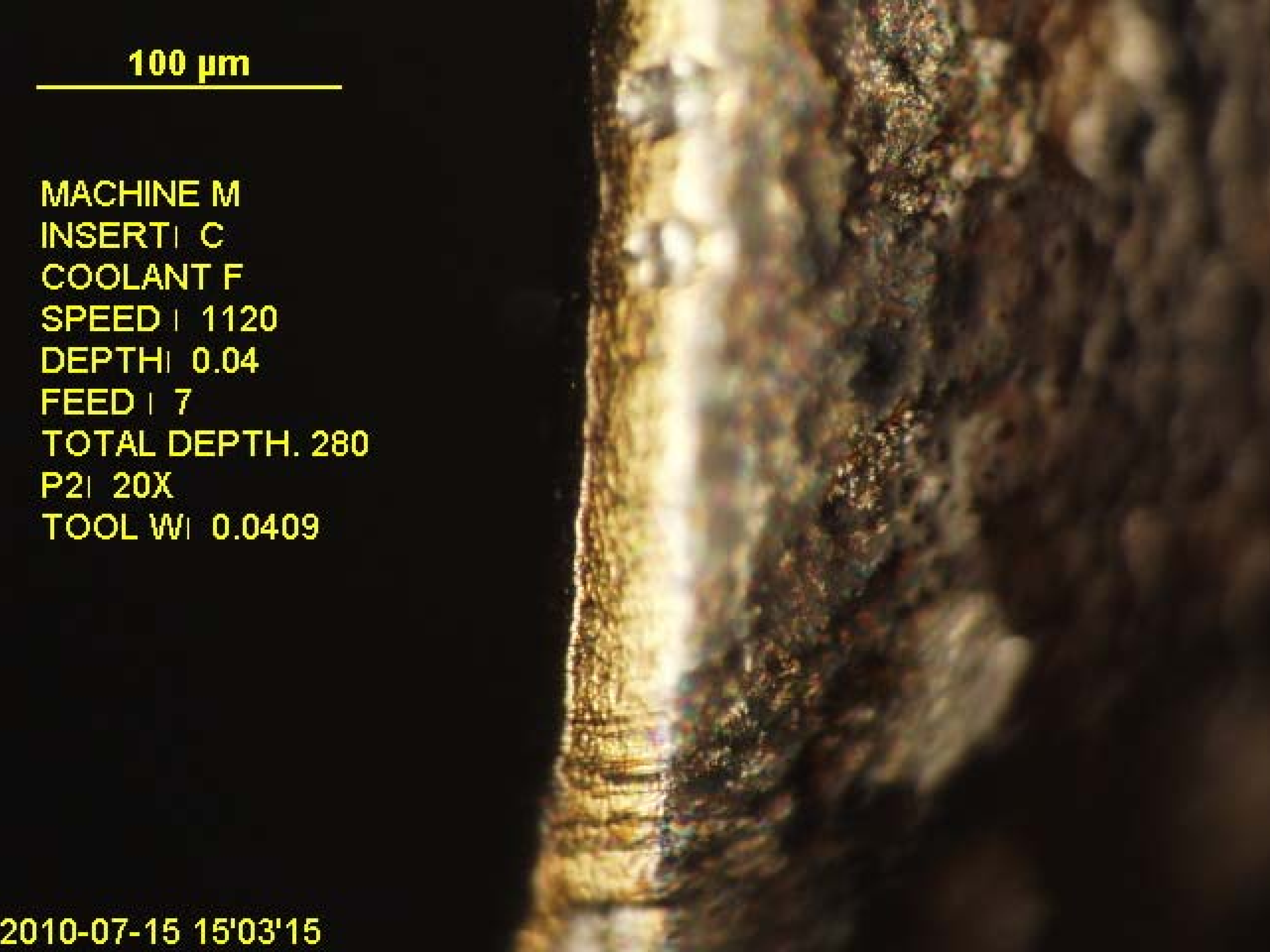


MACHINE M
INSERT| C
COOLANT F
SPEED | 1120
DEPTH| 0.04
FEED | 7
TOTAL DEPTH. 280
P2| 20X
TOOL W| 0.0409

2010-07-15 15'03'15

Impact of Micromist in CNC Machining

Gary SanMiguel[1], Rufus Lamere[2], and Wayne Hung[3]
[1]*Biomedical Manufacturing Center, Athens, TX*
[2]*Texas State Technical College, Waco, TX*
[3]*Texas A&M University, College Station, TX*

Contact: hung@tamu.edu

Present at
Texas HTEC Conference
Waco, Texas
Oct 29, 2010

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 (summer2010)

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)
   - **Marcroface: 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.**

INVESTIGATION: setup

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 (0.017-0.333 in) radial depth, down milling on **D2 tool steel**.
   - **Macrofacing:** 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.**

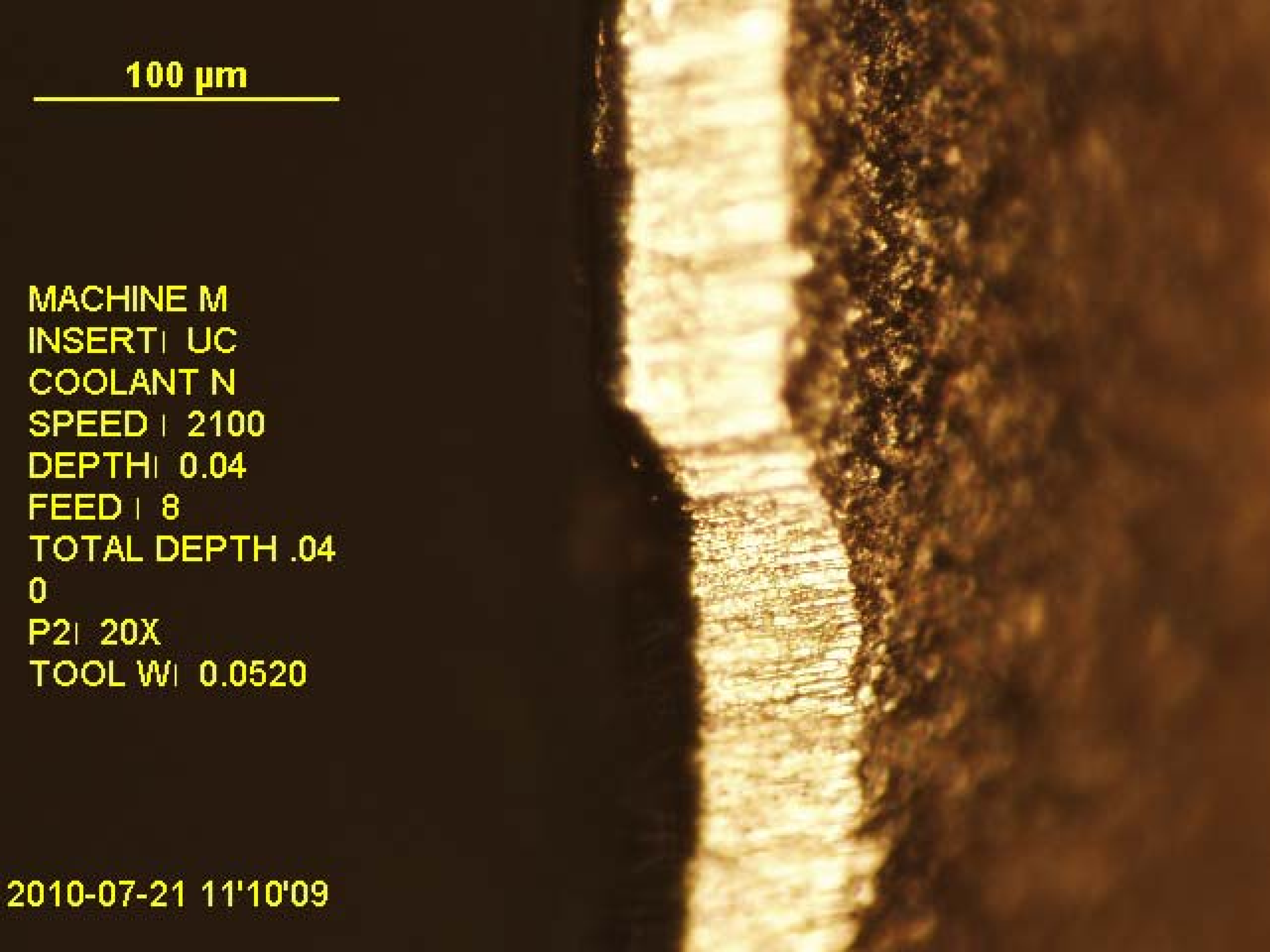
6) **Cutting fluids**:
   - **Dry**
   - **Flood cooling**: synthetic **Blasocut 2000** Universal, 5:1 mixture
   - **Micromist**: UNIST Uni-MAX system, **2210EP oil**, 0.022 cc/min.Use with **Mistbuster500.**

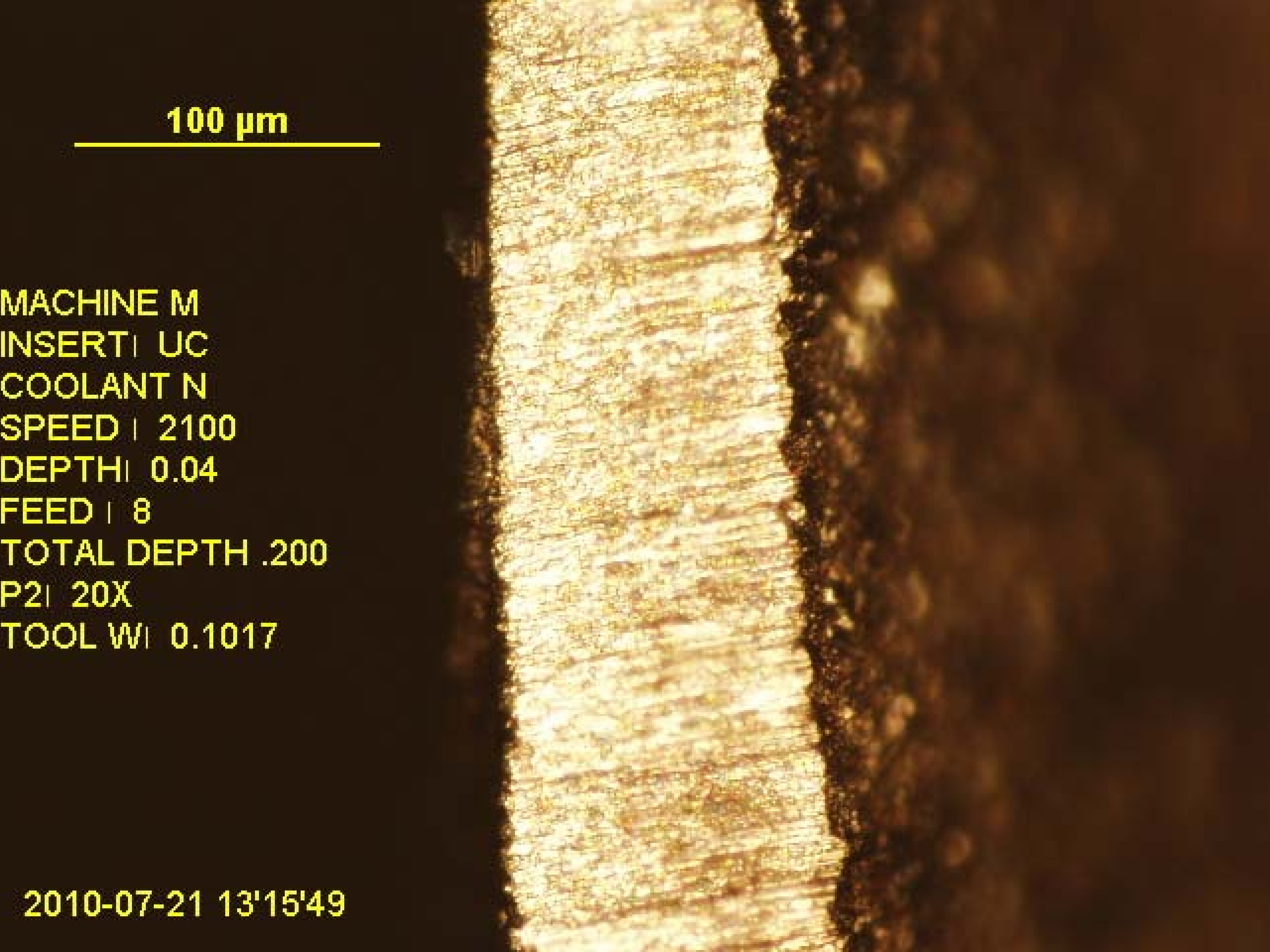
INVESTIGATION: setup

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**

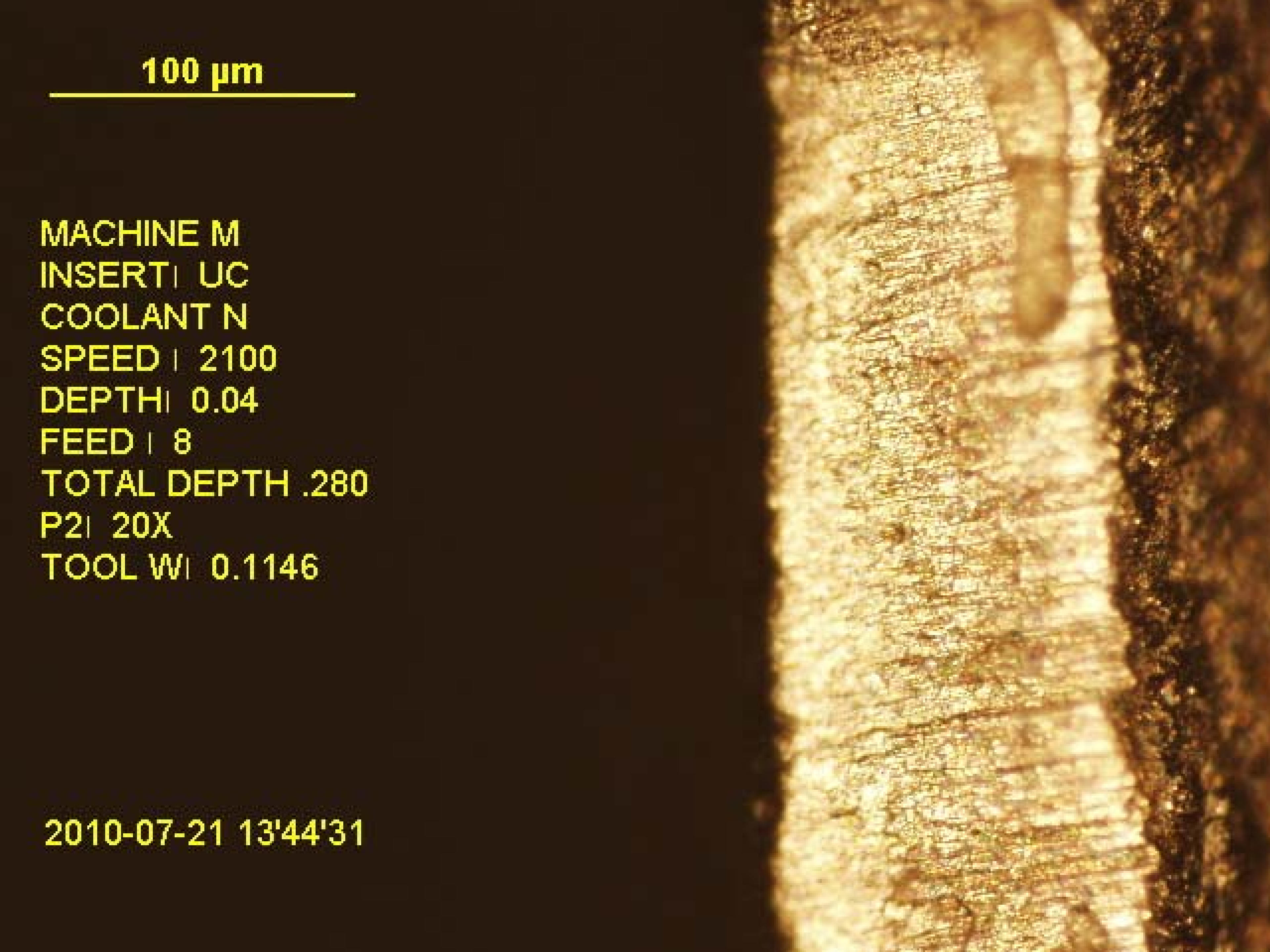
Computer Imaging Lab


100 µm
MACHINE M
INSERT| UC
COOLANT N
SPEED | 2100
DEPTH| 0.04
FEED | 8
TOTAL DEPTH .04
0
P2| 20X
TOOL W| 0.0520
2010-07-21 11'10'09



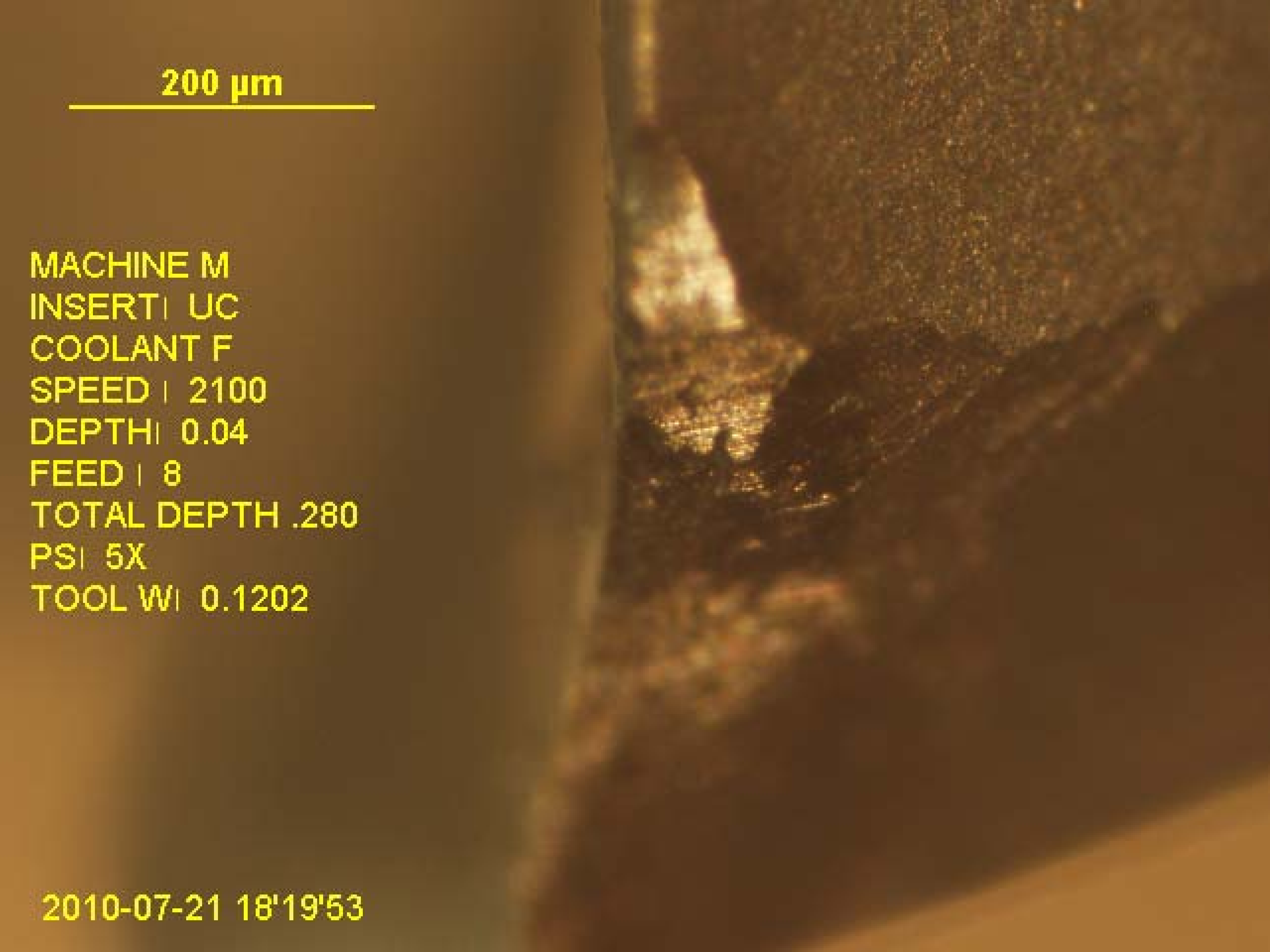
MACHINE M
INSERT| UC
COOLANT N
SPEED | 2100
DEPTH| 0.04
FEED | 8
TOTAL DEPTH .200
P2| 20X
TOOL W| 0.1017

2010-07-21 13'15'49



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 .004
PASSES 50
P2 20X
TOOL W 0.0883

2010 07 09 09'52'29

MACHINE: L
INSERT: UC
COOLANT N
SPEED : 310
DEPTH: 0.02
FEED : .004
PASSES: 70
P1: 10X
TOOL W: 0.1265

2010-07-09 11'00'23

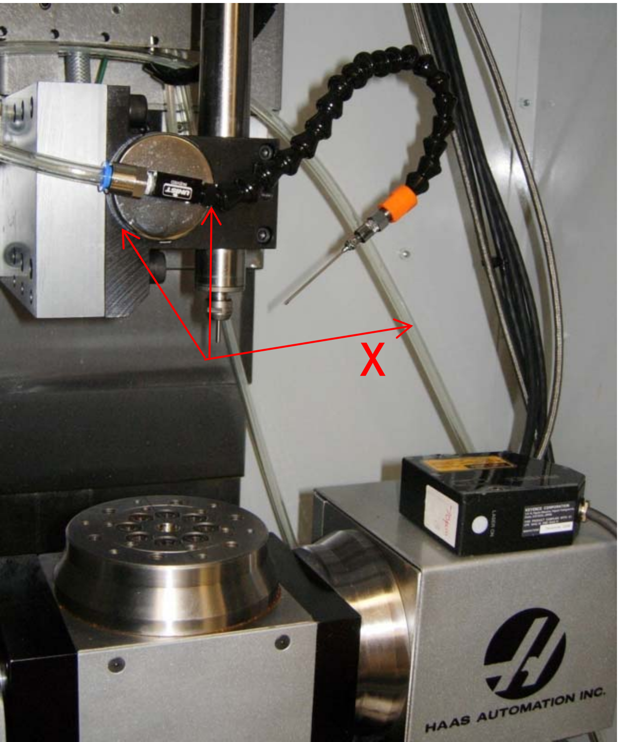
INVESTIGATION: machines

Haas OM2 CNC micromill:

- 5-axis capability
- 50,000 rpm air spindle
- 1 µm spindle runout
- 3 µm repeatability

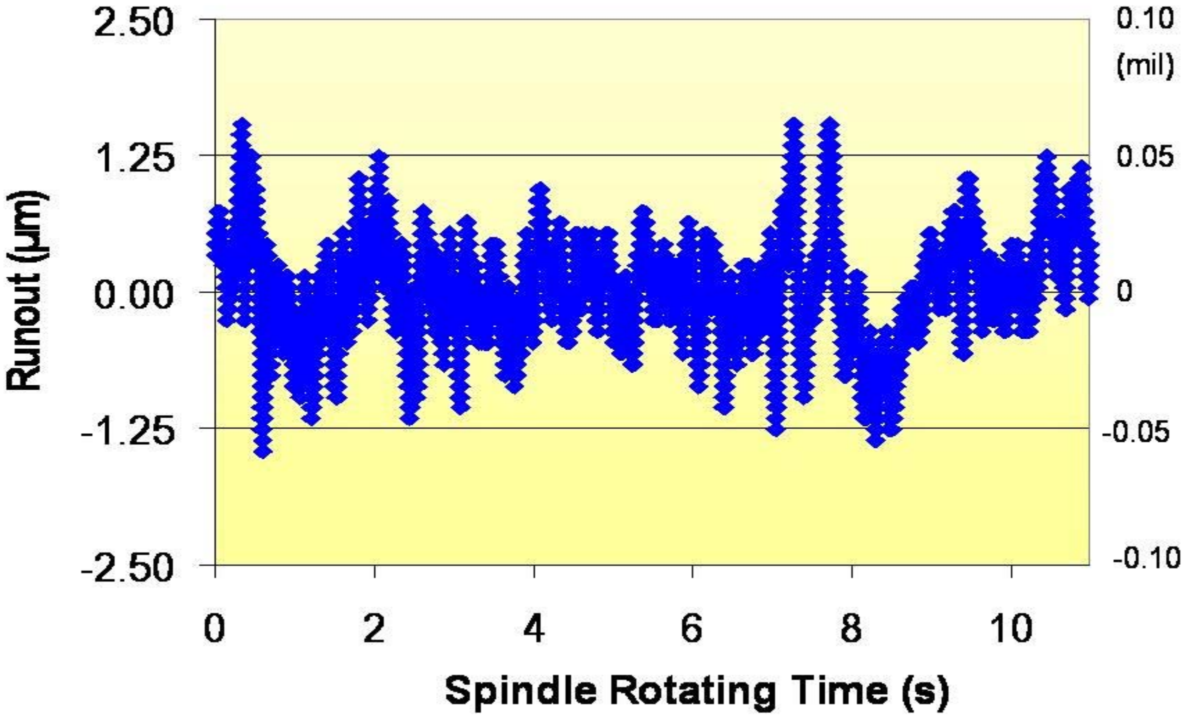
Micromist

- **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



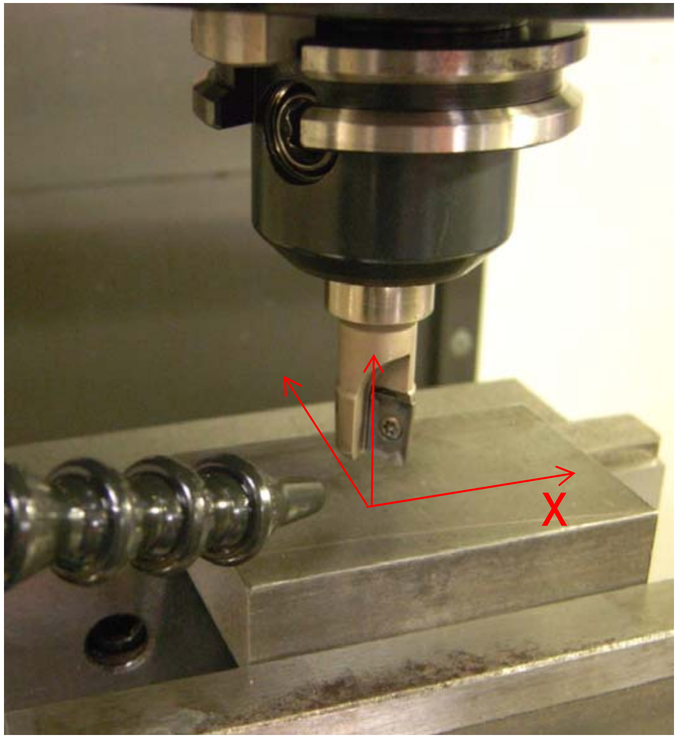
INVESTIGATION: machines

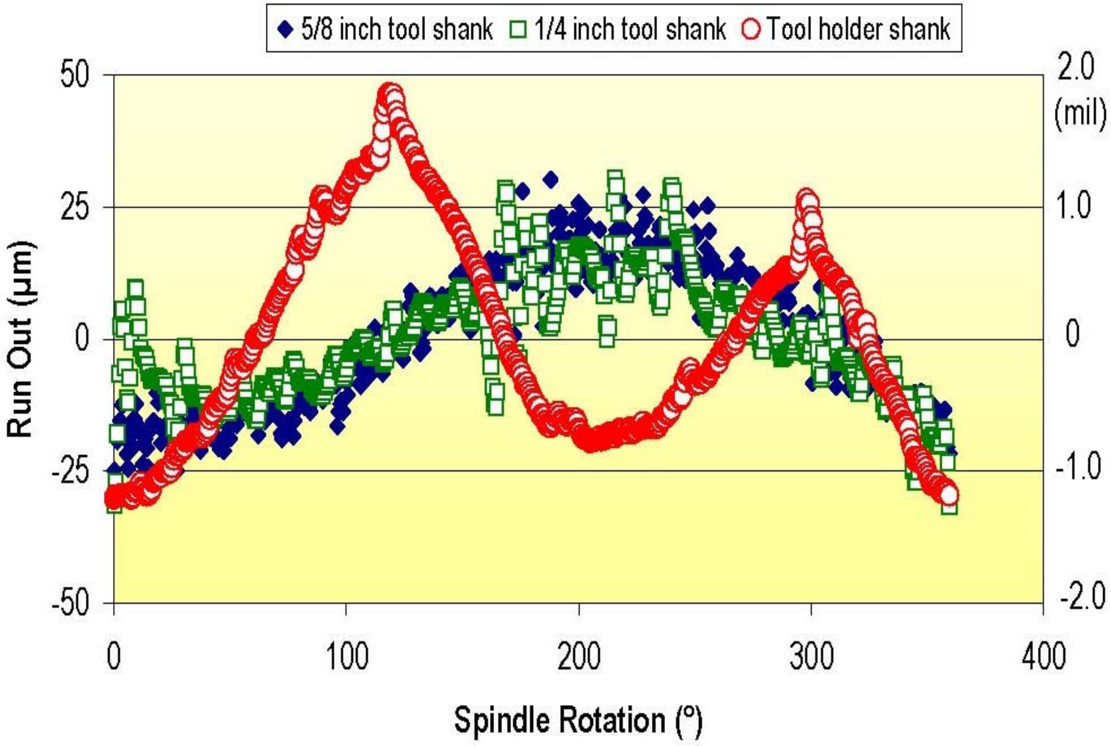
Haas VF1 CNC mill:

- 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**





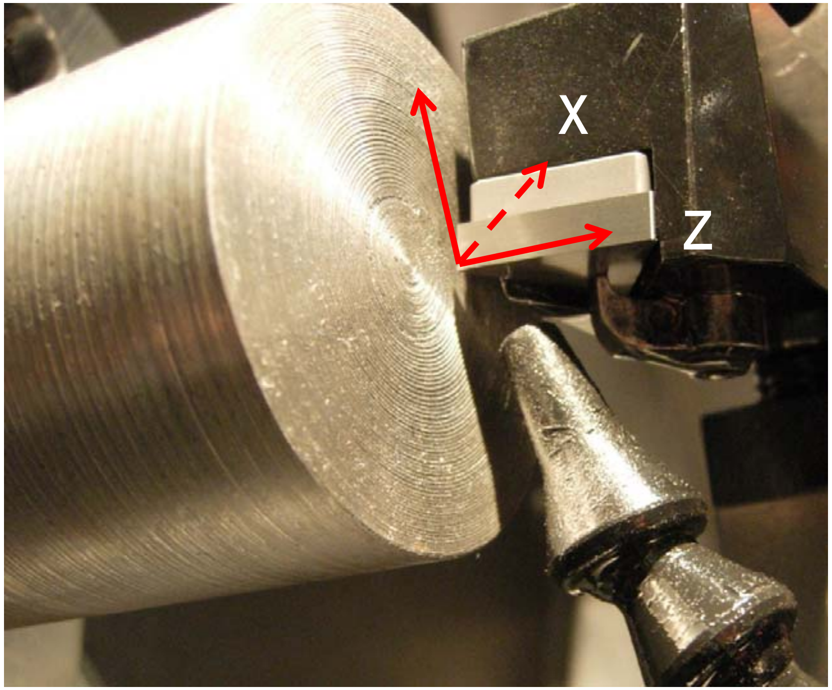
INVESTIGATION: machines

Haas SL20 CNC lathe:

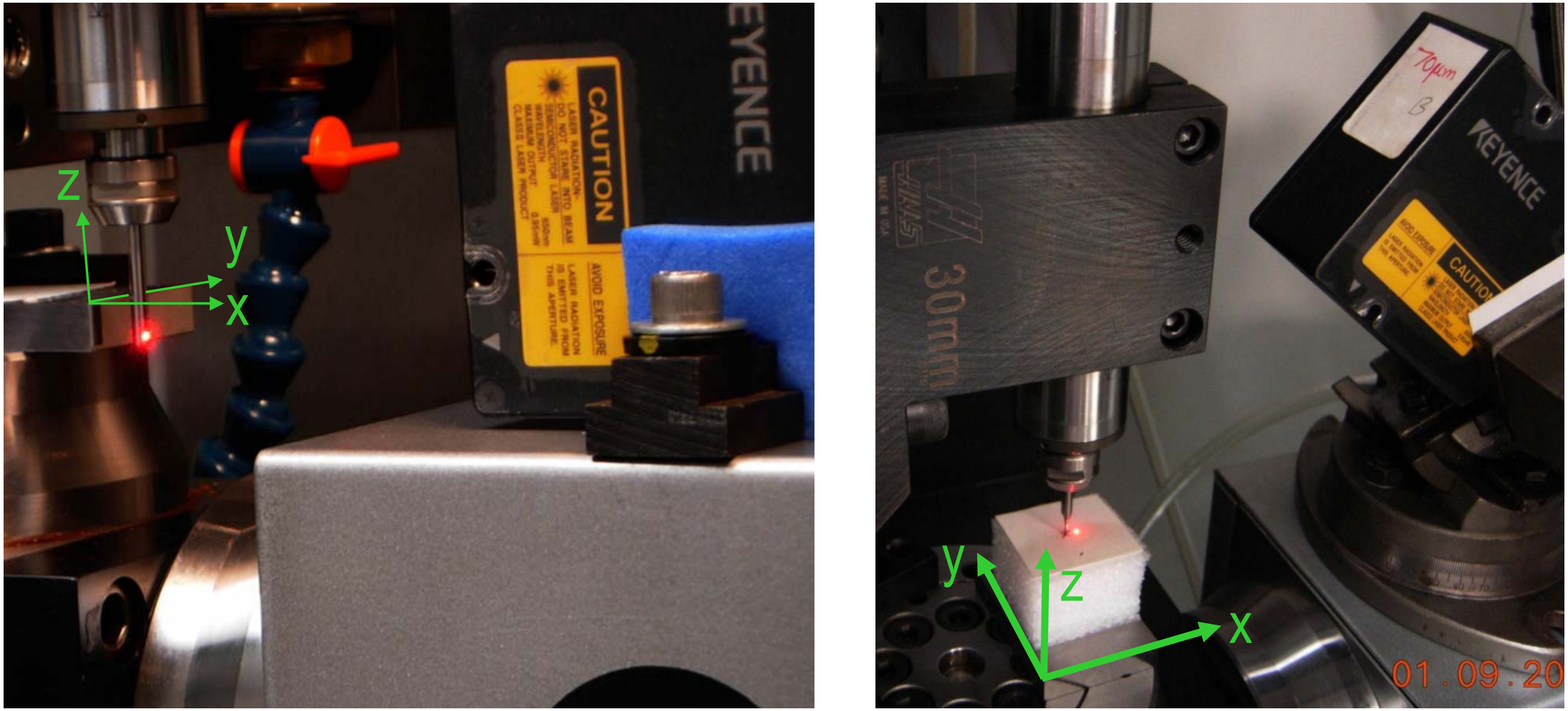
- Live tooling capability
- 3,400 rpm spindle
- 3 µm repeatability

Micromist

- **2210EP oil, 0.022 cc/min**
- **6 mm @150 from y axis**
- **-60 in x-y plane**



MICROMACHINING: tool setting

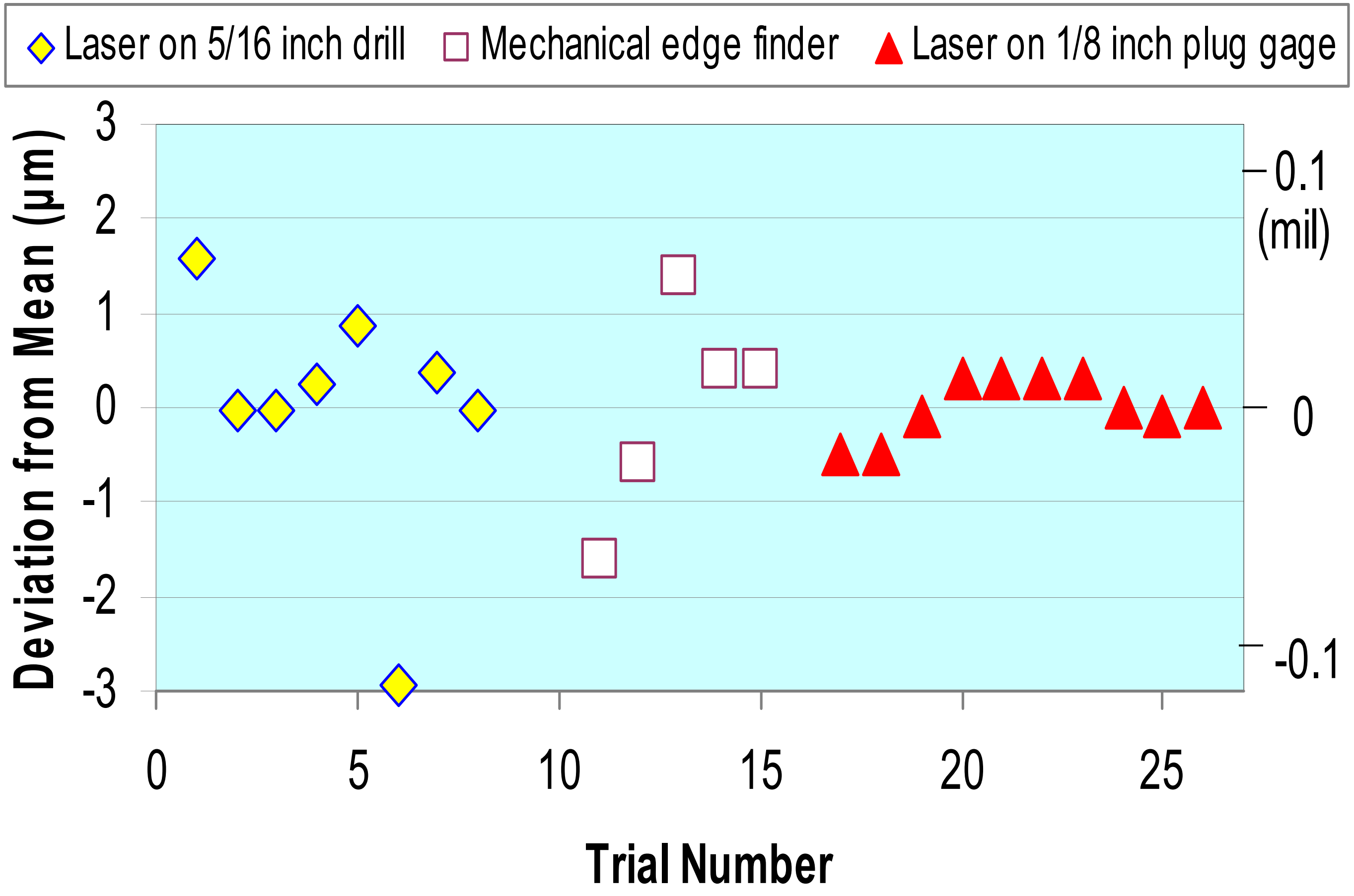


(a)
Set up for edge detection on x-y plane

(b)
Set up for tool height z-offset

Microtool offset using laser sensor

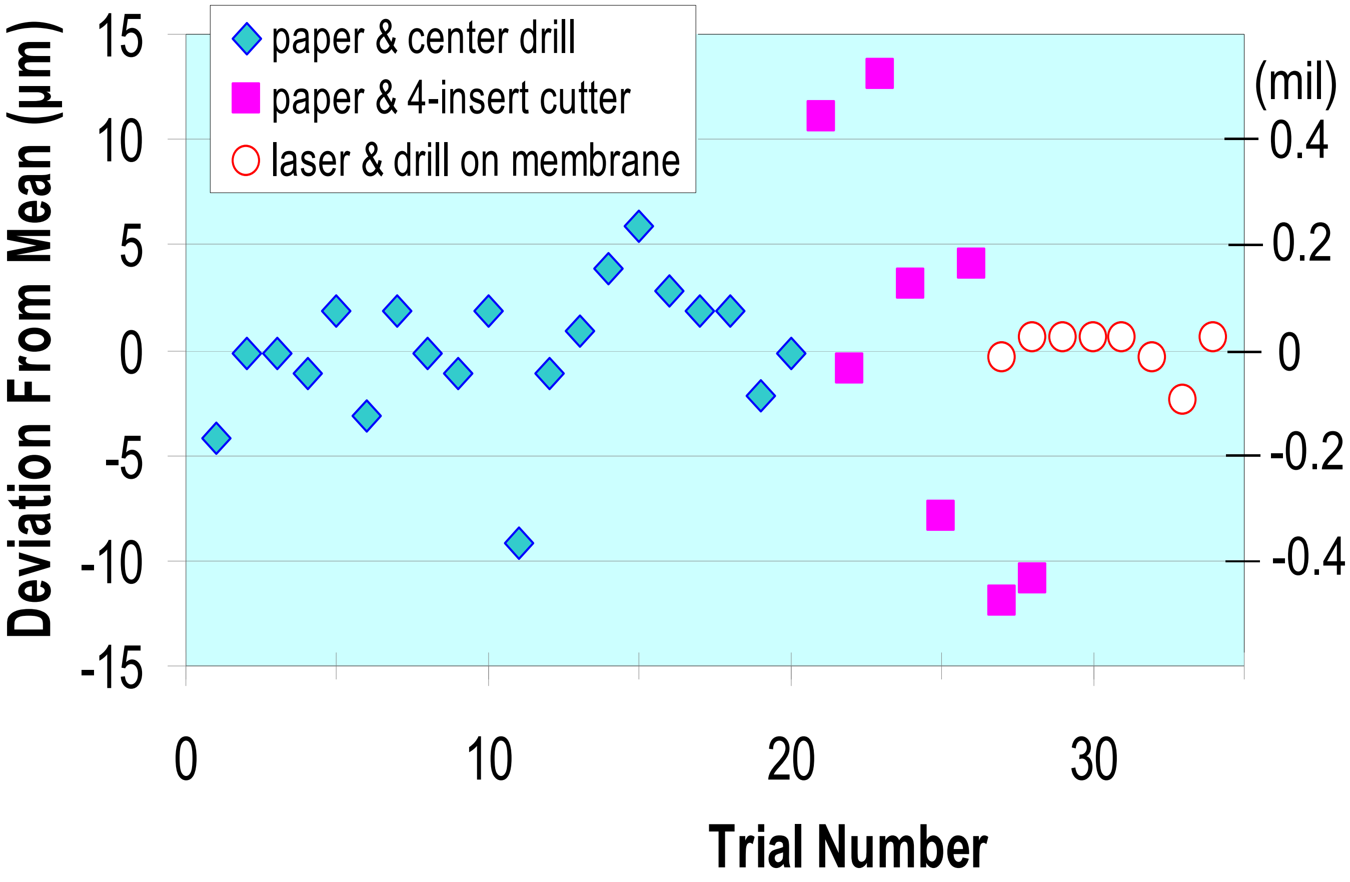
MICROMACHINING: tool setting



- 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**

MACHINING: micromist

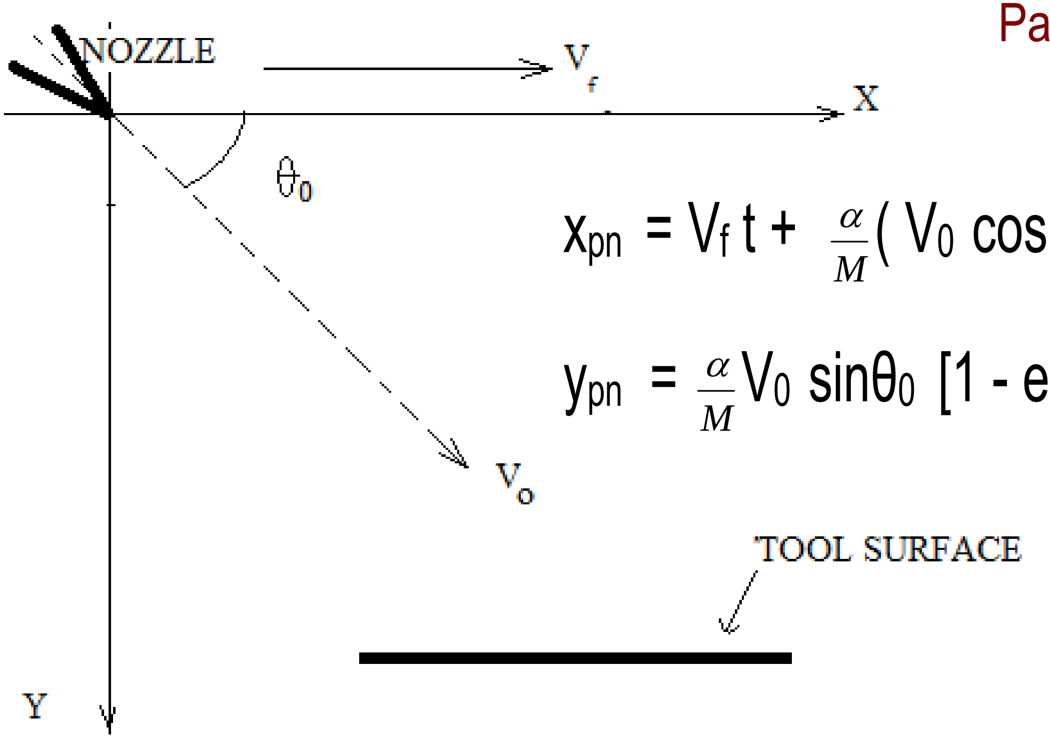
Penetrate?

Particle trajectory

CFD modeling

Optimal tool/workpiece/ nozzle positions

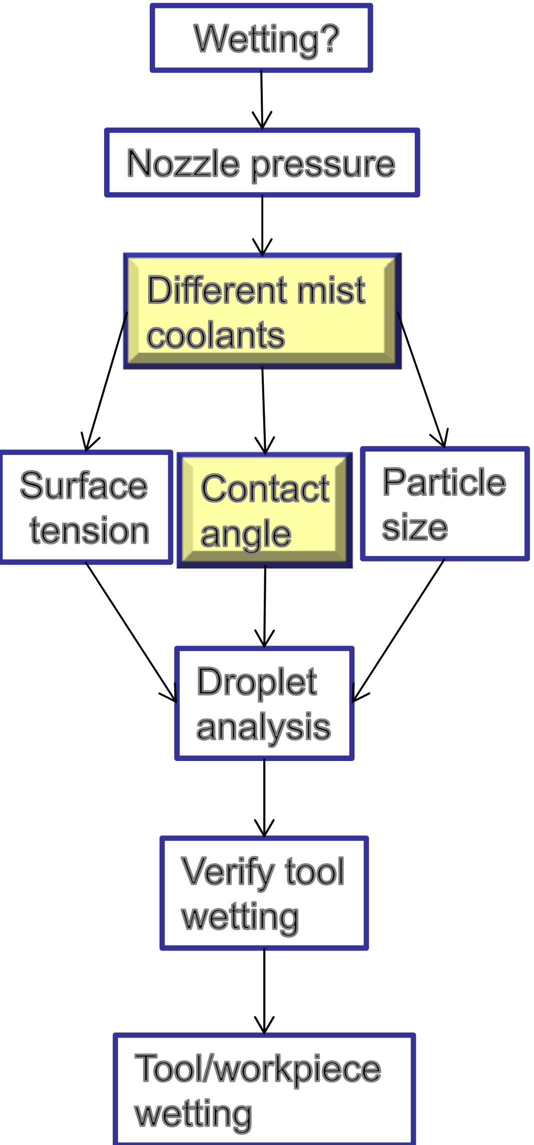
Particle Trajectory



$$x_{pn} = V_f\, t + \frac{\alpha}{M}\left(V_0 \cos\theta_0 - V_f \right)\left[1 - e^{-(\alpha/M)\, t}\right]$$

$$y_{pn} = \frac{\alpha}{M} V_0 \sin\theta_0 \left[1 - e^{-(\alpha/M)\, t}\right]$$

MACHINING: coolant wetting



Wetting?

Nozzle pressure

Different mist coolants

Surface tension

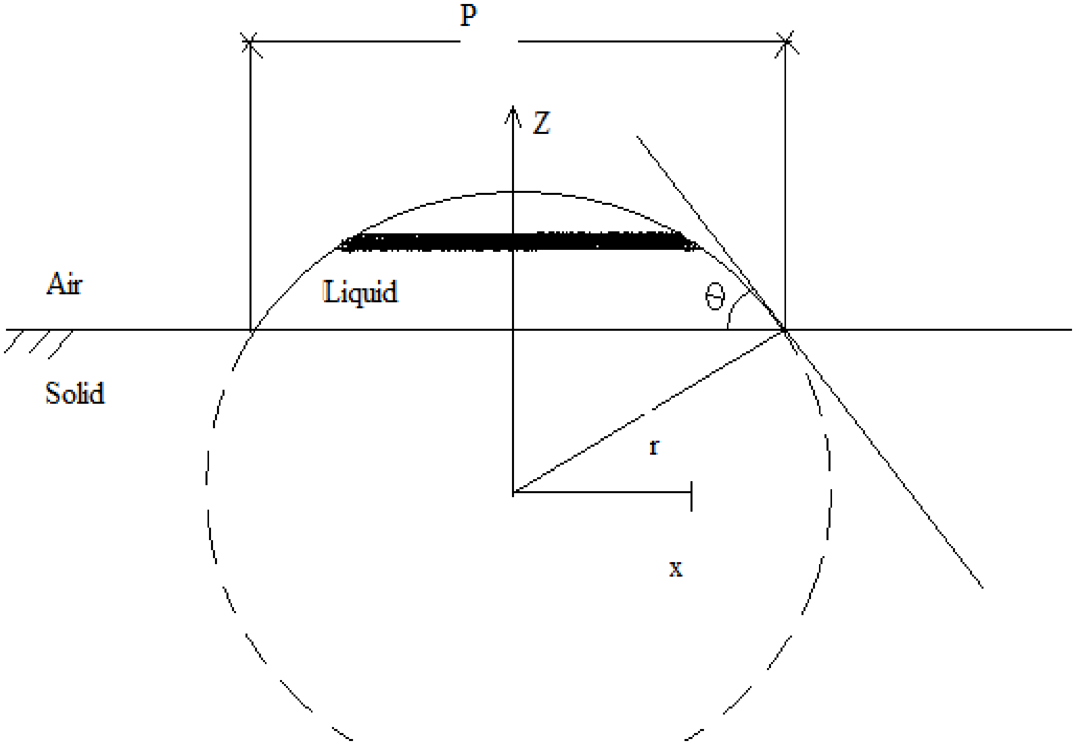
Contact angle

Particle size

Droplet analysis

Verify tool wetting

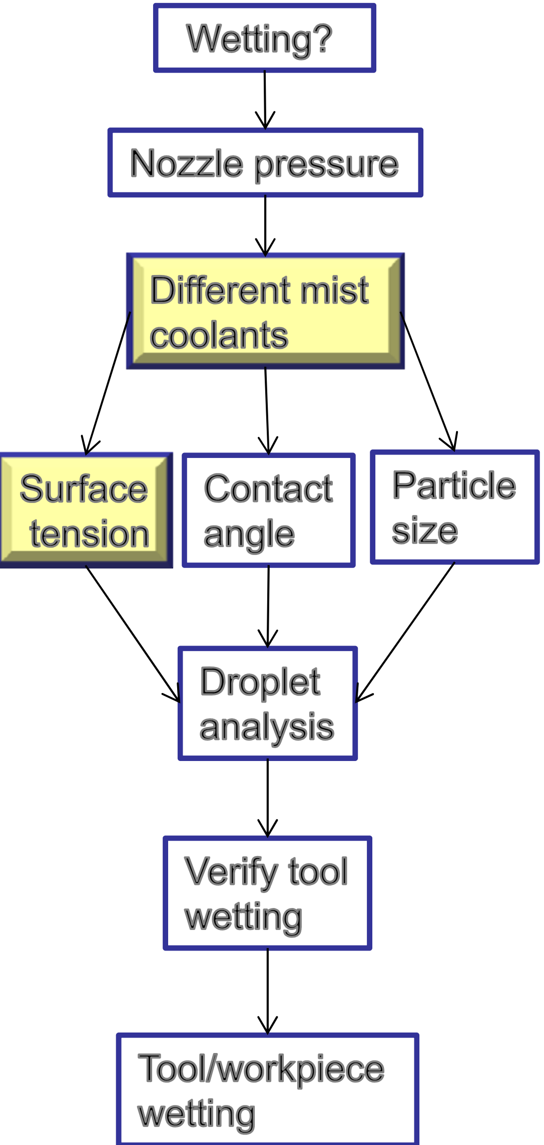
Tool/workpiece wetting



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

V: volume of droplet
P: diameter of droplet
K: 1 for θ<90^0; 0 for θ>90^0
θ : contact angle

MACHINING: micromist



Wetting?

Nozzle pressure

Different mist coolants

Surface tension

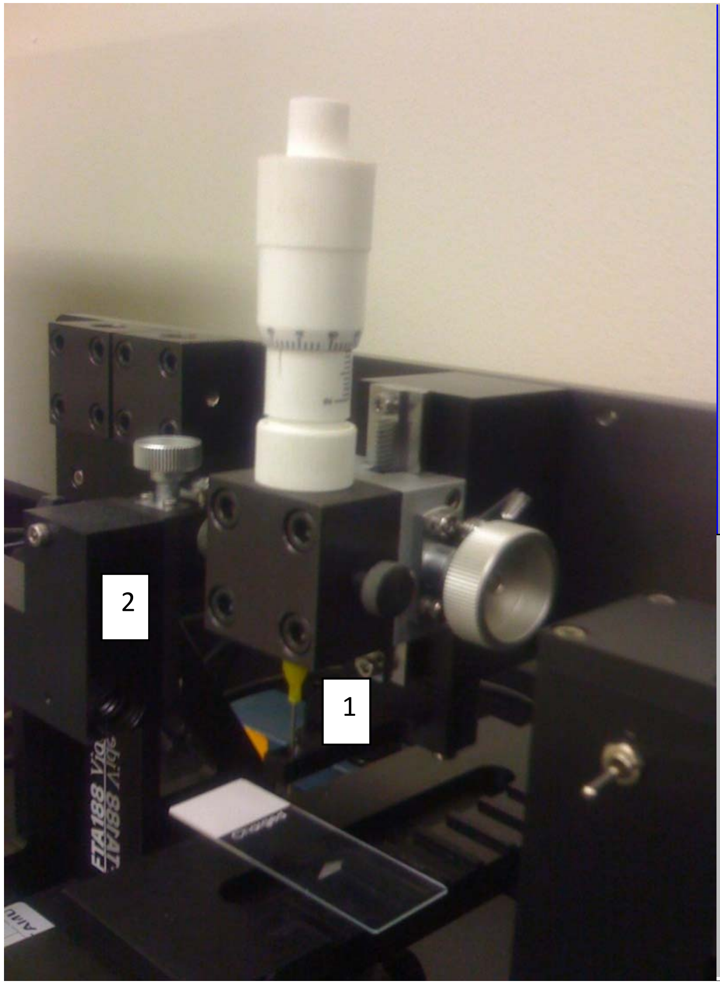
Contact angle

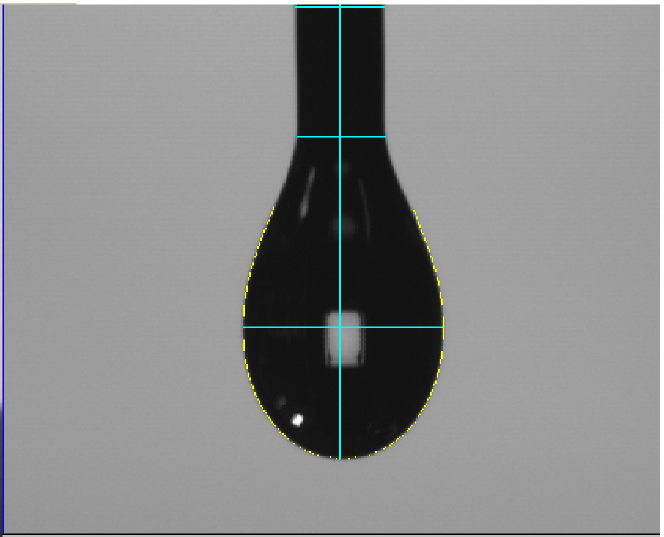
Particle size

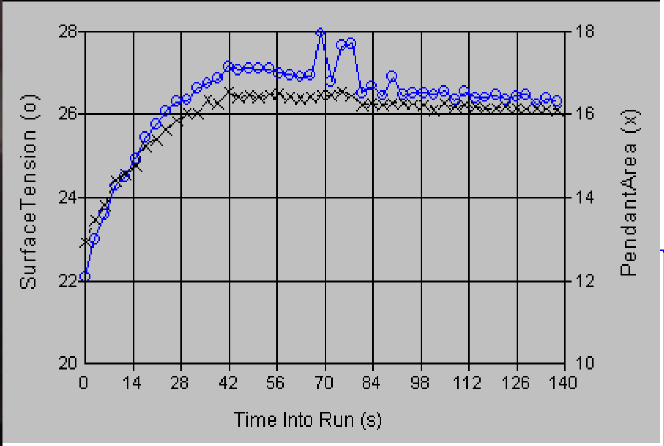
Droplet analysis

Verify tool wetting

Tool/workpiece wetting



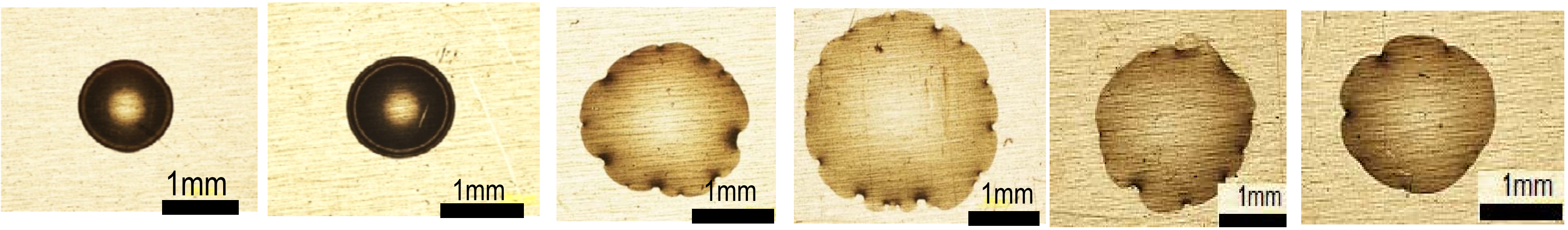


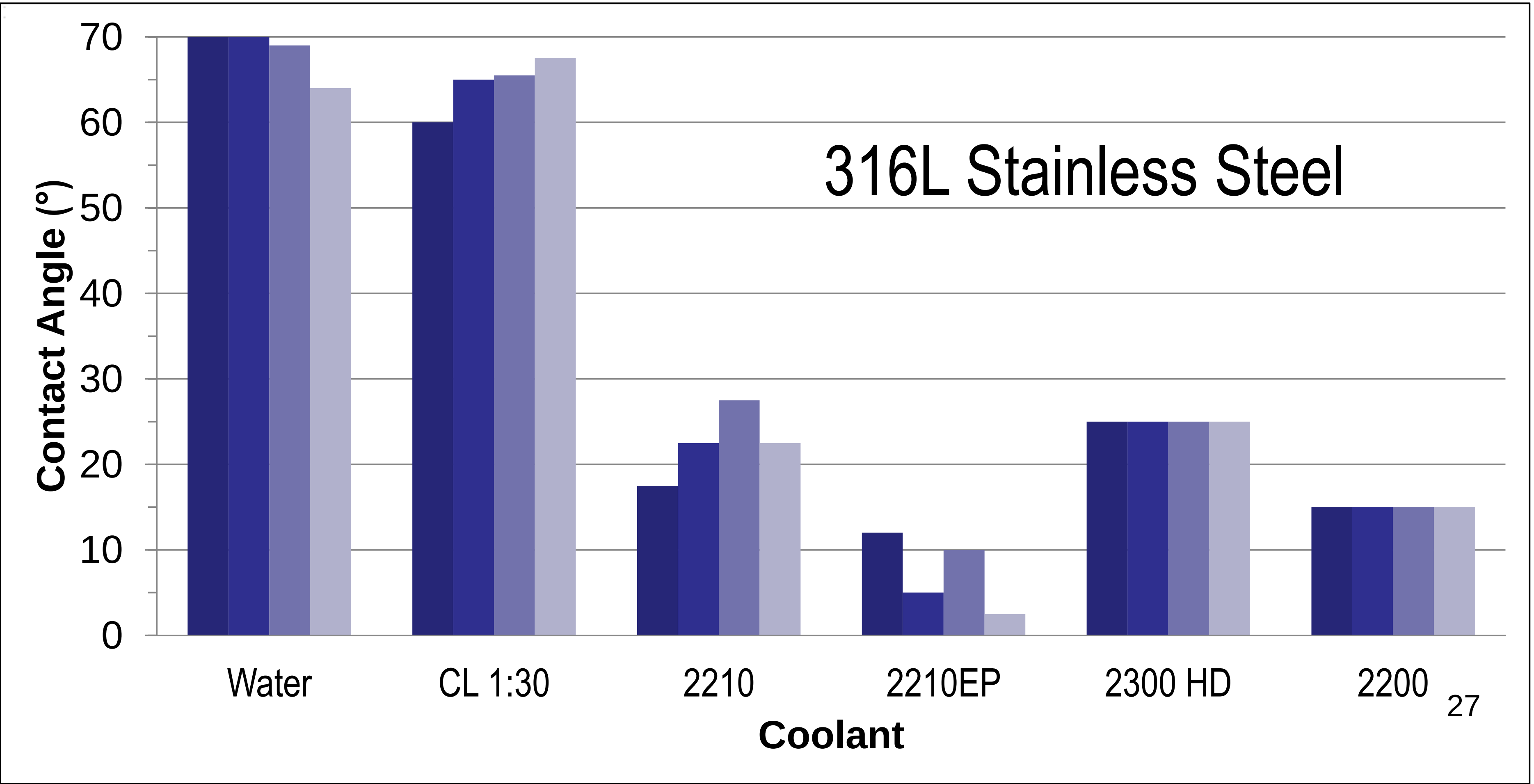


Apparatus for Surface tension measurement

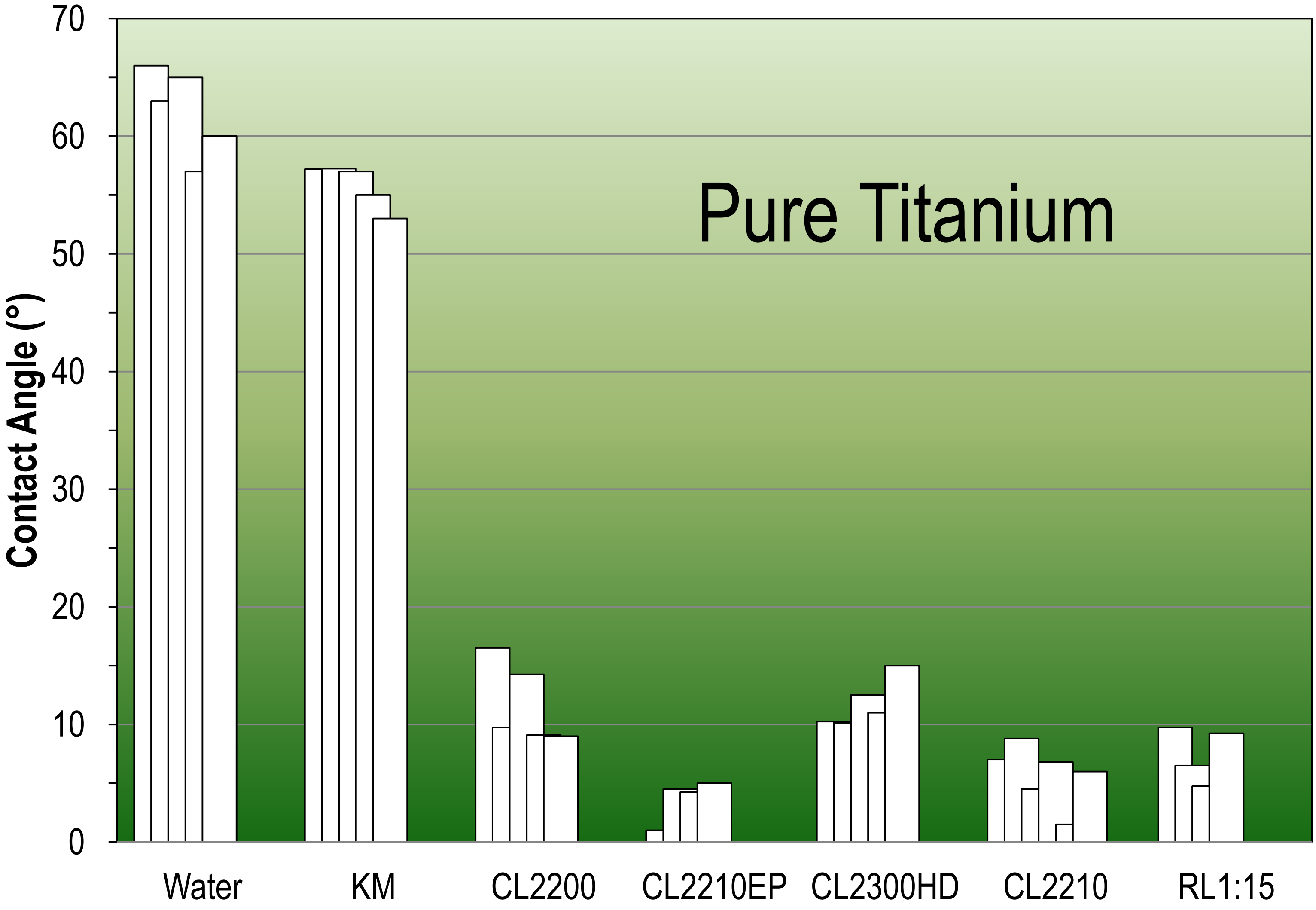
1. Needle for delivering liquid droplets
2. Camera

MACHINING: micromist

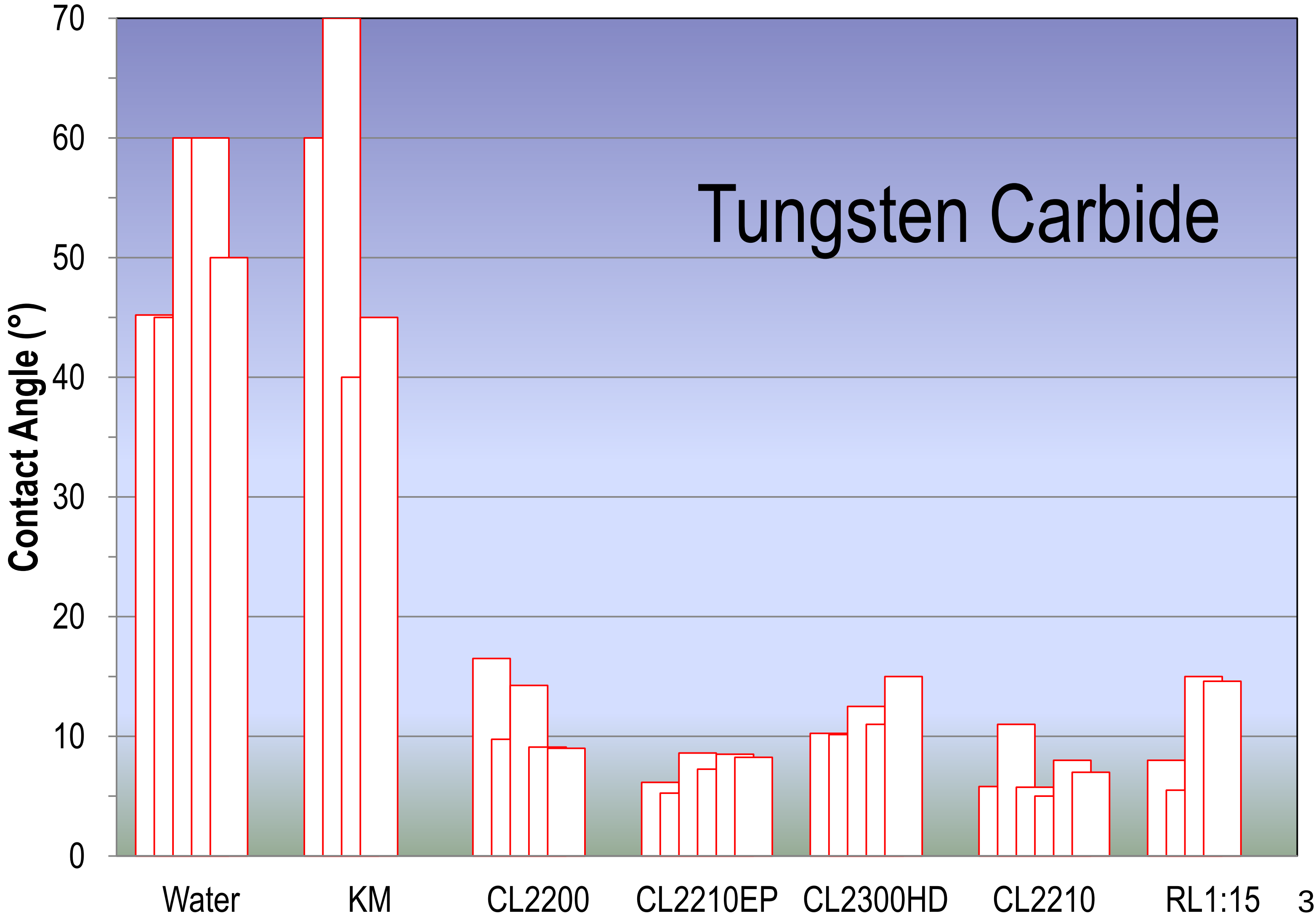




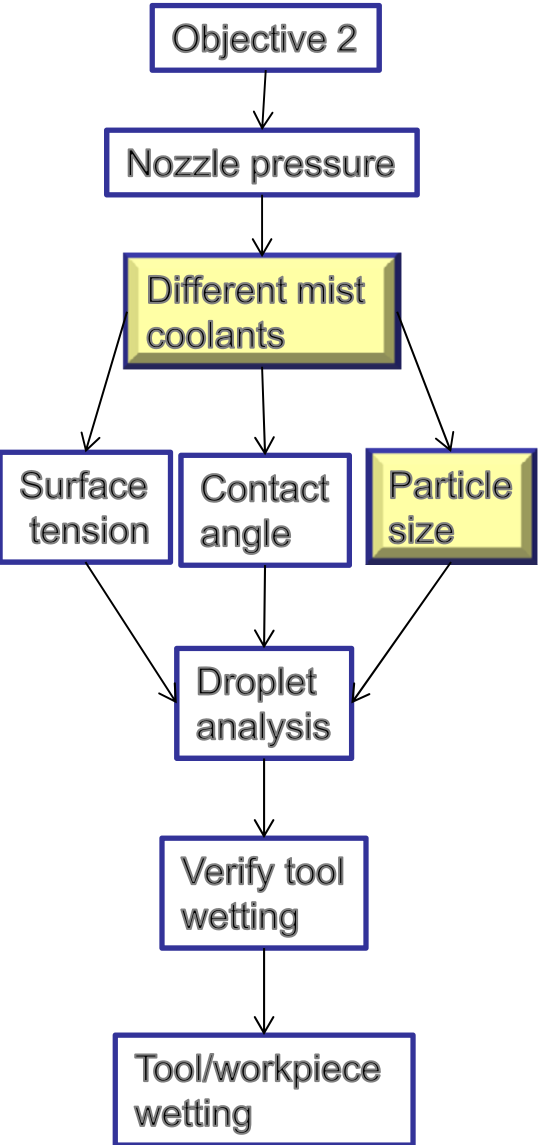
MACHINING: micromist



MACHINING: micromist



MACHINING: micromist



Objective 2

Nozzle pressure

Different mist coolants

Surface tension

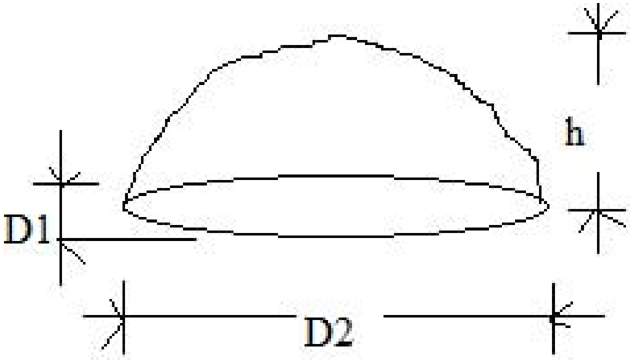
Contact angle

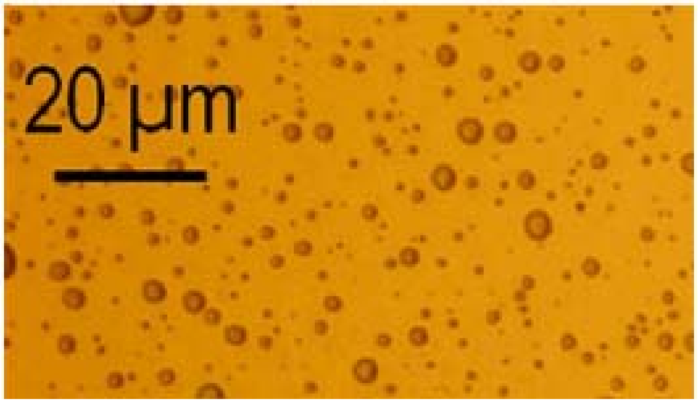
Particle size

Droplet analysis

Verify tool wetting

Tool/workpiece wetting



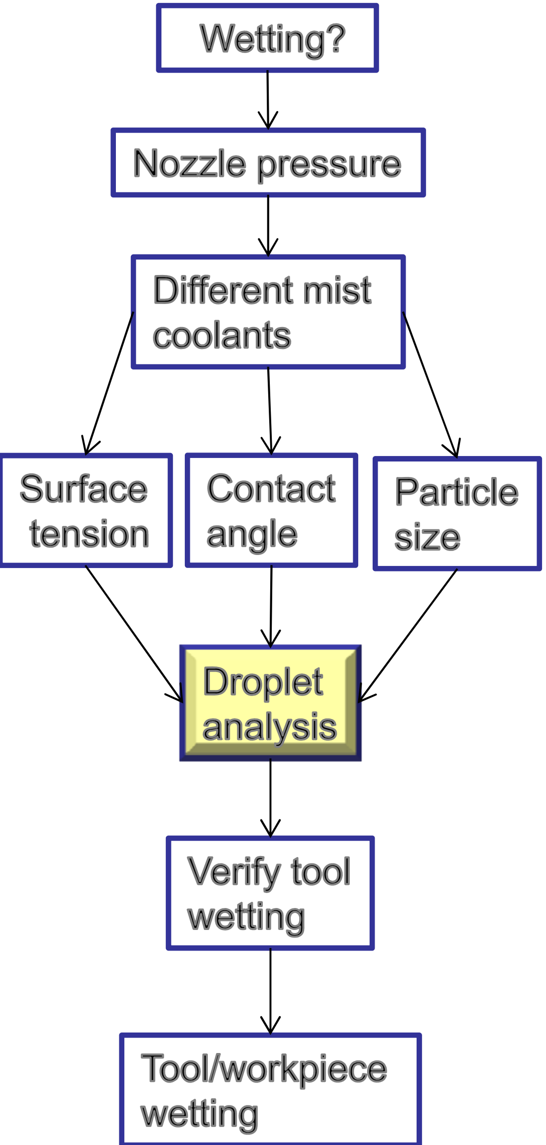


$$V = \pi h^2\left[\frac{h}{6}+\frac{r^2}{2h}\right]$$

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

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

MACHINING: micromist



Wetting?

Nozzle pressure

Different mist coolants

Surface tension

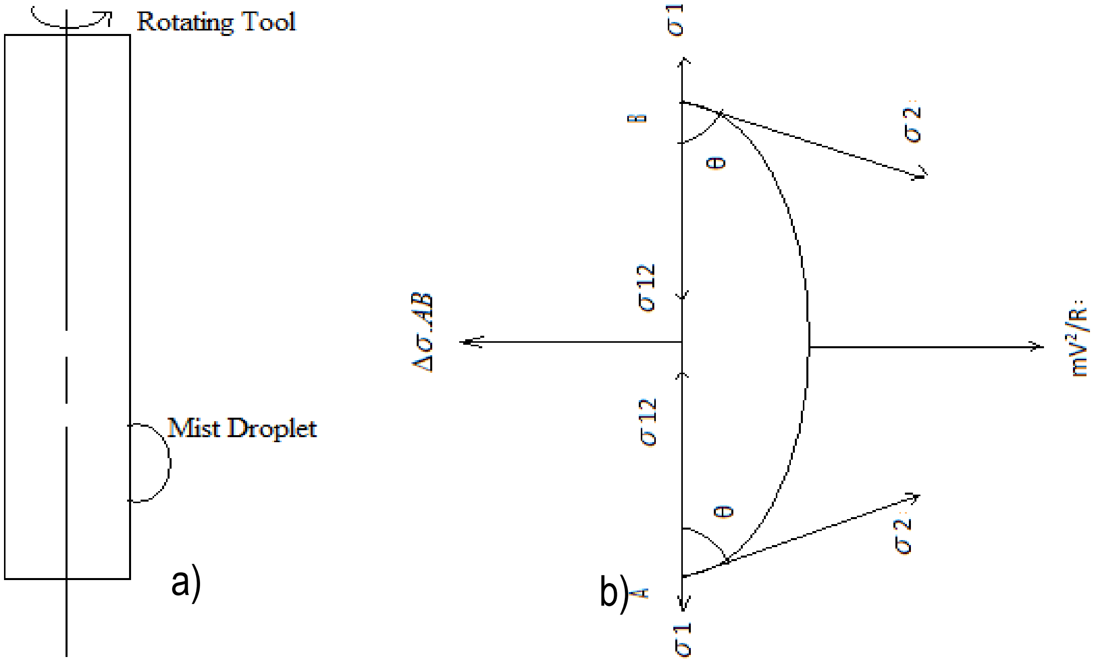
Contact angle

Particle size

Droplet analysis

Verify tool wetting

Tool/workpiece wetting



(a) Micro-droplet on a rotating tool;

(b) Free body diagram of forces acting on the micro-droplet

$$\frac{mv^2}{R} + 2\,\sigma_2 \sin\theta = \Delta\,\sigma\,D$$

m: mass of droplet

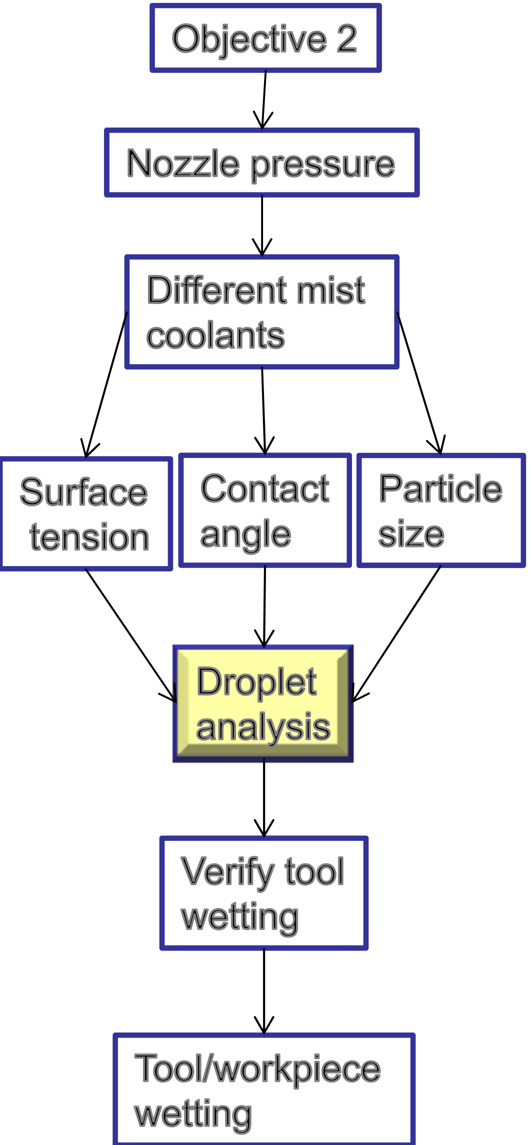
v: surface speed of tool

R: radius of tool

D: diameter of droplet

σ_2: surface tension of liquid

MACHINING: micromist



Objective 2

Nozzle pressure

Different mist coolants

Surface tension

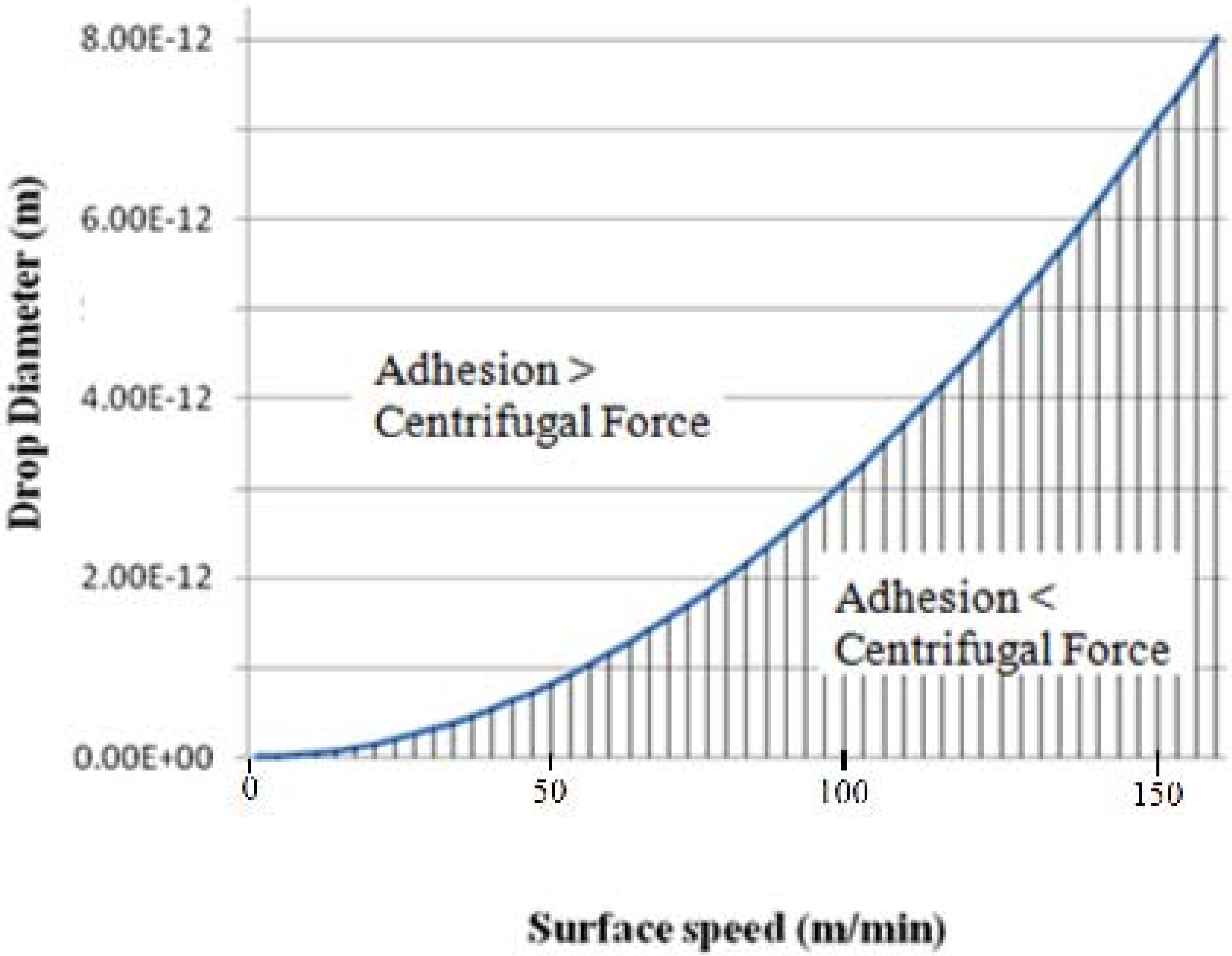
Contact angle

Particle size

Droplet analysis

Verify tool wetting

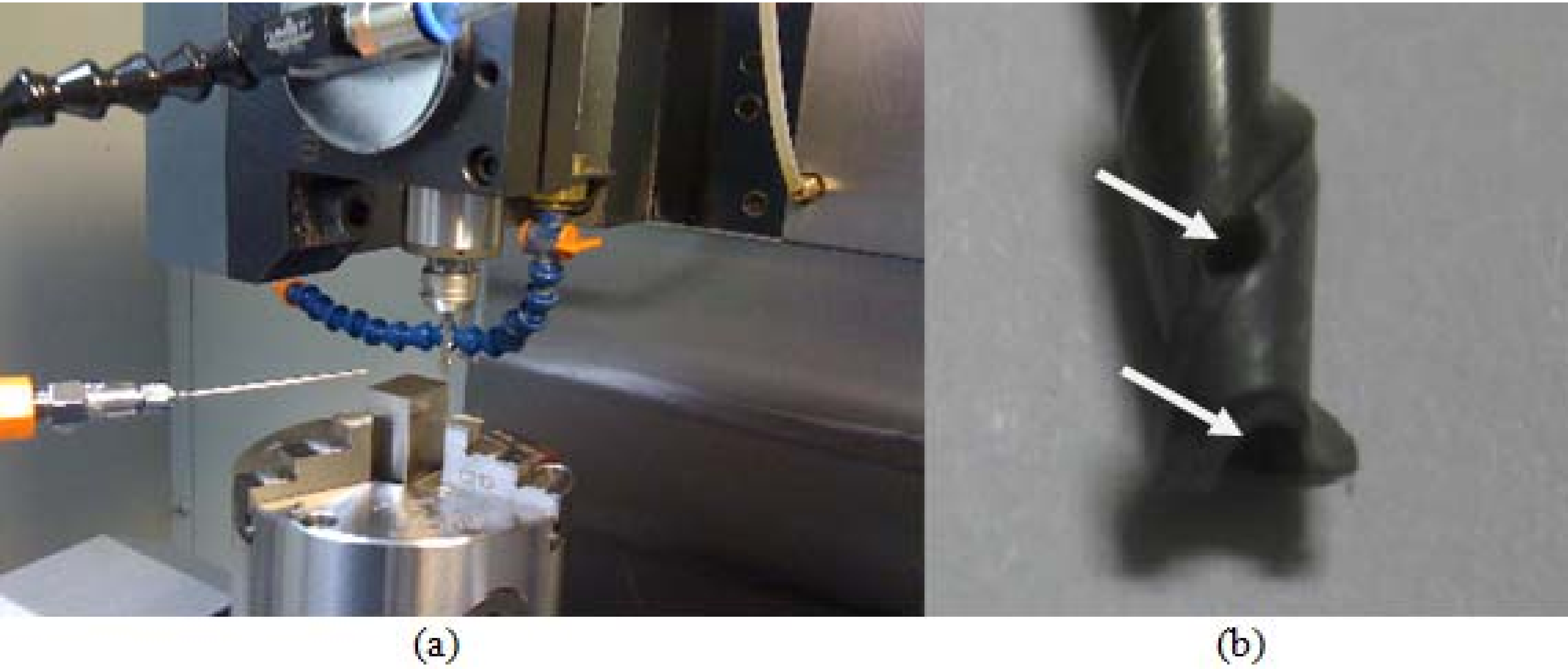
Tool/workpiece wetting



Balance of adhesion and centrifugal force on a 2210EP microdroplet

APPROACH – OBJECTIVE # 2

Setup for validation of tool wetting



(a)Mist spray setup (b) 3.175 mm 2 flute end-mill
12.7mm 2 flute end-mill (not shown)

RESULT: flow of micromist

Flow?

↓

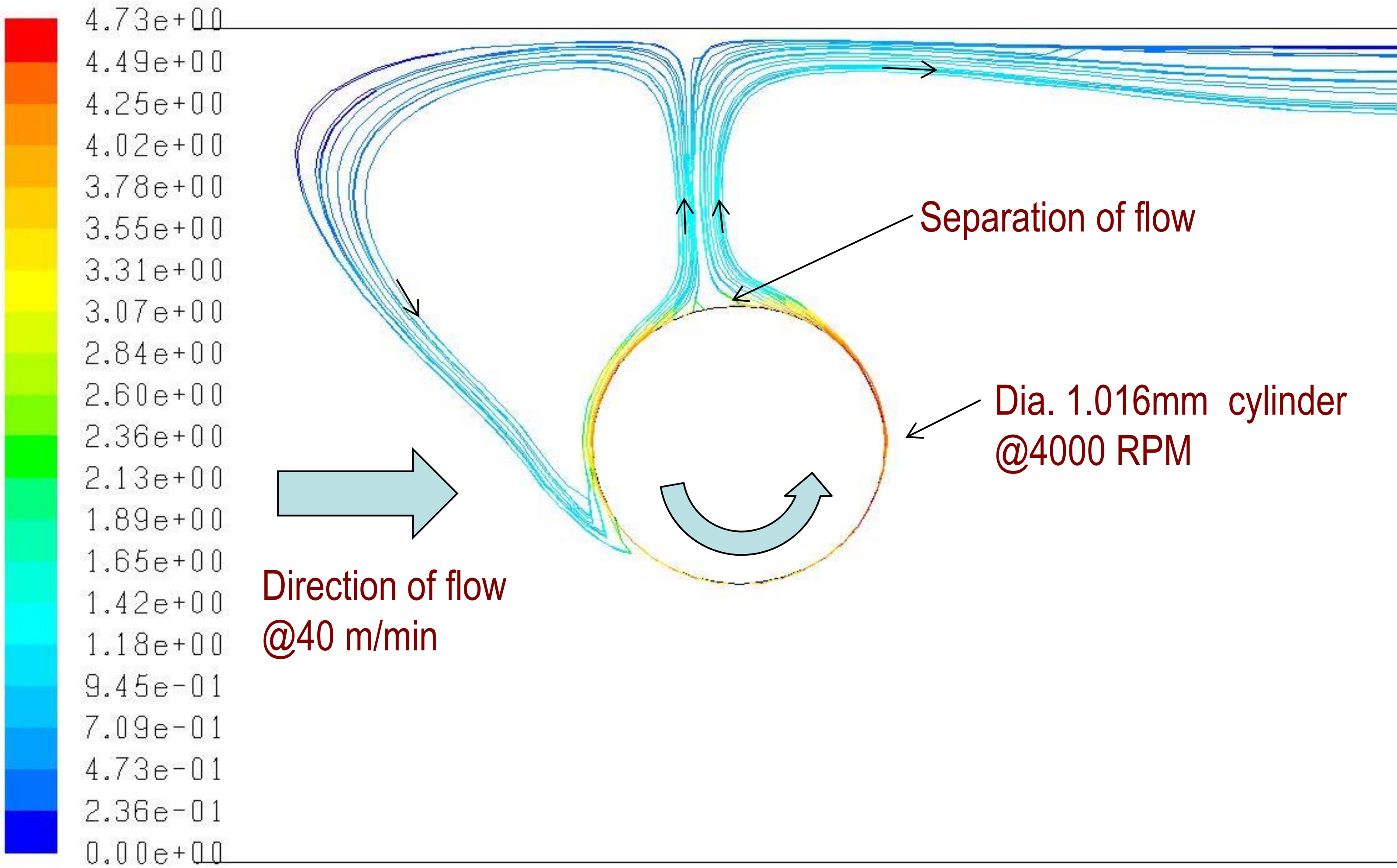
Particle trajectory

↓

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)

Nov 11, 2008
FLUENT 6.3 (2d, pbns, lam)

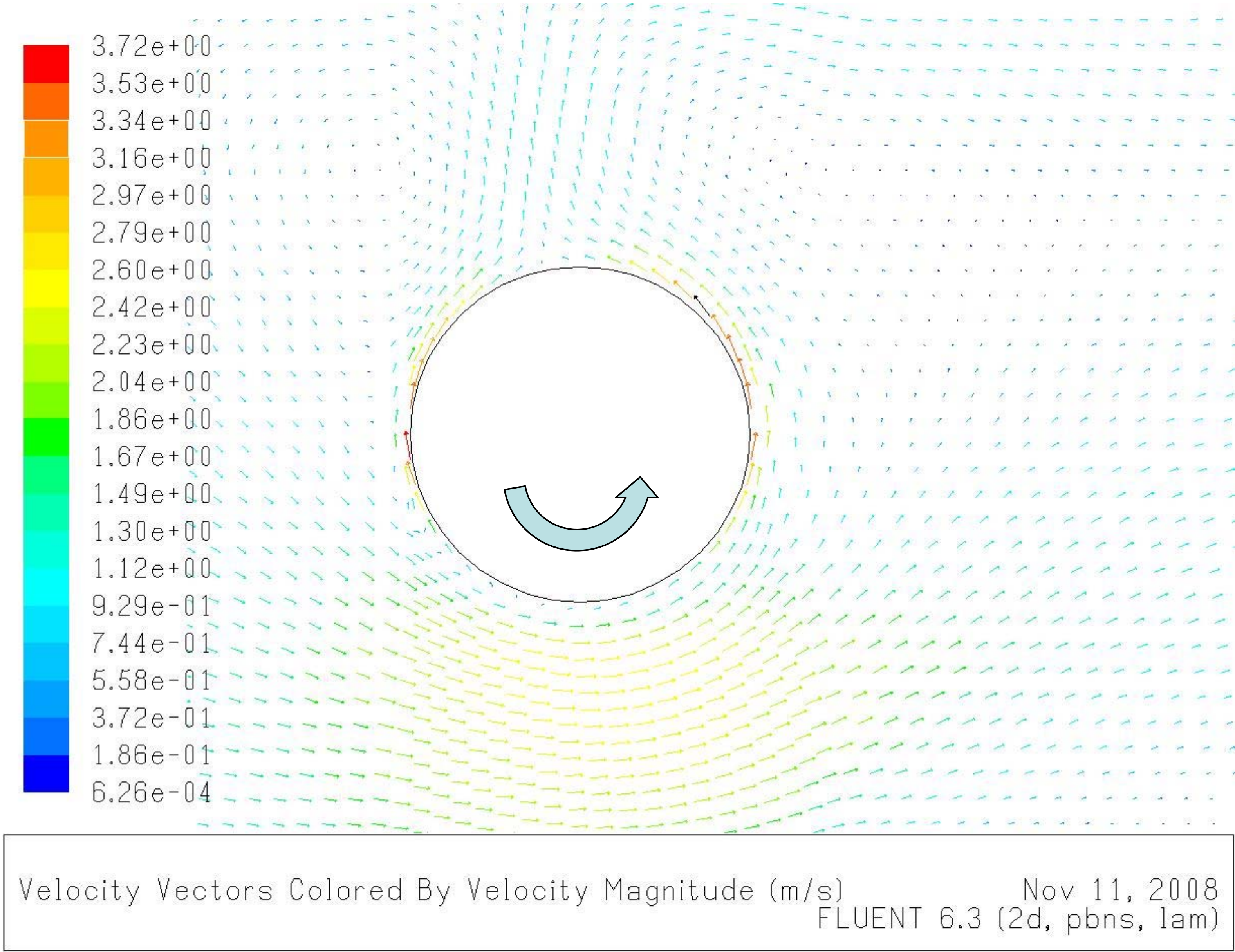
RESULT: flow of micromist

Flow?

Particle trajectory

CFD modeling

Optimal tool/workpiece/nozzle positions

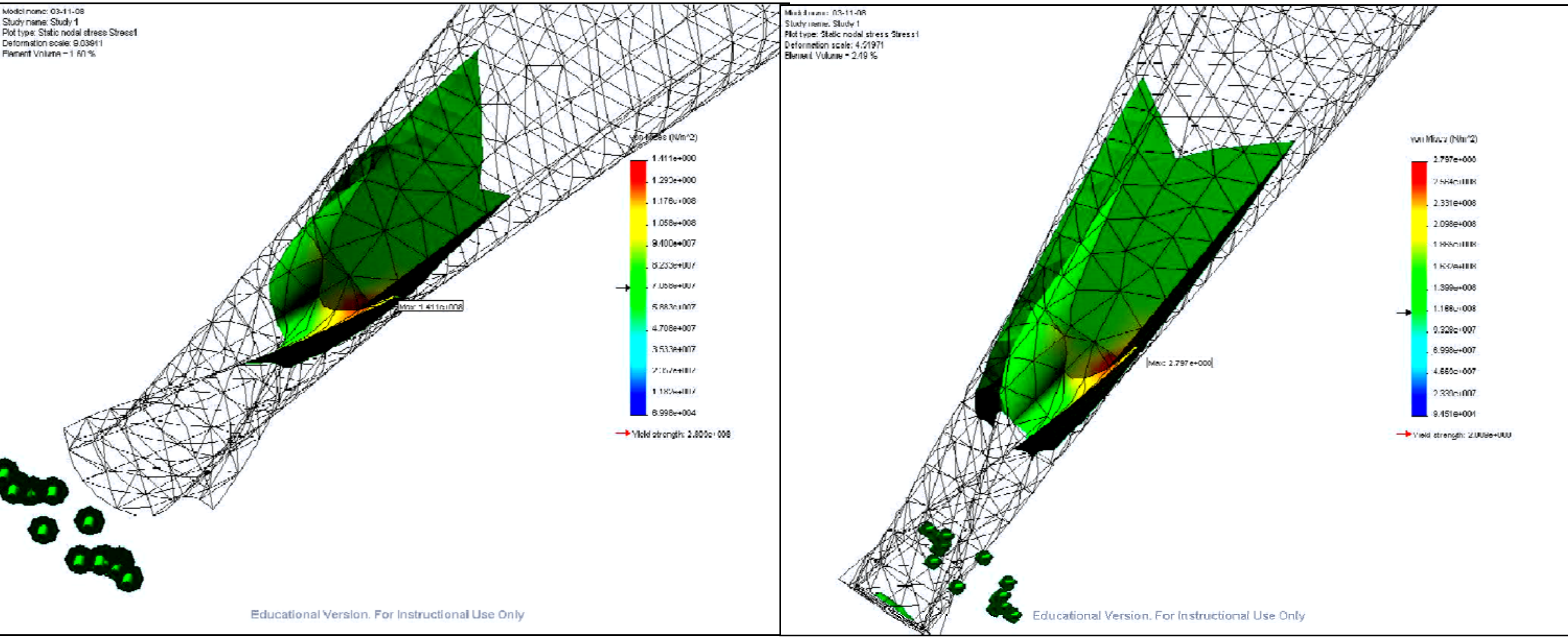


Velocity Vectors Colored By Velocity Magnitude (m/s)

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.

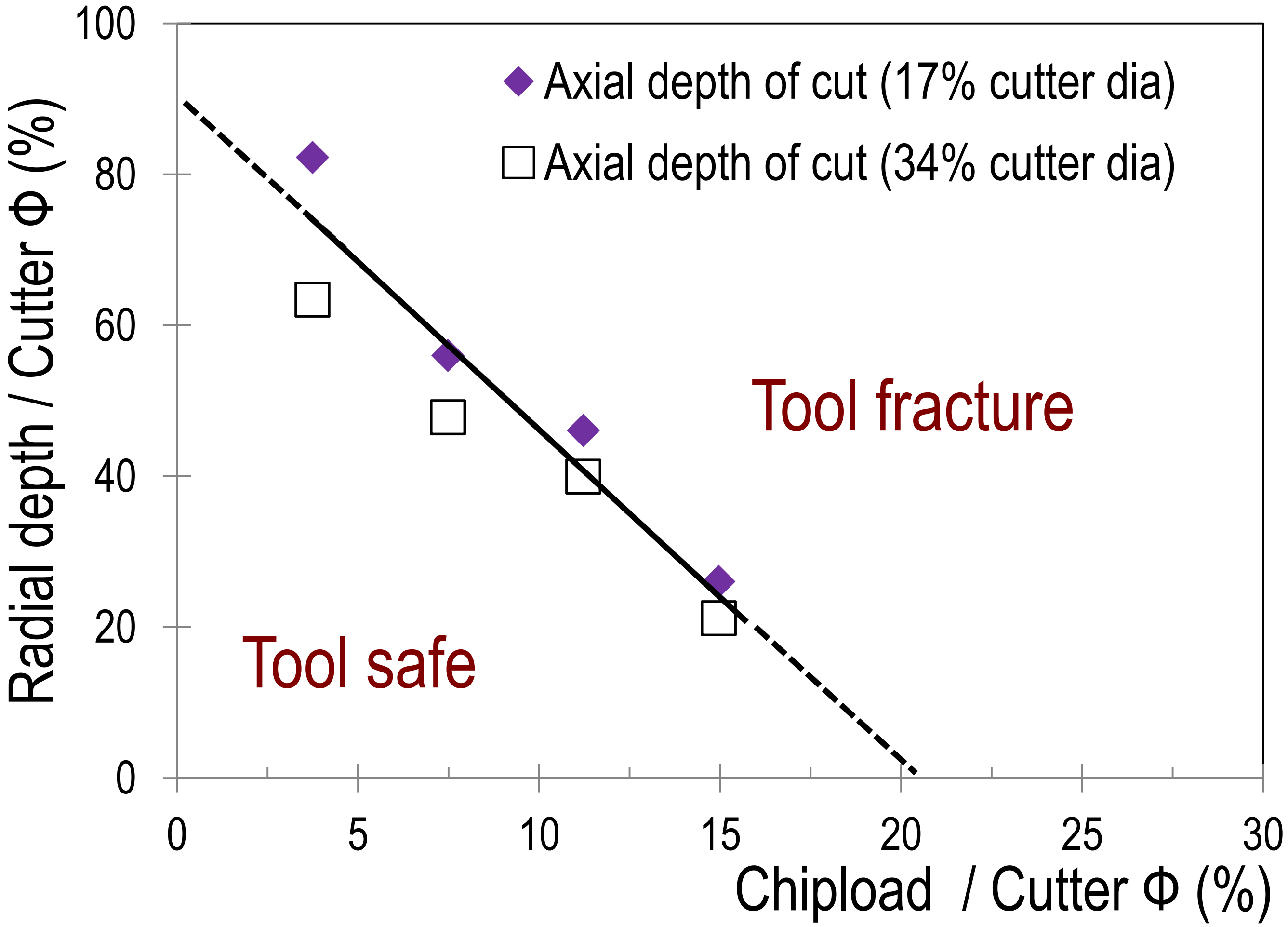


End deflection=17% tool diameter
Bending stress= 50% tool strength

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

Finite element analysis of bending stress on a micromilling tool.

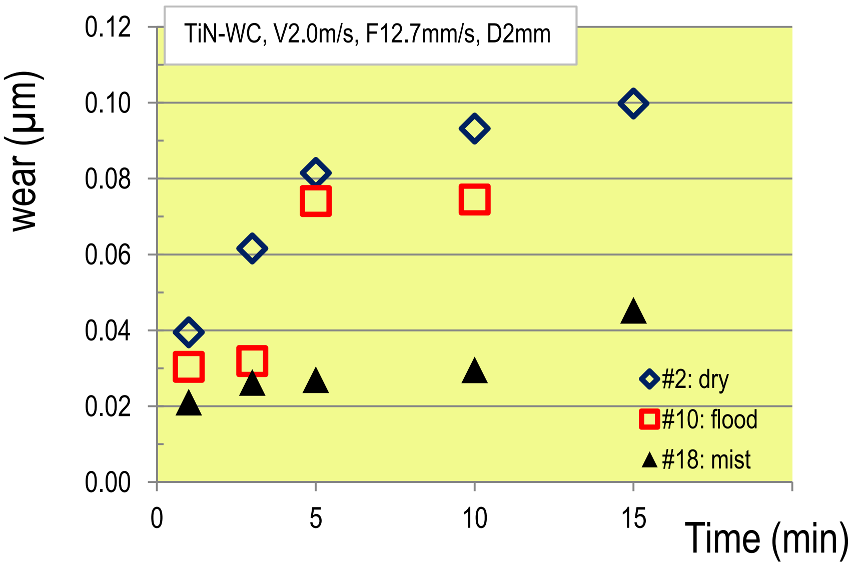
MICROMACHINING: limit of parameters

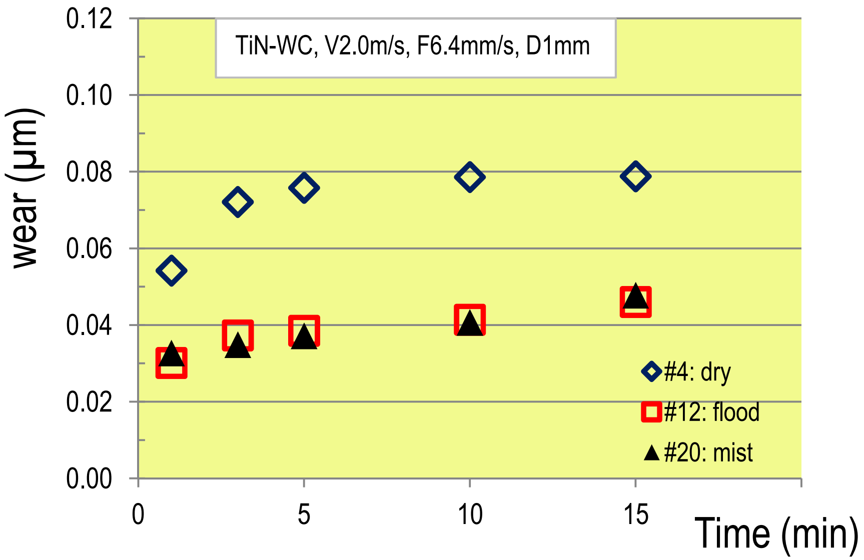


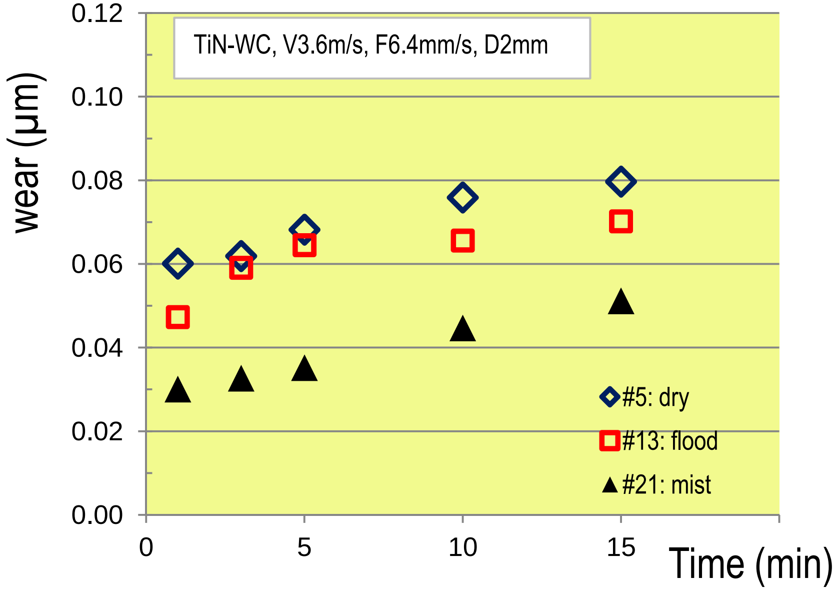
Catastrophic failure threshold of micromilling tools.

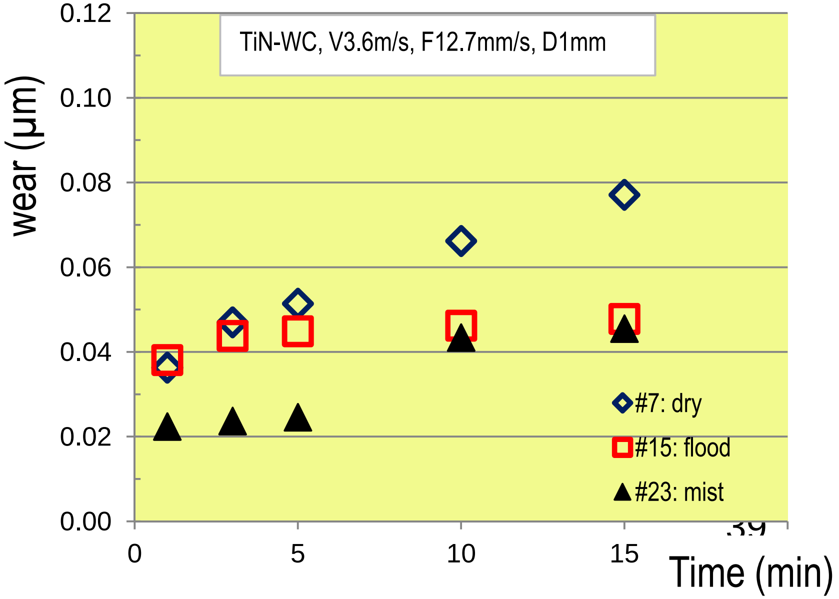
0.35mm (0.014 in) axial depth, dry , climb (down) side milling of 316L stainless steel.

MICROMIST: macromilling

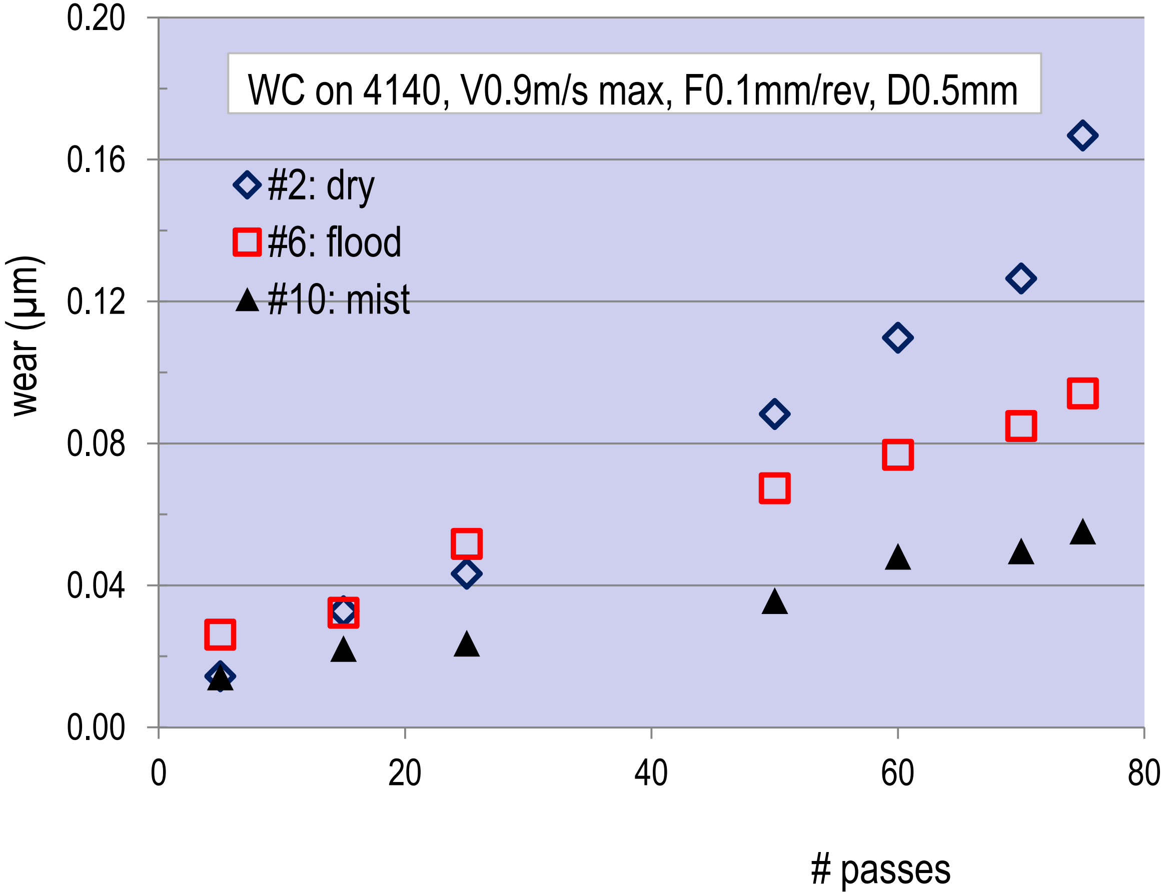


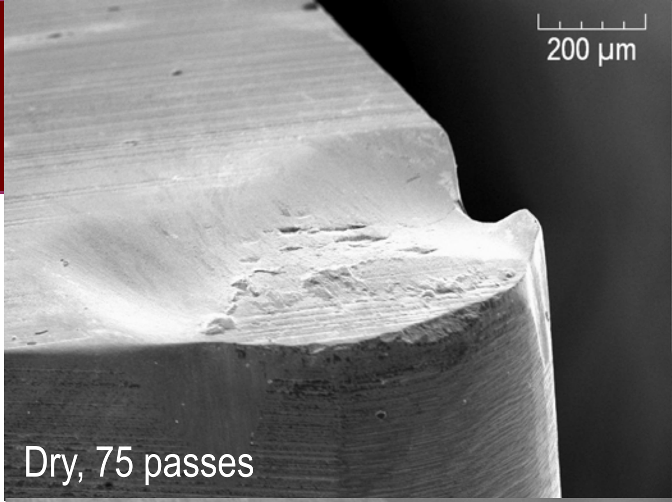


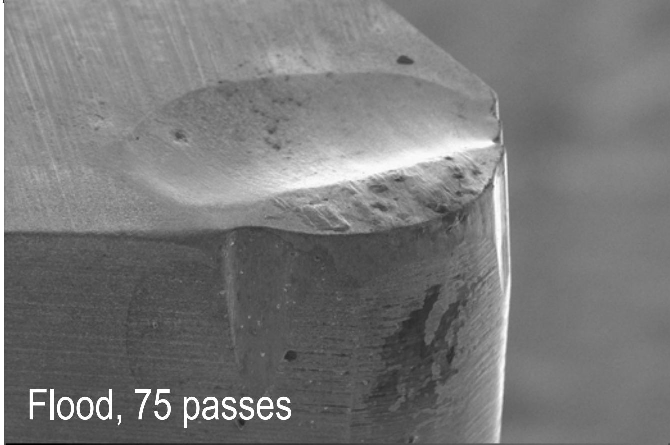


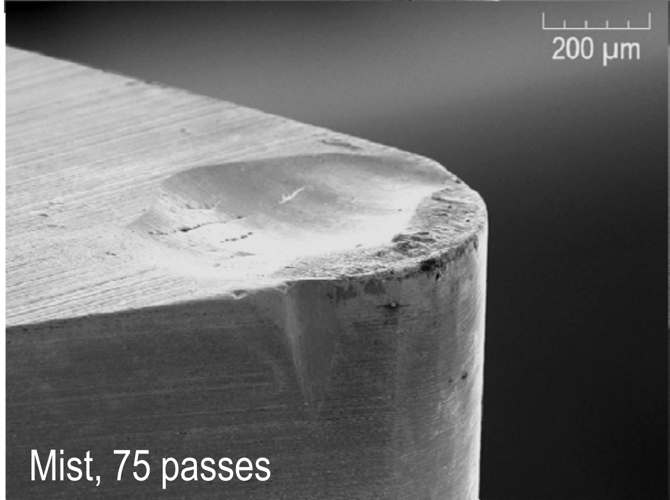


MICROMIST: macrofacing









MICROMIST: summary

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

Summary Continued

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

1) Hung N.P, Kajaria S., Chittipolu S., “Micromachining education and research at Texas A&M University, AC2009-2503, ASEE proceedings, Texas, Jun 2009.
2) Hung N.P., Chittipolu S., Kajaria S. Makarenko M., Bickston L., Williamson D., “Advances in Micromachining of 316L Stainless Steel, SEM proceedings, Mass, Apr 2008.
3) Bifano T.G., DePiero D.K., and Golini D., “Chemomechanical Effects in Ductile-Regime Machining of Glass,” J. Precision Engineering, 1993, 15(4), 238-247.
4) Bissacco G., Hansen H.N., and De Chiffre L., “Micromilling of Hardened Tool Steel for Mould Making Applications,” Materials Processing Technology, 167: 201-207, 2005.
5) Hung N.P., Loh N.L., and Venkatesh V.C., *Machining of Ceramics and Composites*, ch. 10, Marcel Dekker, 1999.
6) Lee K. and Dornfelf D.A., “An experimental Study on Burr Formation in Micromilling Aluminum and Copper,” Trans. NAMRI/SME 30, 2002.
7) Sun J., Wong Y.S., Rahman M., Wang Z.G., and Neo K.S., “Effects of Coolant Supply Methods and Cutting Conditions on Tool Life in End Milling Titanium Alloy,” *Machining Science and Technology*, 10:355-370, 2006.
8) Rahman M., Kumar A.S., and Salam M.U., “Evaluation of Minimal Quantities of Lubricant in End Milling,” *Advanced Manufacturing Technology*, 18:235-241, 2001.
9) Taniguchi N., *Energy Beam Processing of Materials, Clarendon Press, 1989*.

ACKNOWLEDGEMENT

- 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.