MACHINE M
INSERT C
COOLANT F
SPEED 1120
DEPTH 0.04
FEED 7
TOTAL DEPTH 280
P2 20X
TOOL W 0.0409

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Impact of Micromist in CNC Machining

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INTRODUCTION

- The cost of cutting fluids is around 17% of the machining costs of automotive components.
- 1.2 million workers are affected by the chronic effects produced by cutting fluids.
- OSHA demands tighter control on cutting fluids (cost, maintenance, disposal, emission standards…)
- Propose solution: use micromist as minimum quantity lubrication in machining

Source: (Marksberry and Jawahir, 2008)
OBJECTIVES

1) Characterize micromist
2) Apply micromist in macro/micro machining
3) Identify technical issues
4) Study economics of micromist
NSF-RET program (summer 2010)
INVESTIGATION: setup

1) Machines: Haas OM2 CNC micromill, VF1 CNC mill, and SL20 CNC lathe.

2) Workpieces:
   - Micromachining: 12 mm (1/2 in) square bars of 316L stainless steel, CP titanium PEEK plastics, H11 tool steel, 1010 steel, 6061-T6 aluminum.
   - Macromachining: 4140 steel bars / plates

3) Tools
   - Micromill: TiN un/coated WC, Ø100-1016µm (0.004-0.040 in)
   - Microdrill: Uncoated WC Ø50-203µm (0.002-0.008 in)
   - Macromill: TiN un/coated WC Ingersoll APKT102308R-HS insert, Ø15.8 (5/8 in)
   - Macroface: TiN un/coated WC Hertel TNG431 insert

4) Tool failure criteria: 50 µm (0.002 in) flank wear for microtool, 300 µm (0.012 in) for macrotool.
5) Machining parameters:
   - **Micromilling**: 15-157 m/min (50-520 ft/min), 10 µm/tooth (0.0004 in/tooth), 0.35mm (0.014 in) axial depth, 0.56 mm (0.022 in) radial depth, climb (down) side milling.
   - **Macromilling**: 55-102 m/min (183-343 ft/min), 0.043-0.178 mm/tooth (0.0017-.0070 in/tooth), 1-2 mm (0.04-0.08 in) axial depth, 4.25-8.5 mm (0.17-0.333 in) radial depth, down milling on D2 tool steel.
   - **Macrofaceting**: max 44-80 m/min (147-265 ft/min), 0.5 mm (0.020 in) depth of cut, 0.1-0.3 mm/rev (0.004-0.006 in/rev) feedrate, constant RPM, on 4140 steel.

6) Cutting fluids:
   - **Dry**
   - **Flood cooling**: synthetic Blasocut 2000 Universal, 5:1 mixture
   - **Micromist**: UNIST Uni-MAX system, 2210EP oil, 0.022 cc/min. Use with Mistbuster500.
7) Measurement:
   - **Keyence LK-G82 laser system**, 70µm beam, 50 kHz sampling rate, 0.2 µm resolution
   - **Olympus STM6 measurement microscope**, 0.1 µm resolution
   - **JEOL JSM 6400 scanning electron microscope**
   - **Video tensiometer** FTA 188, 001 mN/m accuracy

8) Computer aided tools
   - **SolidWorks, FeatureCam, and MasterCam** software
   - **Cosmos finite element software**
Computer Imaging Lab
MACHINE M
INSERT UC
COOLANT N
SPEED 2100
DEPTH 0.04
FEED 8
TOTAL DEPTH 0.04
0
P2 20X
TOOL W 0.0520

2010-07-21 11'10'09
MACHINE M
INSERT: UC
COOLANT: N
SPEED: 2100
DEPTH: 0.04
FEED: 8
TOTAL DEPTH: .280
P2: 20X
TOOL W: 0.1146

2010-07-21 13'44'31
MACHINE M
INSERT UC
COOLANT F
SPEED 2100
DEPTH 0.04
FEED 8
TOTAL DEPTH .280
PS 5X
TOOL W 0.1202

2010-07-21 18'19'53
MACHINE: L
INSERT: UC
COOLANT: N
SPEED: 310
DEPTH: 0.02
FEED: .004
PASSES: 05
P2: 20X
TOOL WEAR: .0144
MACHINE: L
INSERT: UC
COOLANT: N
SPEED: 310
DEPTH: 0.02
FEED: 0.004
PASSES: 70
P1: 10X
TOOL: 0.1265

2010-07-09 11:00:23
INVESTIGATION: machines

Haas OM2 CNC micromill:
- 5-axis capability
- 50,000 rpm air spindle
- 1 µm spindle runout
- 3 µm repeatability

Micromist
- 2210EP oil, 0.022 cc/min
- 30 mm @60 from z axis
- -45 in x-y plane

Spindle Runout: Laser on Haas OM2
Ø3mm (1/8") plug gage @ 10k rpm

![Spindle Runout Chart]
INVESTIGATION: machines

Haas VF1 CNC mill:
- 5-axis capability
- 7,500 rpm spindle
- 25 µm spindle runout
- 3 µm repeatability

Micromist
- 2210EP oil, 0.022 cc/min
- 25 mm @70 from z axis
- -120 in x-y plane
Haas SL20 CNC lathe:
- Live tooling capability
- 3,400 rpm spindle
- 3 µm repeatability

Micromist
- 2210EP oil, 0.022 cc/min
- 6 mm @150 from y axis
- -60 in x-y plane
MICROMACHINING: tool setting

(a) Set up for edge detection on x-y plane
(b) Set up for tool height z-offset
Microtool offset using laser sensor
MICROMACHINING: tool setting

- X, Y settings depend on tool quality
- A precision plug gage should be used

Edge detection for tool offsets in x, y directions.
MICROMACHINING: tool setting

- Z offset depends on tool geometry
- Expect a larger z offset error than x, y offsets

Tool height offset in z direction.
MACHINING: cutting fluid

For effective cooling/lubricating, cutting fluid must:

1) Penetrate the boundary layer of a rapidly rotating tool,

2) Adhere to a tool surface despite centrifugal force, and

3) Wet the tool/chip interface to provide lubricating/cooling
\[ x_{pn} = V_f t + \frac{\alpha}{M} (V_0 \cos \theta_0 - V_f) [1 - e^{-\frac{\alpha}{M} t}] \]

\[ y_{pn} = \frac{\alpha}{M} V_0 \sin \theta_0 [1 - e^{-\frac{\alpha}{M} t}] \]
MACHINING: coolant wetting

Wetting?

Nozzle pressure

Different mist coolants

Surface tension Contact angle Particle size

Droplet analysis

Verify tool wetting

Tool/workpiece wetting

\[
\frac{P}{V^{1/3}}(\theta) = \left[ \frac{24}{\pi} \cdot \frac{(1 - K \cos^2 \theta)^{3/2}}{2 - 3 \cos \theta + \cos^3 \theta} \right]^{1/3}
\]

V: volume of droplet
P: diameter of droplet
K: 1 for \(\theta<90^0\); 0 for \(\theta>90^0\)
\(\theta\): contact angle
Apparatus for Surface tension measurement
1. Needle for delivering liquid droplets
2. Camera
MACHINING: micromist

316L Stainless Steel

Contact Angle (°)

Coolant

Water
CL 1:30
2210
2210EP
2300 HD
2200
MACHINING: micromist

Pure Titanium

Contact Angle (°)

Water  KM  CL2200  CL2210EP  CL2300HD  CL2210  RL1:15
MACHINING: micromist

Tungsten Carbide

Contact Angle (°)

Water  |  KM  | CL2200 | CL2210EP | CL2300HD | CL2210 | RL1:15  | 30
Objective 2
- Nozzle pressure
- Different mist coolants
  - Surface tension
  - Contact angle
  - Particle size
- Droplet analysis
- Verify tool wetting
- Tool/workpiece wetting

$$V = \pi h^2 \left[ \frac{h}{6} + \frac{r^2}{2h} \right]$$

$$V = \frac{4}{3} \pi R^3$$

V: volume of droplet
h: height of droplet
R: radius of airborne droplet
r: \((D_1 + D_2)/4\)
MACHINING: micromist

(a) Micro-droplet on a rotating tool;
(b) Free body diagram of forces acting on the micro-droplet

\[ \frac{mv^2}{R} + 2 \sigma_2 \sin \theta = \Delta \sigma \Delta \]

- m: mass of droplet
- v: surface speed of tool
- R: radius of tool
- D: diameter of droplet
- \( \sigma_2 \): surface tension of liquid
Balance of adhesion and centrifugal force on a 2210EP microdroplet
Setup for validation of tool wetting

(a) Mist spray setup  
(b) 3.175 mm 2 flute end-mill  
12.7 mm 2 flute end-mill (not shown)
RESULT: flow of micromist

- Flow?
- Particle trajectory
- CFD modeling
- Optimal tool/workpiece/nozzle positions

Separation of flow
Dia. 1.016mm cylinder @4000 RPM
Direction of flow @40 m/min

Pathlines Colored by Velocity Magnitude (m/s)
FLUENT 6.3 (2d. pbns. lam)

Nov 11, 2008
RESULT: flow of micromist

Flow?

Particle trajectory

CFD modeling

Optimal tool/workpiece/nozzle positions

Velocity Vectors Colored By Velocity Magnitude (m/s)

Nov 11, 2008

FLUENT 6.3 (2d, pbns, lam)
MICROMACHINING: tool deflection

Spindle runout, built-up edge, uncontrolled chip, and/or cutting force deflect a microtool cyclically and cause premature tool failure.

End deflection=17% tool diameter
Bending stress= 50% tool strength

End deflection=34% tool diameter
Bending stress= 100% tool strength

Finite element analysis of bending stress on a micromilling tool.
Catastrophic failure threshold of micromilling tools.

0.35mm (0.014 in) axial depth, dry, climb (down) side milling of 316L stainless steel.
**MICROMIST: macrofacing**

WC on 4140, V0.9m/s max, F0.1mm/rev, D0.5mm

- #2: dry
- #6: flood
- #10: mist

Dry, 75 passes
Flood, 75 passes
Mist, 75 passes
1) Conclusions
   - In general, the dry machining produced the most flank wear vs. time. Flooding came in second, with misting obtaining the best results for tool flank wear longevity vs. time.

2) From a cost standpoint:
   - Dry machining is the least expensive in our experiment, but of course for long term machining one would have to factor in purchasing the more expensive coated carbide or ceramic inserts, dimensional stability notwithstanding.
   - Flooding is the most expensive, as coolant cost is high, must be checked regularly for contaminants, and must be disposed of according to environmental procedures.
   - Misting, by far is less costly to flooding
3) Misting Fine points
   - Oil volume of Misting has little effect on the cutting performance once the minimum amount of coolant is established.
   - It is recommended that less oil volume be used to prevent pollution of the environment and to prevent adverse health issues.

4) Submicron mist particles
   - Contaminate other equipment.
   - Pose potential health issues.
   - Should be used with air cleaner unit.
REFERENCES


National Science Foundation (NSF award #0552885).

Mr. Dave Hayes, Haas Automation Inc.

Mr. Joe Kueter, M.A. Ford Inc.

Mr. Wally Boelkins, UNIST Inc.

Mr. Patrick Anderson, PMT Inc.