HV Propulsion Materials

Cost-Effective Machining of Ti Alloys
Project (PM_9278)

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University of Michigan

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Advanced Machining and Sensor Concepts

21CTP Technical Goal: **Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.**

Project Objectives
Investigate new Ti machining technologies to increase the productivity and reduce the cost of component fabrication

FY 2005 Focus
High speed drilling (over 180 m/min) technique to increase the hole making productivity, new TiC-Ni_3Al tool material, and finite element chip and tool thermal modeling

Planned Duration
October 2003 to September 2007

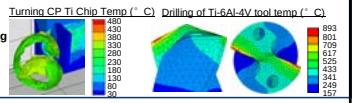
DOE Funding/Industry Cost Share
FY04: $80K; FY05: $100K

Comparison of drilling speed (m/min) (* Machining Data Handbook, Metcut Research Associates, Inc.)

Drill	Al Alloys	Cast Iron	Ti-6Al-4V
HSS standard*	43~105	27~49	9
Carbide standard*	245	60~90	46
This Study: Carbide Spiral			183

Comparison -- High speed turning and milling of Al alloys 600~4500 m/min.

Sample FEM Machining Modeling



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Accomplishments
1. High speed drilling of Ti-6Al-4V exceeding 180 m/min cutting speed demonstrated (0.5 s to penetrate a 6.35 plate). (July 2005)
2. Finite element modeling of Ti turning validated with experiments and accurate prediction of drilling temperature achieved (July, 2005).

Significant Future Milestones
BorgWarner Turbo Ti compressor wheel drilling (Sep 2006)
Drilling and turning process modeling and tool design (Sep 2007)

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9278	Materials Technology	HV Propulsion Materials	Applied Research	8-15-05

Objectives

Investigate new Ti machining technologies to increase the productivity in component fabrication.

- Develop the cost-effective, high speed machining processes
- Investigate new tool material, geometry, coating, and process parameters to enhance process capability and product quality
- Provide accurate prediction of temperature and stress for tool selection and design

Relevance to 21CT Goals

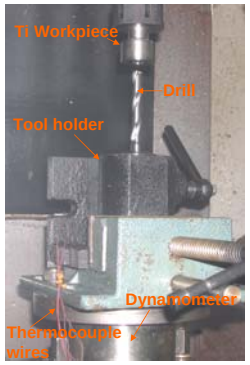
- Low cost production of Ti components for fuel-efficient engines
- Model-based guide for tool design and process parameter selection

Technology Transfer

- Working with BorgWarner on Ti compressor wheel machining
- Collaborating with Kennametal, Third Wave System, and Oak Ridge National Lab on tooling and machining study

Approach

- Develop high speed Ti turning and drilling processes
- Conduct tool wear test for tool selection of Ti turning and drilling
- Carry out the finite element modeling and inverse heat transfer analysis to study Ti turning and drilling processes
- Validate the modeling with experimental results



Experimental setup of inverse heat transfer analysis of drill temperature in Ti drilling

Spiral point drill

Thermocouples embedded in the flank face of spiral point drill for in-situ temperature measurement

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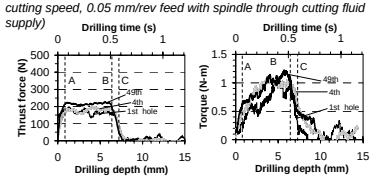
Technical Accomplishments -- Cost-Effective Machining

Comparison of machining speed (m/min)

Tool material	Process	Al alloys	Cast iron	CP Ti
HSS	Turning	300[1]	40[1]	27[2]
	Drilling	43~105[2]	27~49[2]	9[2]
WC-Co	Turning	600~4500[1]	120[1]	90[2]
	Drilling	245[2]	60~90[2]	46[2]
This study	Turning			195
	Drilling			183

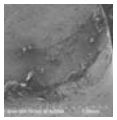
[1] Trent, E. M., Wright, P. K., Metal Cutting, Butterworth-Heinemann.
[2] Machining Data Handbook, Metcut Research Associates, Inc

Thrust force and torque of high speed drilling of 6.35 mm Ti-6Al-4V plate *(183 m/min cutting speed, 0.05 mm/rev feed with spindle through cutting fluid supply)*



- High speed drilling and turning processes over 180 m/min cutting speed have been demonstrated feasible for Ti.
- Tool wear studies have been conducted to understand the wear mechanism and to further improve the tool performance.

Tool wear



Crater wear of worn TiB_2 coated carbide tool insert

Build-up edge at the tip of TiAlN coated carbide tool insert

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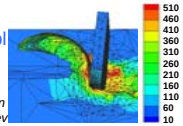
Technical Accomplishments -- Accurate Modeling

Accurate predictions of the temperature and stress distributions of the tool and workpiece in turning and drilling processes have been achieved.

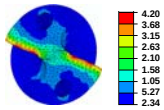
Example I

Temperature (°C) distributions of tool and workpiece in turning CP Ti *(1.02 mm depth of cut, 195 m/min cutting speed, 0.254 mm/rev feed)*



Example II

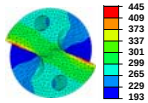
Stress (GPa) distribution of drill in drilling Ti-6Al-4V *(10 mm drill with 73.2 m/min cutting speed, 0.05 mm/rev feed, and 12.7 mm drilling depth)*

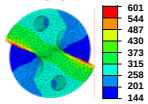


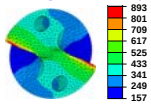
Example III *(10mm drill with 0.05 mm/rev feed rate and 12.7 mm drilling depth)*

Temperature (°C) distribution of drill in drilling Ti-6Al-4V at :

24.4 48.8 73.2 m/min cutting speed







Future Work

- Continue the high speed drilling with internal spindle through cutting fluid supply
- Continue 3D finite element modeling of drilling of titanium alloys
- Continue the test of TiC-Ni_3Al tool with better surface and cutting edge preparation
- Develop drilling strategy of cast Ti for compressor wheel