to their high temperature strength, low thermal conductivity, low modulus of elasticity and chemical reactivity [3].

Great advancement in the development of cutting tools for the past few decades showed little improvement on the machinability of titanium alloys. Previous studies have shown that almost every cutting tool developed so far, including diamond, ceramics and cubic boron nitride, is highly reactive with titanium alloys, causing rapid tool wear [4-8]. Most of the studies had shown that uncoated WC/Co or straight carbide tool still remains the first choice when turning [7,8] and face milling [9, 10] of titanium alloys. However studies have also shown that PVD-TiAlN coated tool was more superior than uncoated carbide when drilling Ti-6Al4V [11].

Severe chipping and flaking of the cutting edge were reported to be the main failure modes when milling titanium alloys with carbide tools. These types of failure modes are due to a combination of high thermo-mechanical and cyclic stresses, as well as the adhesion to and breaking of workpiece material from the tool faces. Despite numerous investigations on milling of titanium alloys [12-15], study on the effect of tool edge geometry on cutting performance is still lacking. Previous studies [16-18] on face milling of steels have shown that edge beveling strengthened the cutting edge and significantly improved the tool life.

As such this work is aim to investigate the influence of edge chamfering of PVD-TiN coated carbide tools on the cutting performance with respect to tool life and failure modes during face milling of titanium alloy, Ti-6246 at various cutting conditions.

2. Experimental Details

2.1 Workpiece Material

Machining trials were conducted on a rectangular bar of alpha-beta Ti-6Al-2Sn-4Zr-6Mo (Ti-6246) or IMI 646 of 125 mm x 52 mm x 400 mm, which was machined from a diameter 203 mm round bar. The received material was open forged at 920^0C in alpha beta condition and air cooled with no further heat treatment. In order to maintain a constant entry and exit angles during face milling trials, one end of the bar where the cutter enters was pre-machined whilst the other end was left uncut. The composition of the workpiece material is shown in Table 1.

Table 1: Nominal composition of Ti-6Al-2Sn-4Zr-6Mo

Al	Sn	Zr	Mo	Fe	H_2	O_2	N_2	Ti
5.5 to 6.5	1.75 to 2.25	3.5 to 4.5	5.5 to 6.5	0.15	0.0125	0.15	0.04	Bal

2.2 Inserts

Investigation was conducted on two PVD-TiN coated carbide inserts of similar substrate and properties but with different edge geometry and labeled as Tool A and Tool B. Properties of the substrate are listed in Table 2. Tool A consists of negative chamfer (γ) of 20^o and a T-land width (b) of 0.213 mm whilst Tool B is a sharp edge insert as shown in Figure 1. Both inserts were square in shape with wiper edges at the corner edge. The inserts were clamped to a standard cutter to provide the cutting geometry listed in Table 3.

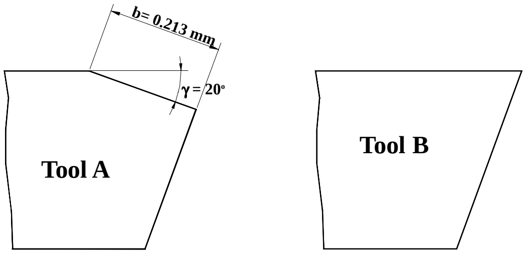

Figure 1: Edge geometry of chamfered (Tool A) and sharp edge (Tool B)

Table 2: Properties of substrate of Tool A and Tool B

SUBSTRATE	
Nominal Composition (wt %)	WC = 86 Co = 11.5 Ta(Nb)C = 2.5
Grain Size (μm)	1 ~ 6
Hardness (kg/mm^2)	1460
Transverse Rupture Strength (GPa)	2.61
Density (gm/cc)	14.2
Thermal Conductivity (cal/cm-sec-^{o}C)	0.161

2.3 Machining test

Face milling tests were carried out on a Sabre 750, 9KW Cincinnati CNC vertical machining center using the machining conditions shown in Table 3.

Table 3: Machining conditions.

Cutter Geometry	Diameter = 80 mm No of inserts = 6 (fully loaded) Approach angle = 45^o Radial rake angle = - 11^o Axial rake angle = +20^o Effective rake angle = +6^o
Cutting conditions	Axial depth of cut (DOC) = 2 mm Radial depth of cut (DOC) = 58 mm Cutting speed = 55, 65, 80, 100 m/min Feed = 0.1 mm/tooth
Inserts	PVD coated with TiN of thickness 2 ~3.5 μm Edge radius, r < 0.02 mm

As recommended by ISO [19], neutral milling mode was performed to avoid the occurrence of "foot formation" as a result of the unfavorable exit angles [20]. The presence of "foot formation" could lead to premature tool failure through excessive chipping and fracture of the cutting edge. Concentration of 6 % coolant under flood condition was used throughout the milling tests.

2.4 Tool Wear Measurement and Analysis

The tools wear land were examined and measured using a Nikon tool-maker's microscope at 30X magnification without dismounting the inserts from the milling cutter. A SEM was used to examined the tool wear and tool failure mode. Tool rejection or failure was determined based when any of the following criteria had reached; average flank wear ≥ 0.35mm (average of all six inserts), maximum flank wear ≥ 0.7 mm (on any of the inserts) or excessive chipping/flaking or catastrophic failure of the cutting edge.

3. Results and Discussion

3.1 Tool Life

Results on tool life when face milling Ti-6246 using Tool A and Tool B are shown graphically in Figure 2. Sharp tool (Tool B) recorded the best tool life performance of 16 minutes at the lowest cutting speed of 55 m/min. when compared to beveled insert (Tool A) which only obtained 6.5 minutes tool life. This implies that an increment of 146% tool life was recorded with Tool B as compared to Tool A. Face milling above cutting speed of 65 m/min showed a significant decrease in tool life for both tools. Shortest tool lives of 3.4 and 3.7 minutes were recorded for Tool A and Tool B respectively at the highest cutting speed of 100 m/min as displayed in Figure 2.

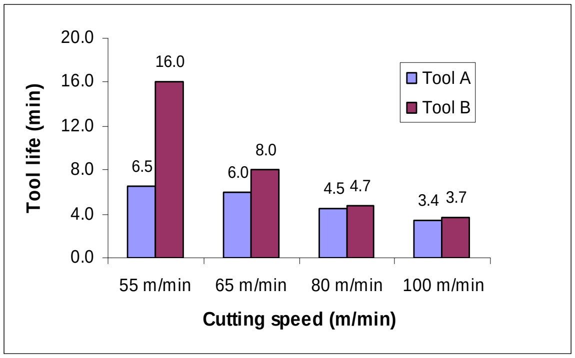

Figure 2: Tool life performance between chamfered tool (Tool A) and sharp edge tool (Tool B) at various cutting speeds and feed of 0.1 mm/tooth.

Tool A or chamfered tool failed prematurely when short tool lives were recorded at all cutting speeds, probably due to the effect of the negative T-land which may cause unstable cutting hence accelerating chipping and flaking of the cutting edge.

As shown in Figure 2, the effect of cutting speed on the performance of Tool A was less significant as compared to Tool B. The influence of cutting speed on tool life of Tool B was very significant especially when cutting speed was reduced from 65 to 55 m/min. An increment of 100% tool life was achieved with only 15% reduction in cutting speed. It can be suggested that sharp cutting edge insert (Tool B) outperformed beveled edge insert (Tool A) with reasonable tool lives at all cutting speeds tested. It is recommended that cutting speed should remain low for maximum tool life performance of TiN coated carbide tools whenever face milling Ti-6246 is to be carried out.

3.2 Tool Wear and Failure Mode

Results showed that both tools exhibit a similar flank wear pattern at all cutting speeds except at 55 m/min, where the wear rate of Tool B was more gradual than Tool A. The growth of flank wear was significantly reduced by employing the lowest cutting speed of 55 m/min. In general, an increase in cutting speed, increases the tool wear. Non-uniform flank wear was dominant at all cutting conditions for both tools. Uniform flank and nose wear which were pronounced during the initial cut were suppressed as cutting progressed. Wear on the minor cutting edge of the tool was too small to cause any significant effect to the tool during machining. In general, the flank wear rate of sharp Tool B was slightly lower than the chamfered Tool A resulting in better tool lives.

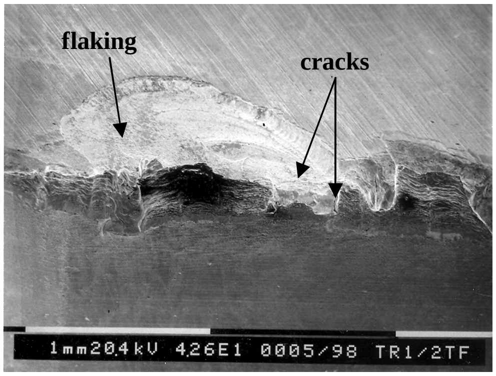

Figure 3: Severe flaking and thermal cracks on Tool A after 3.5 minutes of face milling Ti-6246 at 100 m/min

Results on the tool failure modes indicated that in most cases, average flank wear with combination of excessive chipping and/or flaking on the rake face were the dominant modes of failure in rejecting both tools especially at higher cutting speeds as shown in Figure 3 and 4. Thermal cracks were also observed on Tool A (Figure 3) and Tool B (Figure 4) after reaching their tool life criteria.

Wang and Zhang [21] reported that the temperature at the tool-chip interface can reach up to 800 ^{o}C when face milling Ti-6Al4V at cutting speed of 47 m/min with feed of 0.1 mm/tooth. The high cutting temperature and cyclic mechanical stresses encourage thermally related wear mechanisms to operate such as diffusion, plastic deformation and thermal cracks on the cutting tools. These may eventually promote chipping and flaking of the tool. In this study, machining trials were carried out at higher speeds hence higher temperature generation was anticipated which would facilitate the thermally related wear mechanisms to operate.

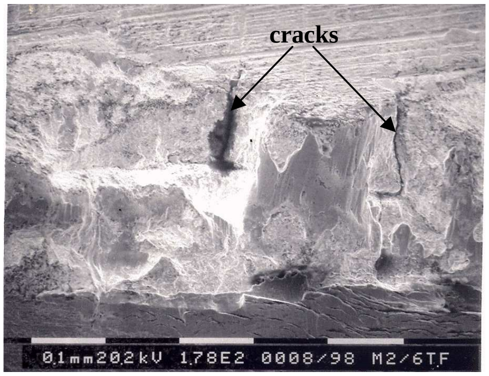

Figure 4: Severe chipping and thermal cracks on Tool B after 5 minutes of face milling Ti-6246 at 80 m/min

It was observed that at lower cutting speed of 55 m/min, attrition wear was the major contributor to the occurrence of chipping and flaking on the rake face of both tools and sample of such wear on Tool B is shown in Figure 5.

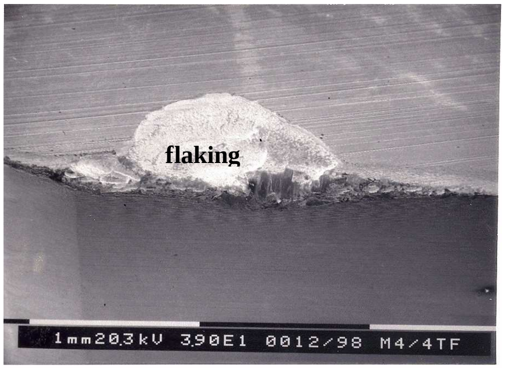

Figure 5: Severe flaking on Tool B after face milling Ti-6246 for 16 minutes at 55 m/min

Both tools experienced coating delamination almost instantly (after 5 seconds) as the cutter enters the workpiece. Such evidence is shown in Figures 6 and 7 for Tool A and Tool B when face milling Ti-6246 at 80 m/min and 55 m/min respectively.

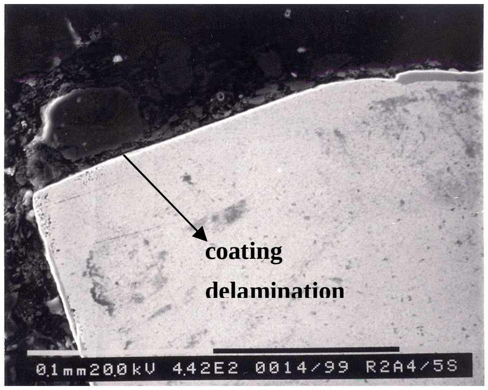

Figure 6: Section of Tool A showing delamination of coating on the chamfered face after 5 seconds of face milling at 80 m/min.

Figure 7: Delamination of coating and adherent of work material on Tool B after face milling for 5 seconds at 55 m/min.

The early delamination of TiN coatings exposed the substrate to various wear mechanisms such as adhesion, attrition, plastic deformation and diffusion which may eventually lead to the failure of tool. Based on this findings, it is appropriate to suggest that TiN coatings is not recommended to be used as coating material for protecting the carbide substrate from wear and plastic deformation when dealing with titanium alloys, probably due the high reactivity of titanium material.

An examination of the sectioned worn inserts under the SEM, demonstrates that both Tool A and Tool B suffered severe plastic deformation and adherent of work material when face milling Ti-6246 at high cutting speed. Sample of such deformation on sharp edge (Tool B) is illustrated in Figure 8 after 4 minutes of machining at 100 m/min. One of the main contributor for plastic deformation to occur when machining with cemented carbide tools was the extrusion of cobalt content after the softening effect [22]. This softening effect intensifies with higher cobalt content and high cutting temperature as what happened in this investigation. In addition, the high reactivity of titanium towards cobalt element accelerated the diffusion process hence weakening the structure of the tool substrate.

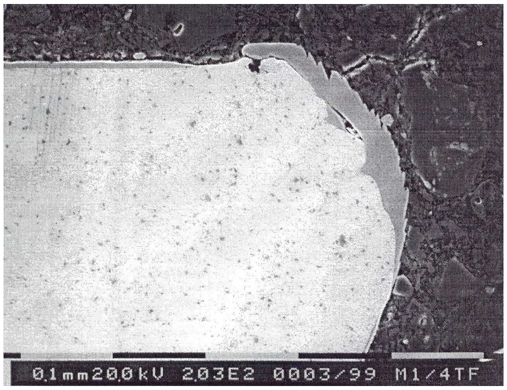

Figure 8: Section of Tool B, showing severe plastic deformation after face milling for 4 minutes at 100 m/min

Notching at the depth of cut (DOC), a common phenomena in turning of titanium alloys [6,7] was not observed on any of the worn tools for both Tool A and Tool B throughout the face milling trials.

3.3 Effect of edge geometry

Researchers [16-18, 23] have found that beveling or chamfering of the main cutting edge may influence the tool life quite significantly. Results showed that chamfered Tool A which was originally designed to cater the problem of edge fracture did not exhibit promising results when face milling Ti-6246 as a result of shorter tool lives recorded. Tool life results in Figure 2 illustrate that the performance of Tool A was never higher than Tool B at all cutting speeds investigated. The tool life variations of both tools were quite substantial when machining at lower cutting speed between 55 and 65 m/min.

Introducing a negative T-land that is greater than the feed on Tool A restricts the chip flow within the chamfer face which results in a negative rake cutting. Hence the geometry of the cutter with Tool A inserts changed to a negative-negative cutter from a negative-positive cutter which was the case for Tool B inserts. The disadvantages of double negative cutter when machining titanium alloys were probably the reasons underlying the poor performance of chamfered tool (Tool A).

The generation of high cutting forces [18-25] and the poor ejection of the serrated chips [24,25] with the negative-positive cutter can cause severe damage to the tool and the workpiece. All these factors coupled with the high cutting temperature at the chamfer face of Tool A may escalate the wear mechanisms of diffusion and attrition thus promoting the occurrence of various failure modes. As a result, rapid flank wear and premature failure of Tool A occurred at all cutting conditions and no improvement in tool life was achieved. Even at the lowest cutting speed of 55 m/min, the tool life obtained was relatively short (6.5 minutes).

Despite experiencing similar failure modes and wear mechanisms as chamfered tool, (Tool A), sharp edge (Tool B) offered much better tool lives when machining Ti-6246 at all cutting conditions investigated. The outstanding performance of Tool B was probably due to the favorable geometry of negative-positive cutter which offered many advantages when machining titanium alloys. The negative radial rake angle of the tool provides a strong cutting edge, while positive axial rake angle allows smooth ejection of the chips and reduces cutting force during machining [24-25].

Although many researchers have outlined the advantages of using chamfered tool, this study indicates that chamfered tool (Tool A) was not recommended to be used in face milling titanium alloy, Ti-6246 when compared to sharp tool (Tool B). In order to realize the greatest potential of chamfered tools when machining titanium, optimization of the edge parameters such as rake angles and edge geometry are essential.

4. Conclusion

Conclusions drawn from face milling titanium alloy Ti-6246 with two different geometry coated carbide inserts are as follows:

1. In general, sharp cutting edge inserts (Tool B) produced better tool life performance at all cutting conditions when compared to chamfered/beveled edge inserts (Tool A) when face milling titanium alloy Ti-6246. The best cutting condition with respect to highest tool life (16 minutes) was achieved with sharp edge inserts (Tool B) at cutting speed of 55 m/min and feed 0.1 mm/tooth.
2. Edge beveling or chamfering of the cutting edge had not improve the cutting performance of the tools when face milling titanium alloy Ti-6246 as what have been claimed when face milling of steel.
3. A combination of non-uniform flank wear, excessive and flaking and/or chipping of the cutting edge were the dominant failure mode on both tools at most cutting conditions.
4. TiN coatings was not able to prevent the occurrence of plastic deformation and thermal cracks at the cutting edge due to its early delamination effect during face milling Ti-6246.

Acknowledgements

The authors wish to thank Rolls Royce Plc, Kennametal Hertel UK Ltd and Timet UK Ltd for their supports in providing the consumables in carrying out this work. Special appreciation should also be extended to the Research Management Center, UTM and the Ministry of Science, Technology and Innovation Malaysia for their financial support to this work through the IRPA funding 03-02-02-0068 PR0074/03-01 – Vote number 74545.

Reference

[1] Boyer R.R., 1995, Titanium for Aerospace: Rationale and Applications, Advances Performance Materials, 2.

[2] Brewer, W.D., Bird, R.K. and Wallace, T.A., 1998, Titanium Alloys and Processing for High Speed Aircraft, Mater. Eng. Sci. A, 243, pp 299-304.

[3] Hong A.T., Riga J.M., Cahoon and Scott C.G., 1993, Machinability of Steels and Titanium Alloys under Lubrication, Wear 162, pp 34-39.

[4] Souza, J.V.C., Crnkovic, S.J., Kelly, C.A., Moreira, M.R.V., Ribeiro, M.V. and Silva O.M.M., 2006, Behavior of the Silicon Nitride Cutting Tool During Ti-6Al-4V Maching, 5th Int. Conf. on High Speed Machining, France.

[5] Kramer B.M., 1987, On Tool Materials for High Speed Machining, J. of Engg for Industry, Vol. 109, pp 87-91.

[6] Komanduri R. and von Turkovich B.F., 1981, New Observations on the Mechanism of Chip Formation When Machining Titanium Alloys, Wear 69, pp 179-188.

[7] Hartung P.D. and Kramer B.M, 1982, Tool Wear in Machining Titanium, CIRP Annals, Vol. 31/1, pp 75-80.

[8] Narutaki N., and Murakoshi A., 1983, Study on Machining of Titanium Alloys, CIRP Annals, Vol. 32/1, pp 65-69.

[9] Ezugwu E.O. and Machado A.R., 1988, Face Milling of Aerospace Materials, Proc. of the 1st. Int. Conf. on the Behaviour of Materials in Machining, pp 3.1-3.11.

[10] Jawaid, A. Sharif S. and Koksal S., 2000, Evaluation of Wear Mechanism of Coated Carbide Tools when Face Milling Titanium Alloy, J. of Mat. Proc. Tech., 99, (2000), pp. 266-274.

[11] Sharif, S. and Rahim, E. A., 2007, Performance of Coated and Uncoated-Carbide Tools When Drilling Titanium Alloy – Ti-6Al4V, J. Mater. Processing Tech. Vol. 185, pp 72-76.

[12] Fujiwara, J., Miyamoto, T., Koizumi, H. and Wada, T., 2006, High Speed Milling of Titanium Alloy, 8th Int. Conf. on Progress of Machining Technology (ICPMT 2006), Matsue Japan, pp 37-40.

[13] Su, Y., He, N., Li, L. and Li, X.L., 2006, An Experimental Investigation of Effects of Cooling/Lubriaction Conditions on Tool Wear in High-Speed End Milling of Ti-6Al-4V, Wear 261, pp 760-766.

[14] Min W., and Youzhen Z., 1988, Diffusion Wear in Milling Titanium Alloys, Materials Sci and Tech. Vol. 4, pp 548-553, June 1988.

[15] Usuki H., Narutaki N, and Yamane Y., 1996, Face Milling of Beta Titanium Alloys, Proc. of the 3rd. Int. Conf. on Progress of Cutting and Grinding, Osaka, Japan, pp 57-62.

[16] Paul S., Sikdar C., Venkatesh V.C. and Chattopadhay A.B., 1994, Geometrical Modification of Coated Carbide Inserts for Improved Performance in High Production Face Milling, Int. J. of Machine Tools Manuf., Vol. 34, No. 2, pp169-182.

[17] Sabberwal A.J.P. and Fleischer P., 1964, The Effect of Material and Geometry on the Wear Characteristics of Cutting Tools During Face Milling, Int. J. of Machine Design and Res., Vol. 4. pp 47-49.

[18] Sidkar C. Paul S. and Chattopadhay A.B., 1992, Effect of Variation in Edge Geometry on Wear and Tool Life of Coated Carbide Face Milling Inserts, Wear 157, pp 111-126.

[19] Tool Life Testing in Milling – Part 1: 1989, Face Milling, ISO 8688-1 (E).

[20] Pekelharing A.J., 1984, The Exit Failure of Cemented Carbide Face Milling Cutters, Part 1-Fundamentals and Phenomena, CIRP Annals, Vol. 33/1, pp 47-50.

[21] Wang M., and Zhang Y.Z., 1988, Investigation on Tool Wear Mechanisms in Milling of Titanium Alloys, 16th NAMRC: North American Manuf. Res. Conf., Ch. 62, pp 190-194.

[22] Trent, E. M., (1970), Wear Processes Which Control the Tool Life of Cemented Carbide Cutting Tools, BSRA-ISI Conf., pp 10-15.

[23] Colwell L.V., 1961, Residual Stresses in Metal Cutting, Handbbook of Mechanical Wear, University of Michigan, USA, pp 403-453.

[24] Fowler D., 1960, Get More From Your Milling Cutter, Manuf. Engg, pp 74-79.

[25] Stephenson A. and Agapiou J.S., 1997, Metal Cutting Theory and Practice, Marcel Dekker Inc.