A Screening Test For Cutting Fluids When Milling Titanium

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TechSolve, an Ohio Edison and NIST MEP Center

- An Ohio Edison Technology Center: Focus Aerospace Industry, Advanced Machining and General Manufacturing Assistance

- A National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP) Center: 59 federally-funded manufacturing centers providing improvement services to small manufacturers across the US

- 50+ employees: Business experts, engineers, and scientists

- TechSolve Facility in Cincinnati, Ohio

- Industry and Designated Lead Staff for the Governor’s Aerospace and Business Aviation Council
Fluid Evaluation Background
Background

- In 1995 the EPA provided a grant to the Institute of Advanced Manufacturing Sciences (now TechSolve) to produce *Pollution Prevention Guide to Using Metal Removal Fluids in Machining Operations*.

- Industrial Working Group
  - Chaired by Boeing Commercial Airplane Group
  - 25 Working Group Members

- Within the guide, a standard test was defined to be used as a first screen by industry for selecting fluids when milling steel. The test is commonly known as the IWIG Milling Test.
The Problem

- The development of advanced cutting tools and coating materials has now made this test obsolete.

- For the Aircraft industry an interest in developing a similar test when milling titanium was expressed. It is known that the properties of titanium place a more stringent requirement on cutting fluids which experience has verified.
Objective

Develop a repeatable and inexpensive screening test to distinguish the performance of various cutting fluids when milling titanium.
Baseline Testing - Set Up
M. Eugene Merchant Technology Development Center

Fully instrumented machining laboratory (formerly MetCut Research Machining Laboratory, founded 1948)

**Major Equipment List**

- Mazak i200S Mill Turn
- Makino V55 - 3 Axis VMC w/ 20K spindle
- GBI CV4020 – 3 Axis VMC w/MTI CNC
- Deckel Maho DMU-50 - 3+2 Axis VMC w/ Siemens 840D & through-spindle coolant
- Deckel Maho DMU-70 eVo Linear - 5 Axis VMC w/ Siemens 840D & 580 psi through-spindle coolant
- Hardinge Cobra 65 – 2 Axis HTC w/ Fanuc 21T & Bar Feed
- Milltronics HMC35 - 4 Axis HMC w/ Fanuc Oi-MC
- Chevalier Smart B1224II
- Sheffield Cordax D-8 - CMM
- Kistler Milling Dynamometer
- Kistler Drilling Dynamometer
- Keyence – VHX Digital Microscope
- Fluids Lab
Baseline Testing - Set Up

Experimental work determined that tests using similar cutting conditions to those documented below resulted in a stable cutting operation with a regular flank wear pattern in a reasonable time.

- The depth of cut was set to 0.100” to:
  - conserve titanium material
  - facilitate accurate flank wear measurements

- Only one insert is utilized in the 5 pocket cutter to:
  - conserve titanium material
  - simplify tool wear measurement
  - eliminate any runout issues
  - reduce horsepower requirements
Knowing that tooth impacts can result in insert chipping rather than a smooth wear pattern, the test was setup to minimize the chipping:

- A face milling operation was selected to maximize the time in cut per tooth entrance.
- Employed a radial width of cut so that the tooth will enter nearly parallel to the workpiece surface when the chip thickness is at a minimum. Thus the peak force is not upon entrance.

Round inserts were selected and have several advantages:

- Round inserts are the strongest shape.
- The insert will ease into the workpiece and minimize shock and notching at the depth-of-cut line.
Baseline Testing - Set Up

- The insert chosen has a 0.002" edge hone to further resist chipping. Acceptable as long as the feed (.010 IPT) is sufficient to create a certain chip thickness. If not, it would result in chip smearing.

- While the test described herein does not simulate finishing cuts, it does provide a true test of relative fluid characteristics.
Baseline Testing - Set Up

Deckel Maho DMU 50 VMC

- Kistler Type 9255B Milling Dynamometer
- 15 Gallon Coolant Tank
- Flood Coolant
- Siemens 840D CNC
Baseline Testing - Set Up

Workpiece

- Material: Titanium 6-4
- Hardness: 30-33 HRC
- Block Size: 4.00” wide x 6.00” long x 4.00” thick
Baseline Testing - Set Up

Cutting Tool

- Tool Holder-Kennametal, CV40BSMC100206
- Shell Mill-Kennametal, BMD300R1605S100L200
  - 2.458” effective diameter at 0.100” axial depth
  - 5 teeth
- Inserts-Kennametal RPET1605MOSGE
  - Grade KC725M
  - One round insert .625” diameter
Baseline Testing - Set Up

**Fluids**

**Cooling**

- Water w/Trim 299 @ 2.5% (as a rust inhibitor)
- Water-soluble oil - Trimsol @ 12%
- Soy oil

**Lubrication**
Baseline Testing - Performance

- Tool Wear - Tool life endpoint uniform flank wear of 0.010”

![New Insert - Note the 0.002” Hone (30X)](image1)

![Typical Worn Insert with 0.010” Hairline (10X)](image2)
Performance of Baseline Fluids
Performance of Baseline Fluids

Ranking of Tool Life @ 144 SFPM
Soy Oil: 100%, Trimsol: 42% Trim: 7%

This comparison is used to rate the performance of candidate fluids
Performance of Baseline Fluids

Ranking of Cutting Speed @ 60 Inches of Cut
Soy Oil: 100%,  Trimsol: 79%  Trim: 56%

This comparison is used to rate the performance of candidate fluids.
Performance of Baseline Testing

Cutting forces, particularly the “Y” force, can be used to monitor tool wear progression. When this force approaches 400 pounds under test conditions, one can be assured the tool flank wear is nearing the 0.010” endpoint.
Evaluation Test
Evaluation Test

Procedure
- Make two 6”-long cuts in the same feed direction at one level
- Monitor forces at the beginning of the second pass
- Measure tool wear after each two passes
- Repeat until tool exhibits 0.010” flank wear
- Continue this procedure for the other two speeds
Evaluation Test

Machining Parameters

- Depth of Cut:
  - Axial depth: 0.100”
  - Radial depth: 2.00”

- Milling mode: Climb

- Cutting Speeds
  - 142 SFPM (220 RPM)
  - 161 SFPM (250 RPM)
  - 177 SFPM (275 RPM)

- Chip Load: 0.010 IPT for all runs
Evaluation Test

Example of Test Fluid Performance

![Graph showing tool life vs cut speed for different fluids.](image)

- **Tool Life vs Cut Speed**
- **Soy Oil**
- **Trimsol @ 12%**
- **Trim 229 @ 2.5%**

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Candidate Fluid
For Additional Information

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