Impact of Micromist in CNC Machining

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AGENDA

Impact of Micromist in CNC Machining

Source: furtech.typepad.com

1) Introduction
2) Objectives
3) NSF-RET program
4) Investigation
    - Cutting fluids
    - Micromist
    - Machinability
5) Summary
6) Future works

Acknowledgement

References

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

1) Is funded by National Science Foundation
2) Provides research experience to teachers /instructors from nearby high schools /community colleges.
3) Covers 9 weeks in summer
4) Must implement to home institutions

NSF-RET program (summer2010)

- Rufus Lamere, Texas State Technical College, Waco, TX
- Gary Miguel, Biomedical Manufacturing Center, Athens, TX
- Wayne Hung, Texas A&M University, College Station, TX

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

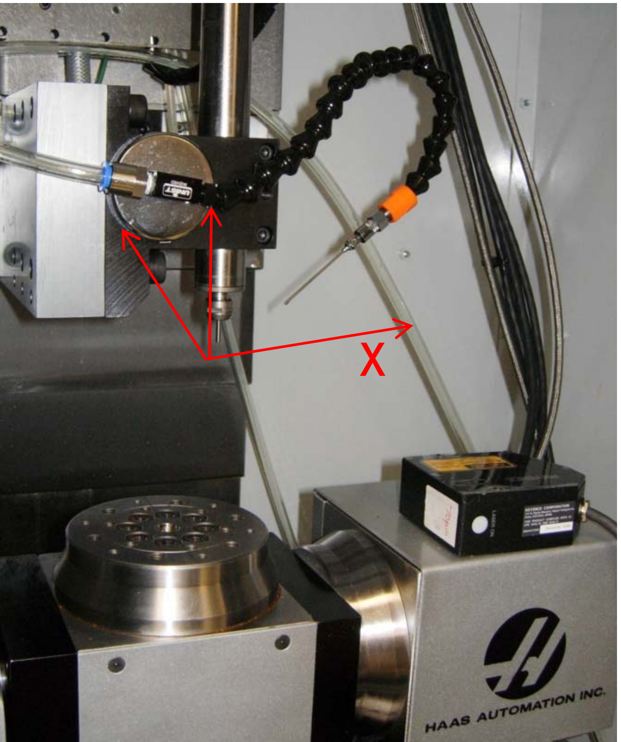
INVESTIGATION: machines

Haas OM2 CNC micromill:

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

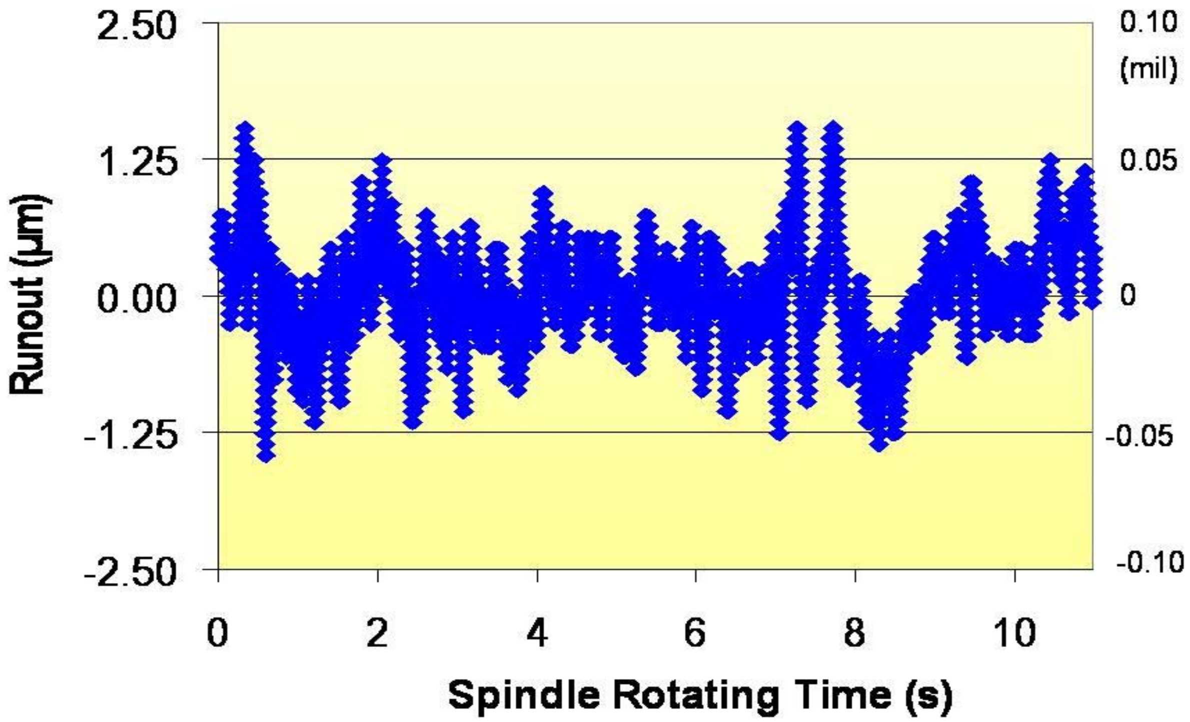
Micromist

- 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



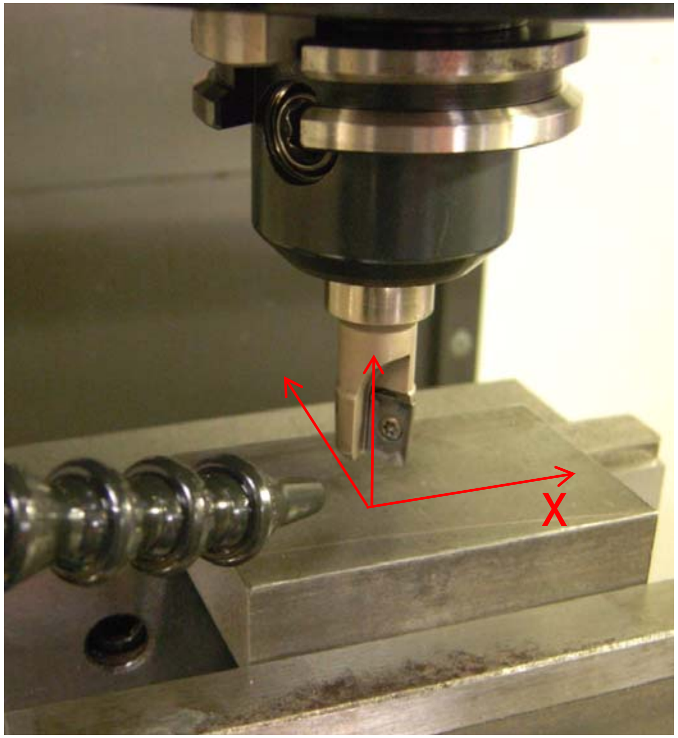
INVESTIGATION: machines

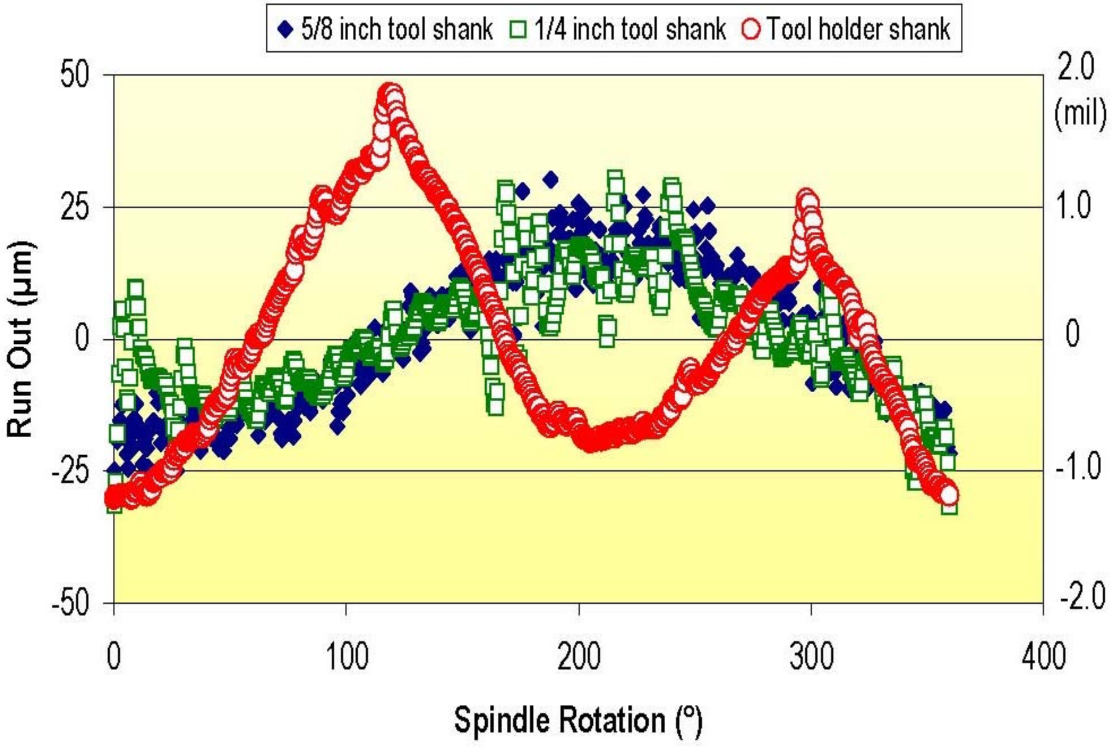
Haas VF1 CNC mill:

- 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





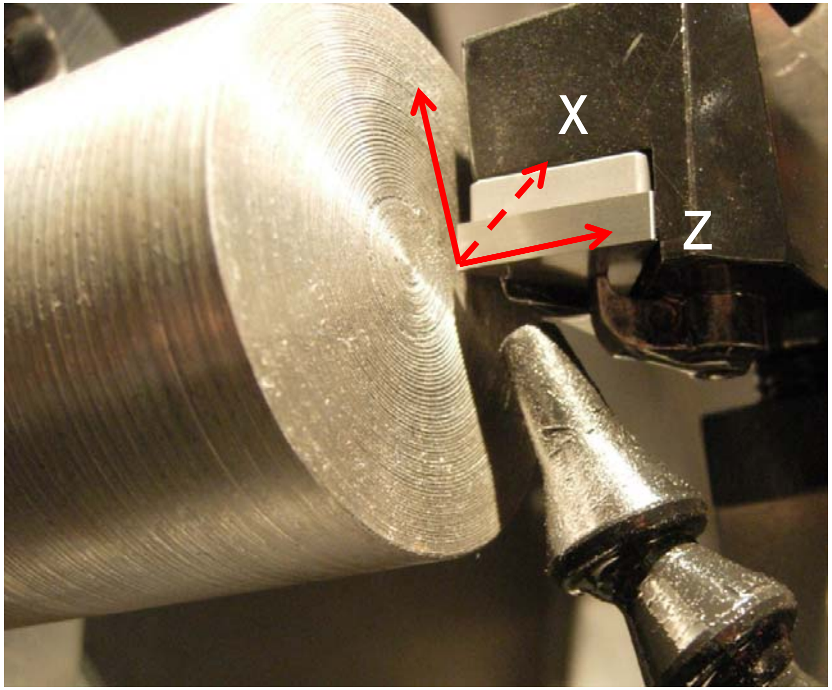
INVESTIGATION: machines

Haas SL20 CNC lathe:

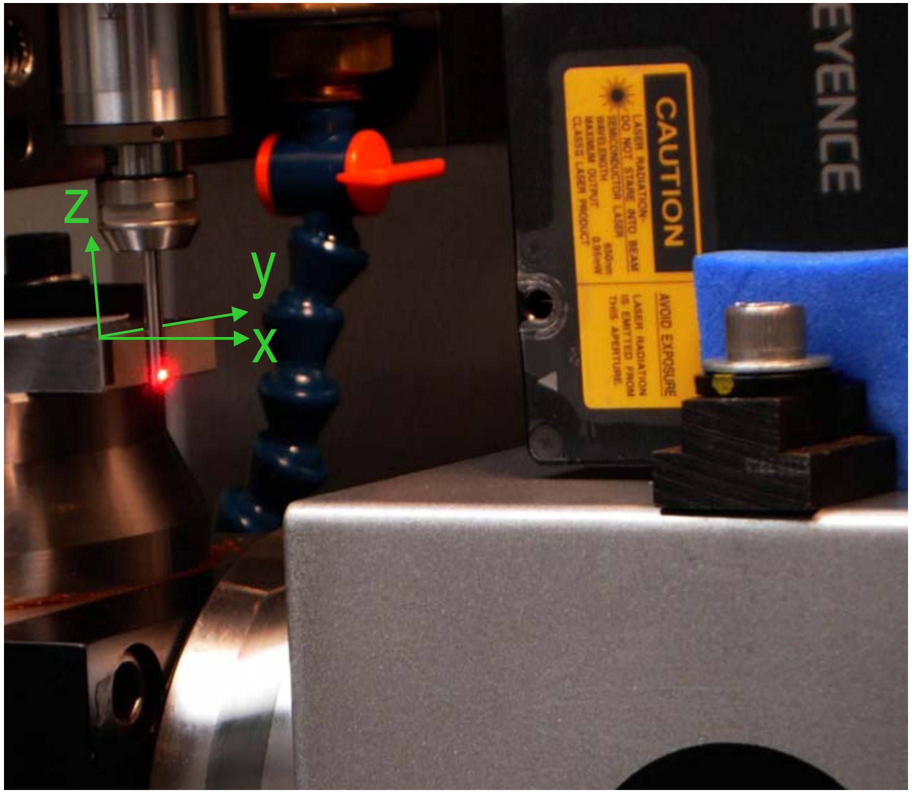
- Live tooling capability
- 3,400 rpm spindle
- ±3 µm repeatability

Micromist

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

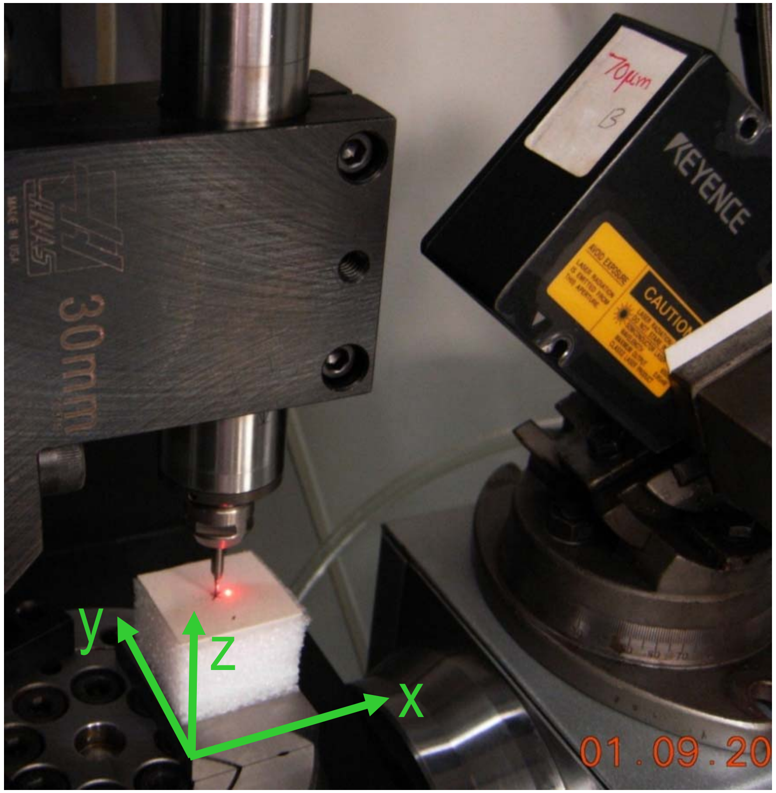


MICROMACHINING: tool setting



(a)

Set up for edge detection on x-y plane

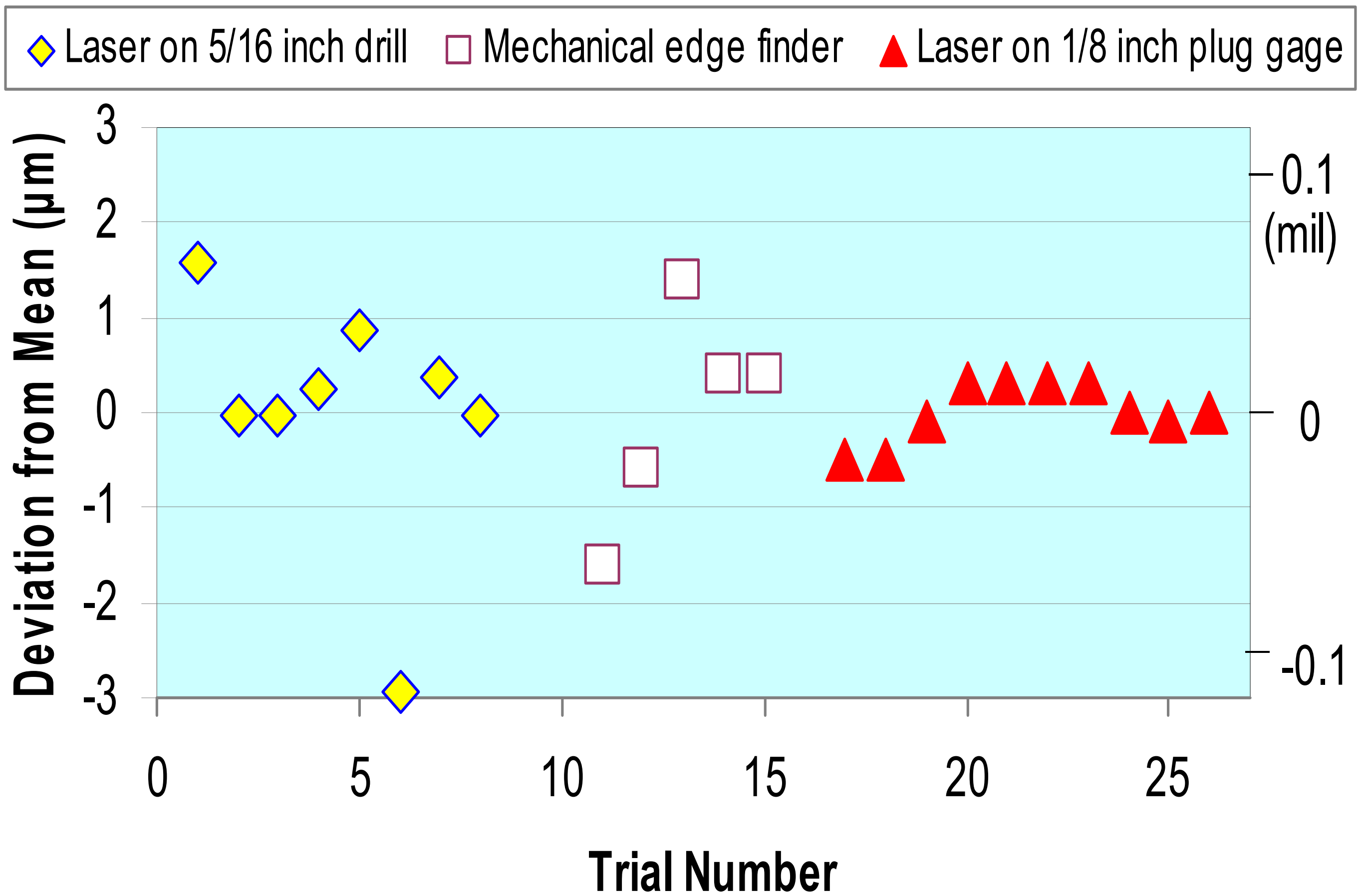


(b)

Set up for tool height z-offset

Microtool offset using laser sensor

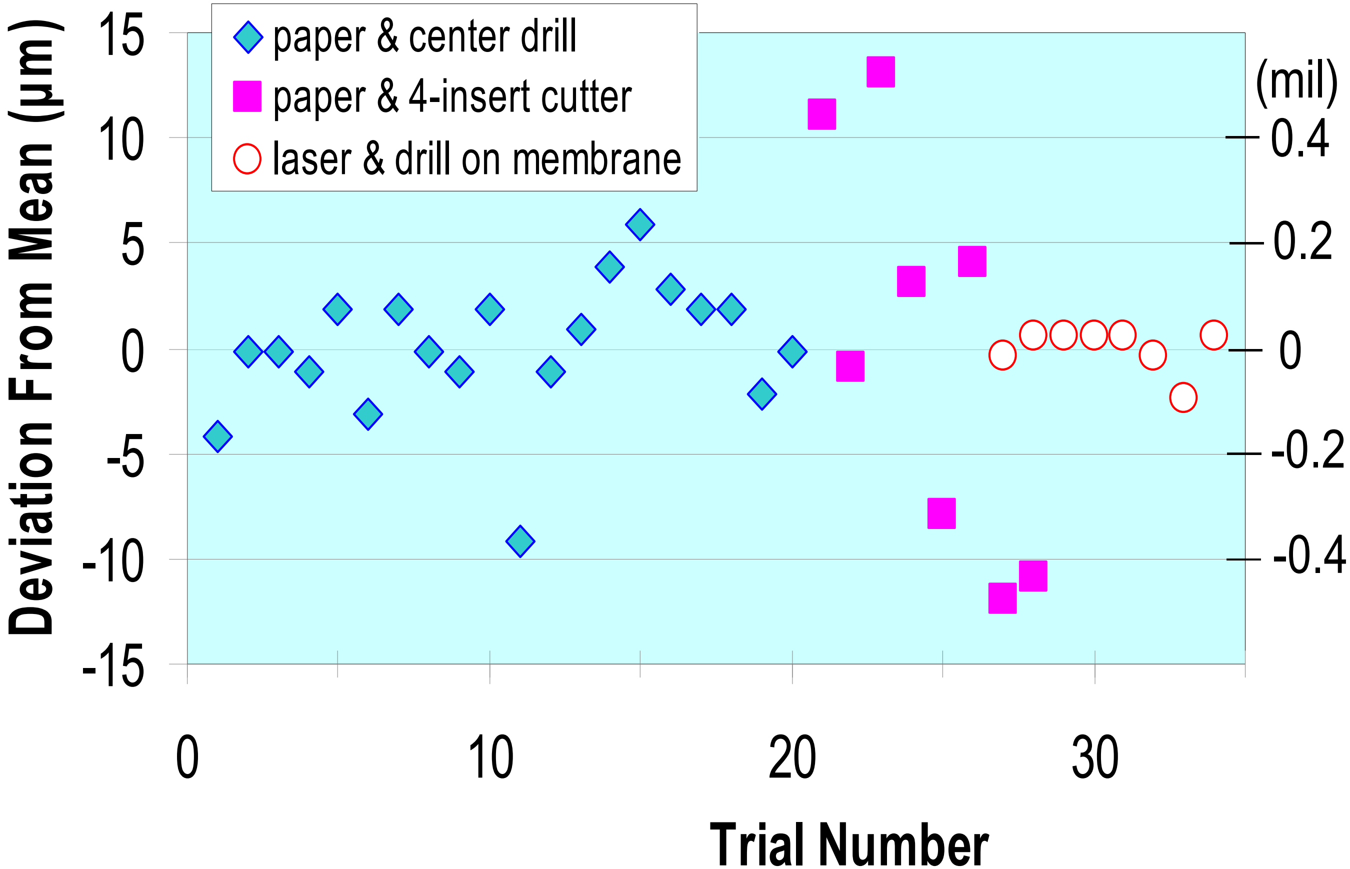
MICROMACHINING: tool setting



- 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.

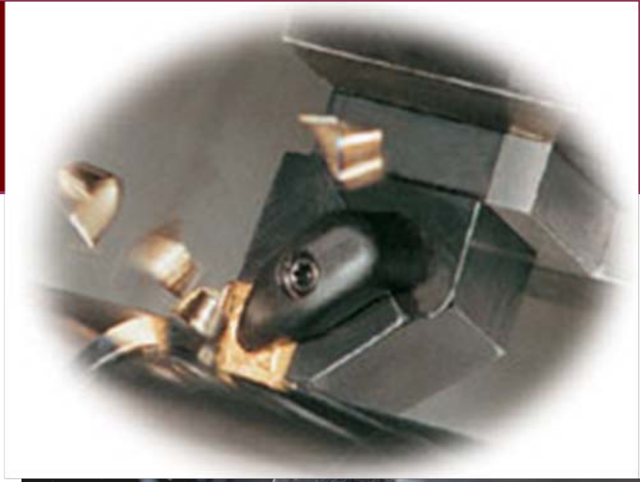
MACHINING: cutting fluid

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



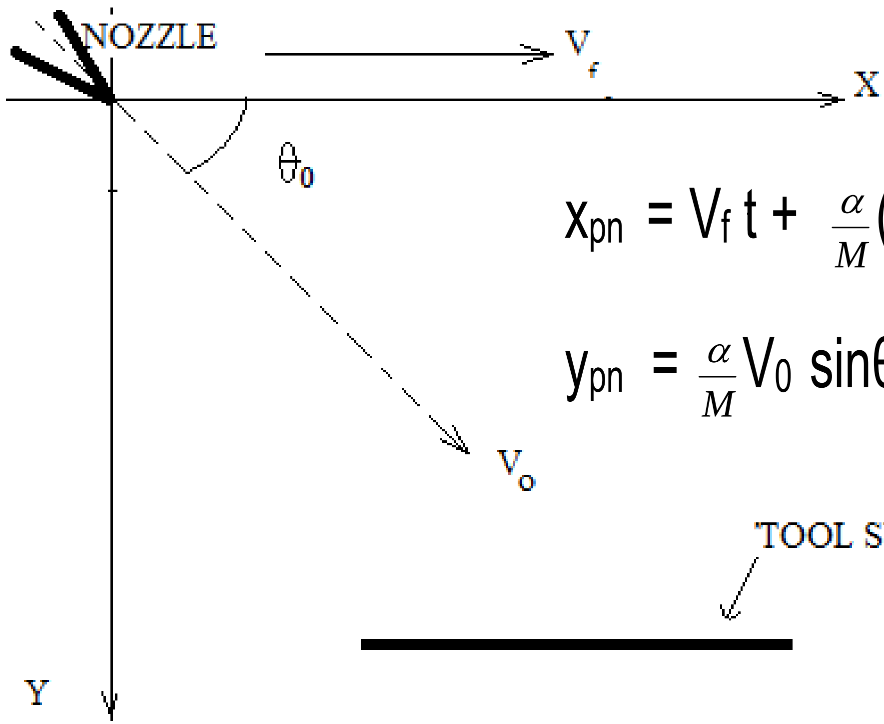
MACHINING: micromist

Penetrate?

Particle trajectory

CFD modeling

Optimal tool/workpiece/ nozzle positions

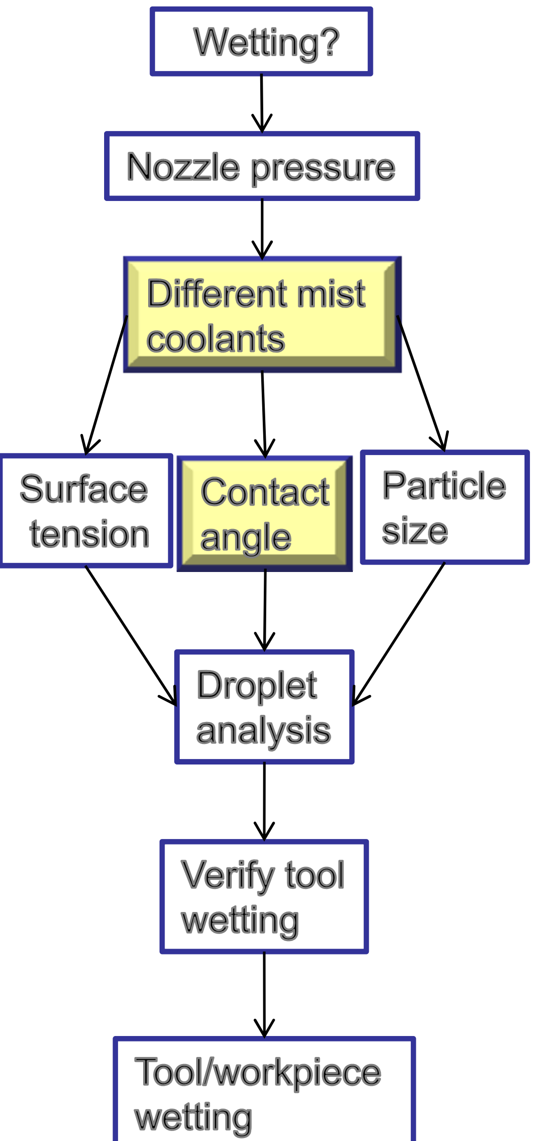


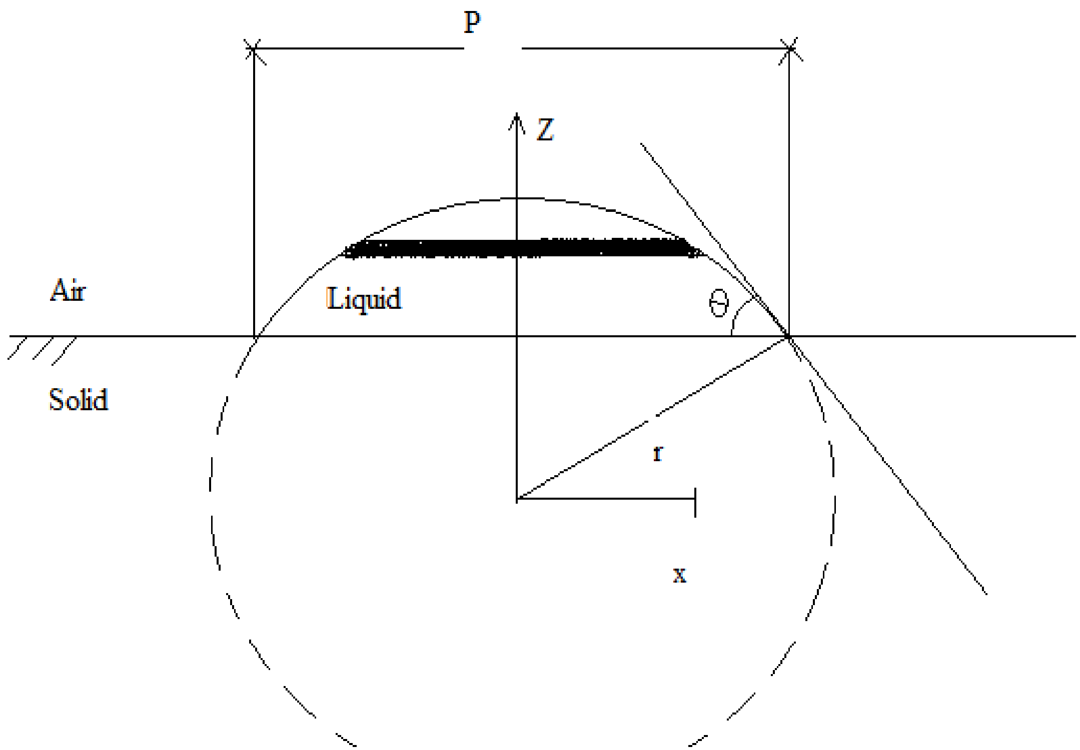
Particle Trajectory

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

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

MACHINING: coolant wetting





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

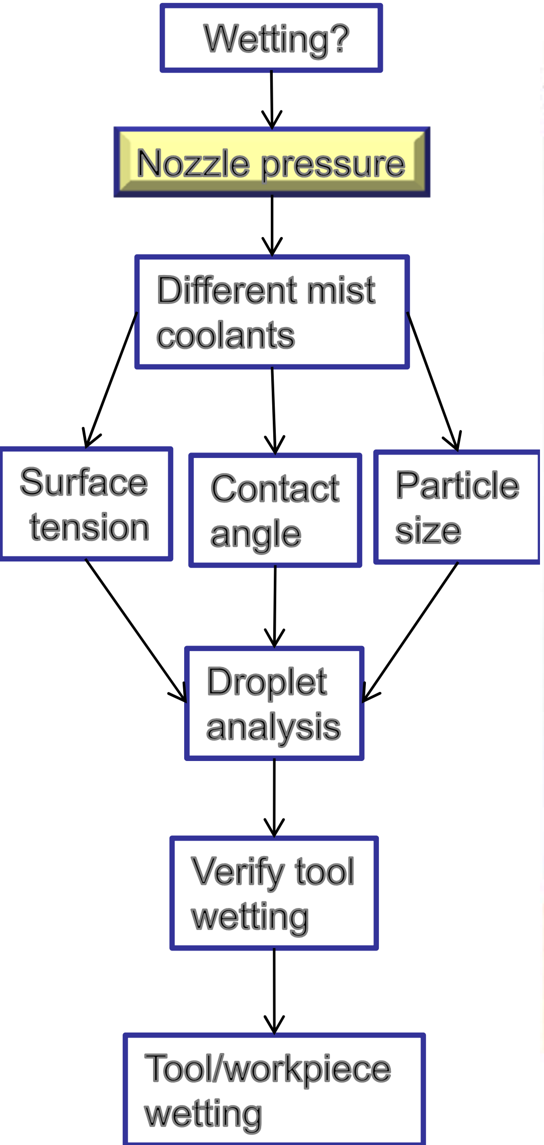
V: volume of droplet

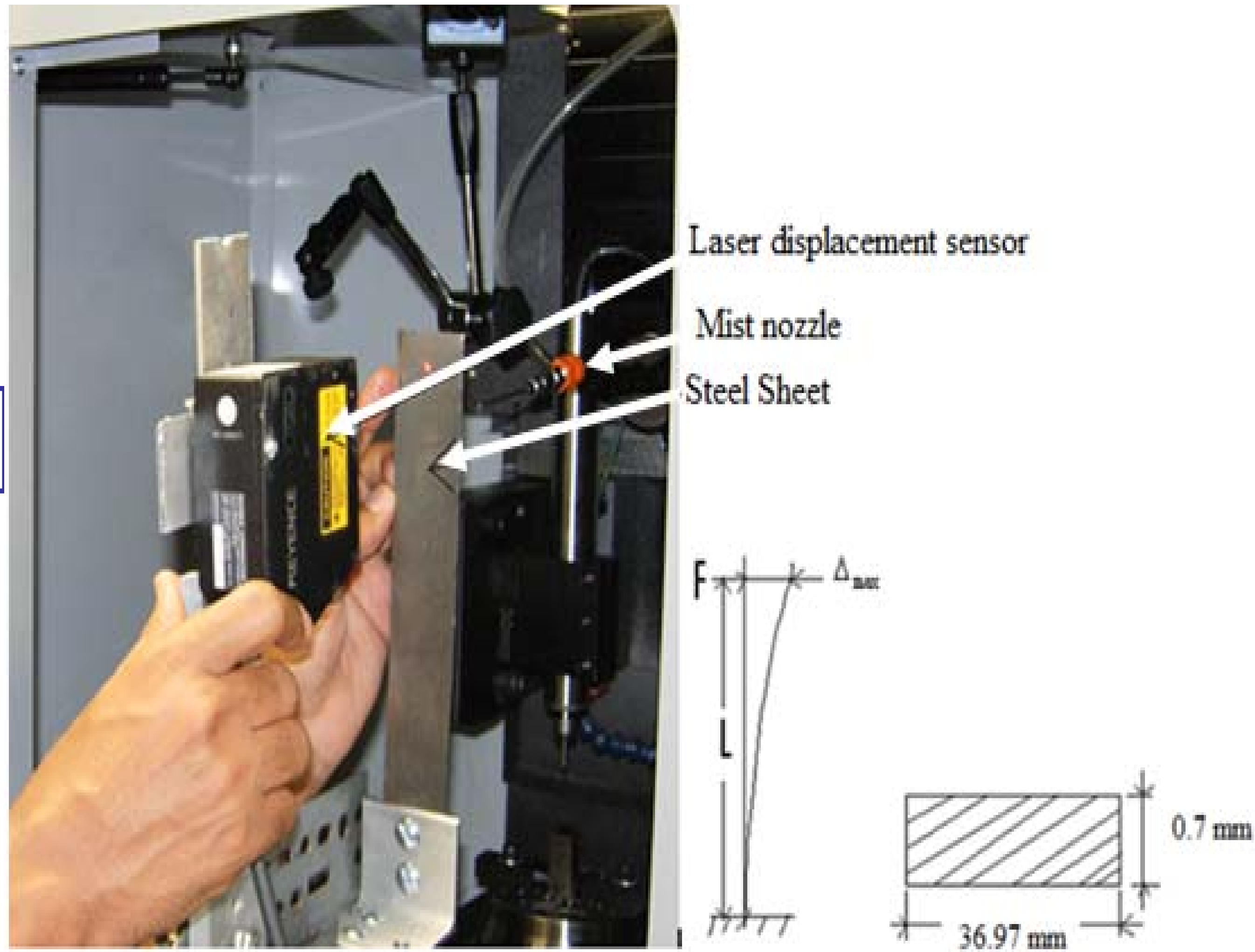
P: diameter of droplet

K: 1 for $\theta<90^0$; 0 for $\theta>90^0$

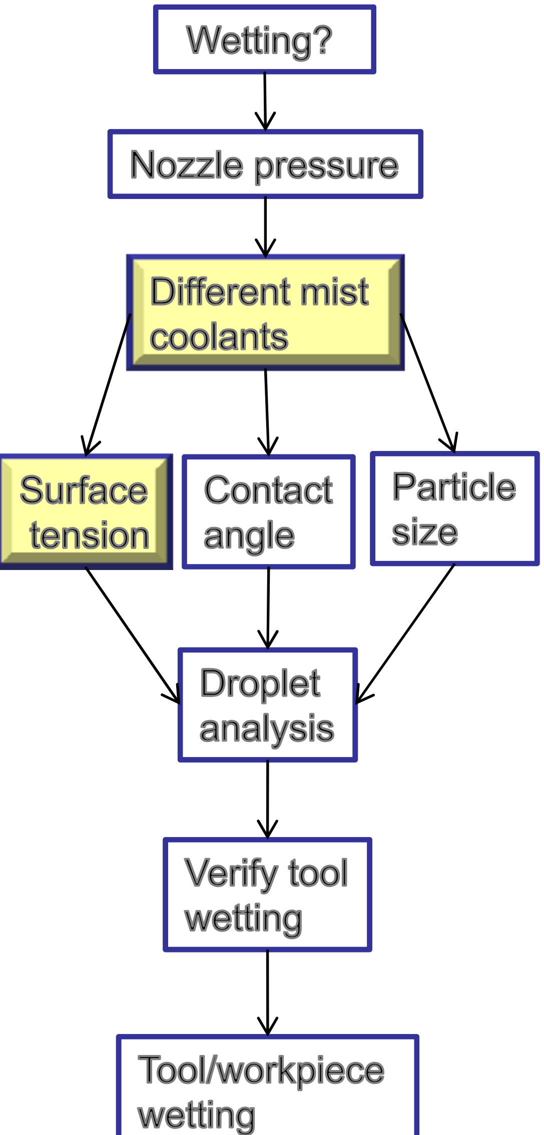
θ : contact angle

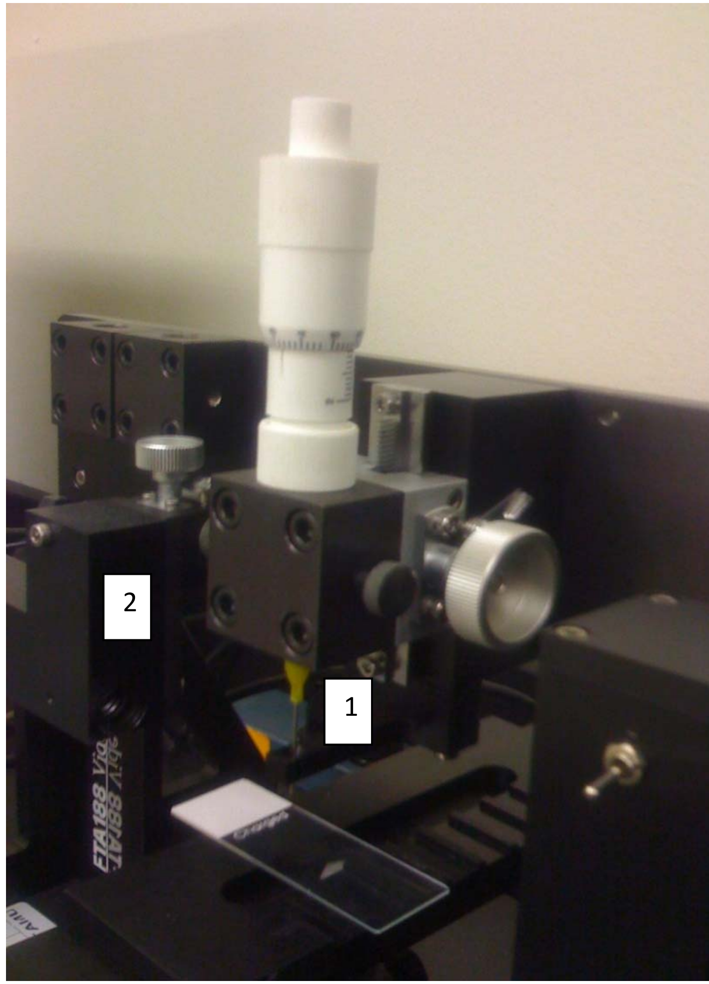
MACHINING: micromist

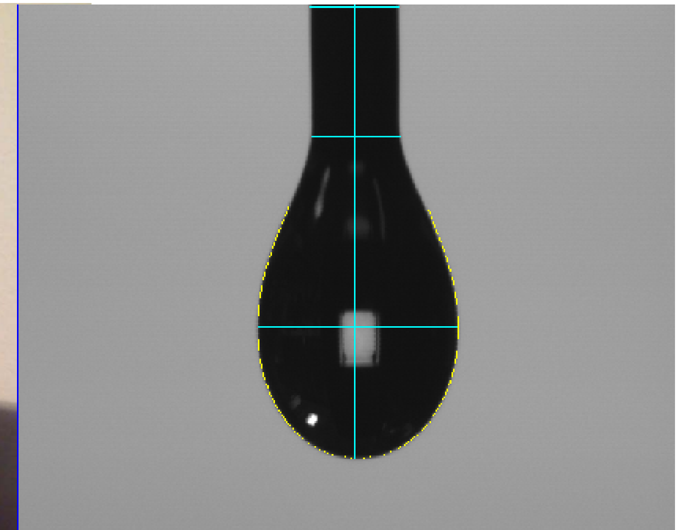


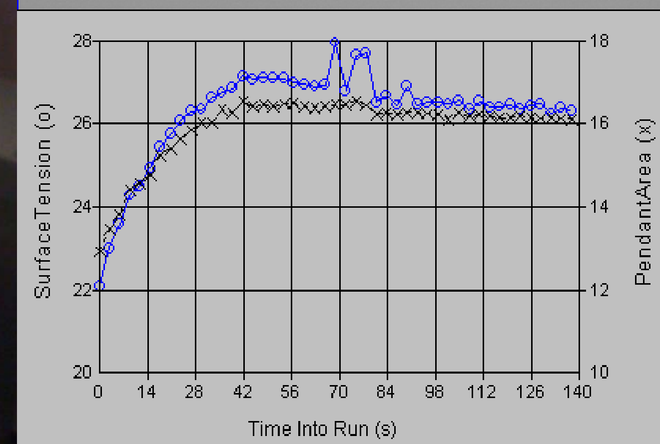


MACHINING: micromist





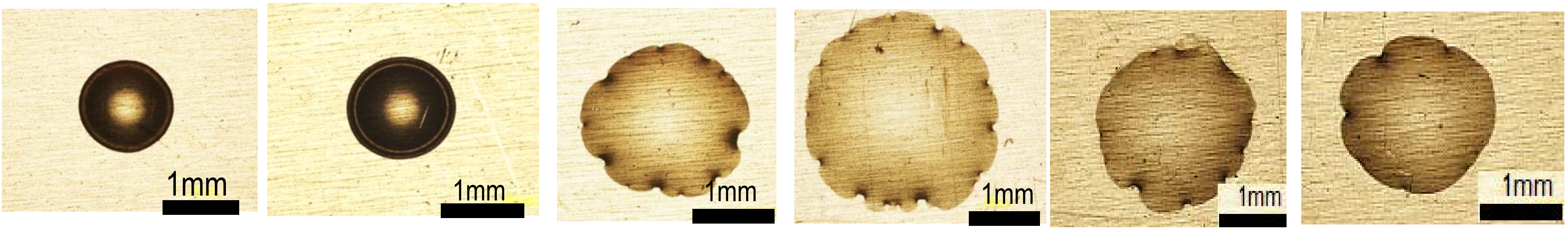


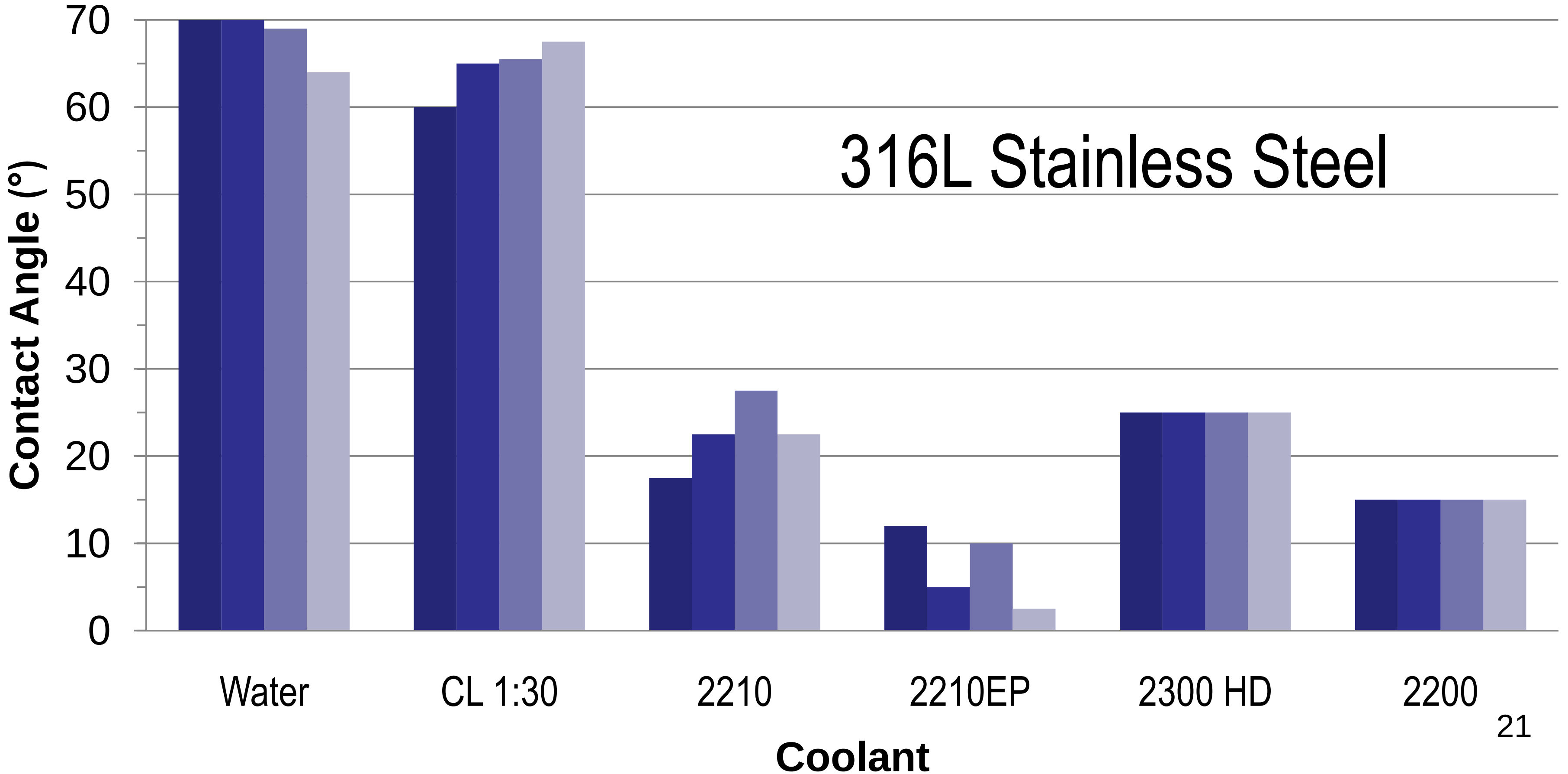


Apparatus for Surface tension measurement

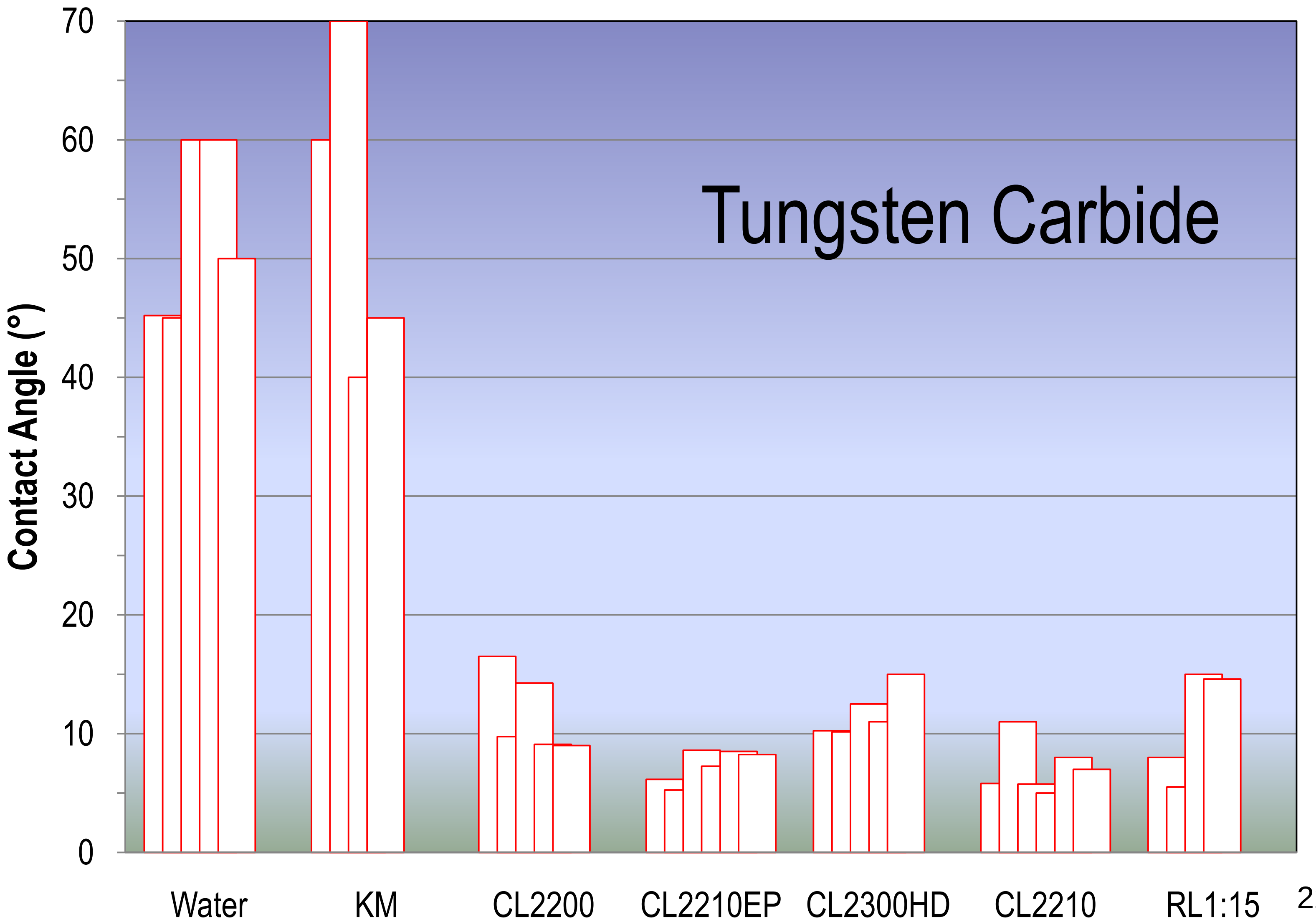
1. Needle for delivering liquid droplets
2. Camera

MACHINING: micromist

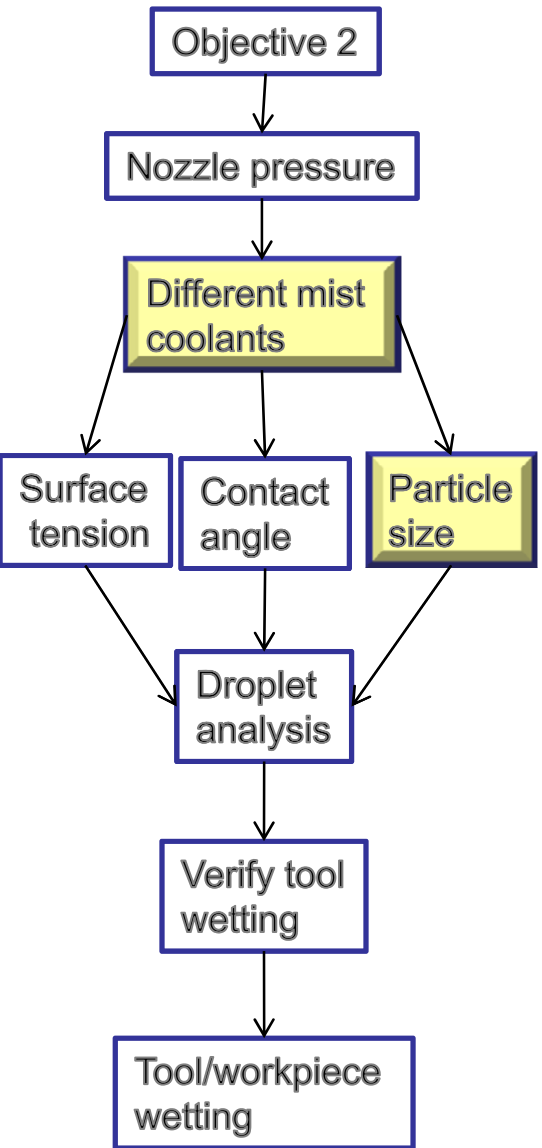


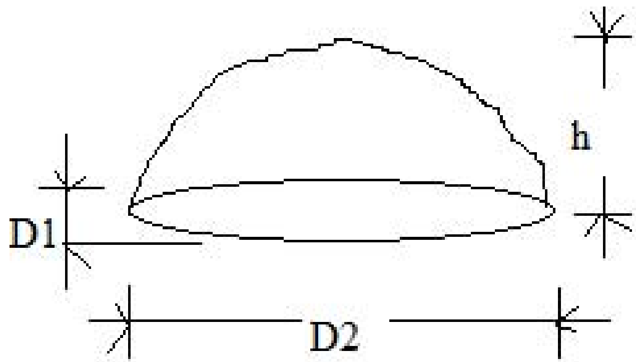


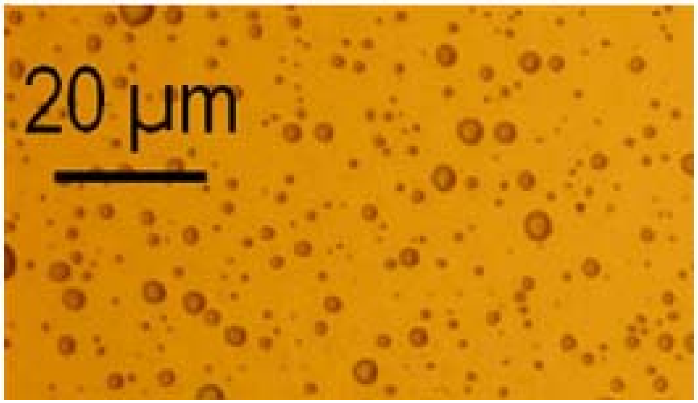
MACHINING: micromist



MACHINING: micromist



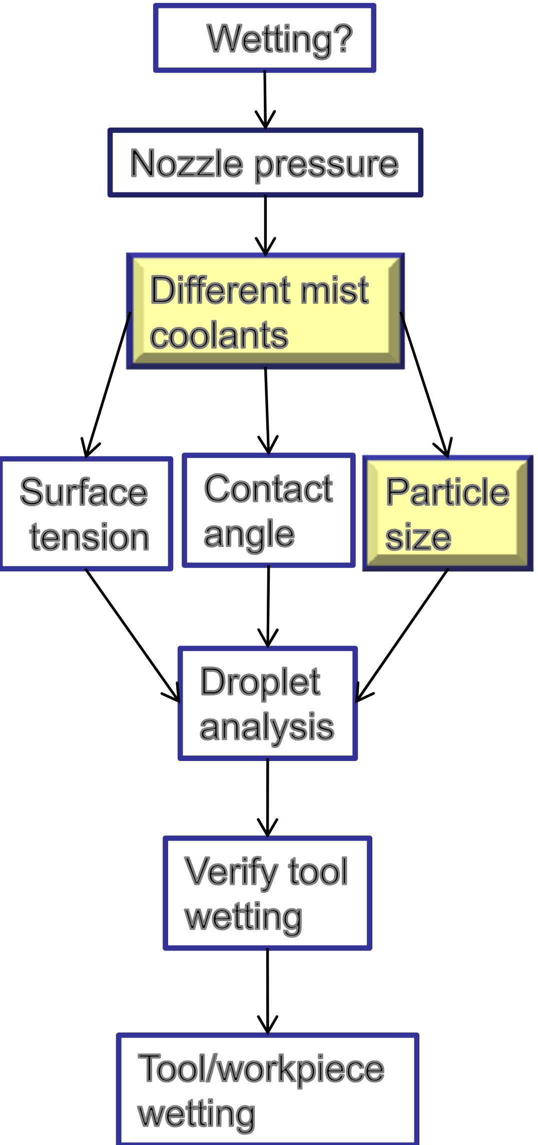


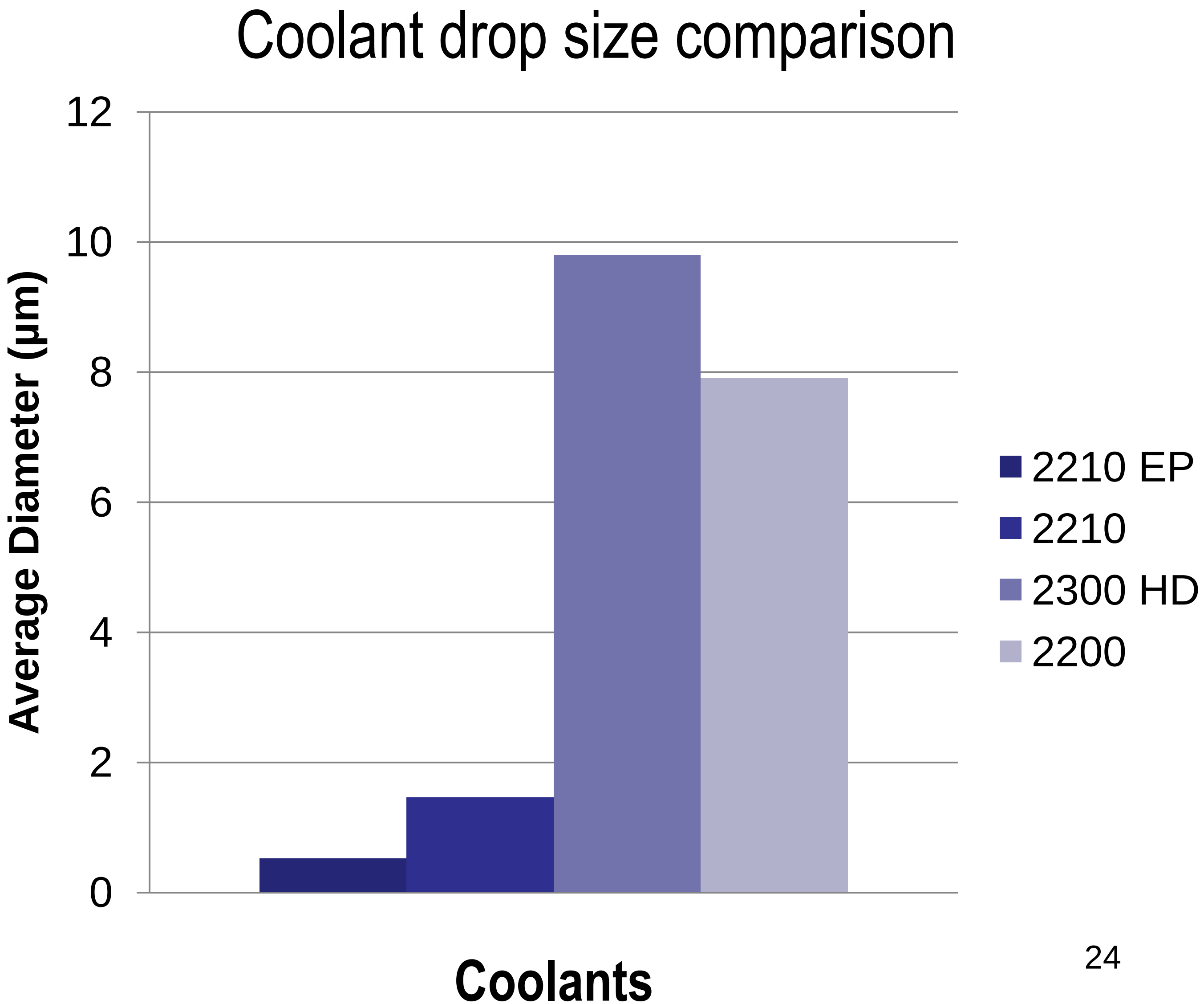


$$V = \pi h^2 \left[\frac{h}{6} + \frac{r^2}{2h} \right] \qquad V = \frac{4}{3} \pi R^3$$

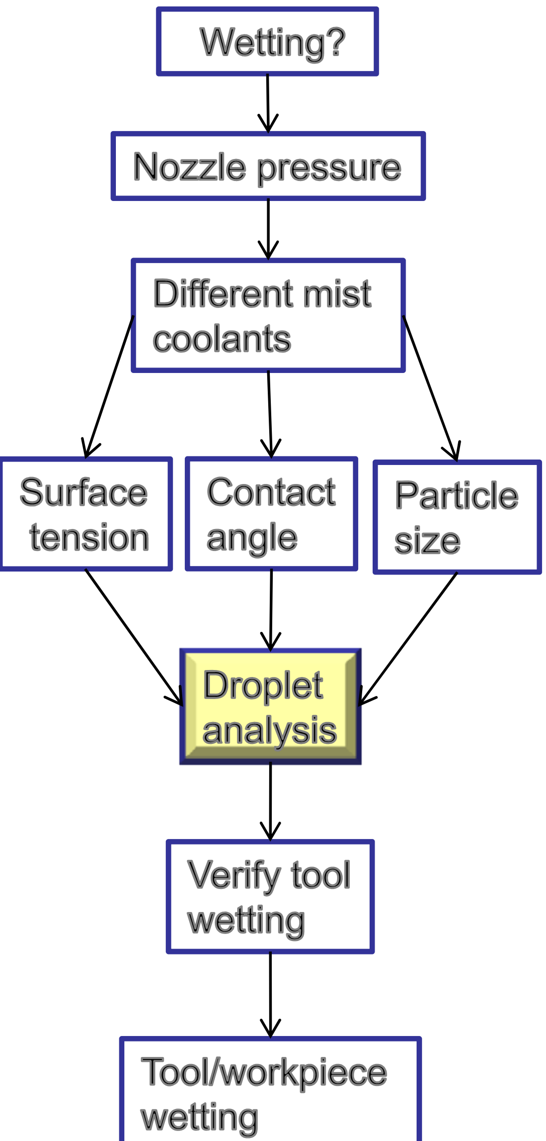
V: volume of droplet
h: height of droplet
R: radius of airborne droplet
r: $(D_1+D_2)/4$

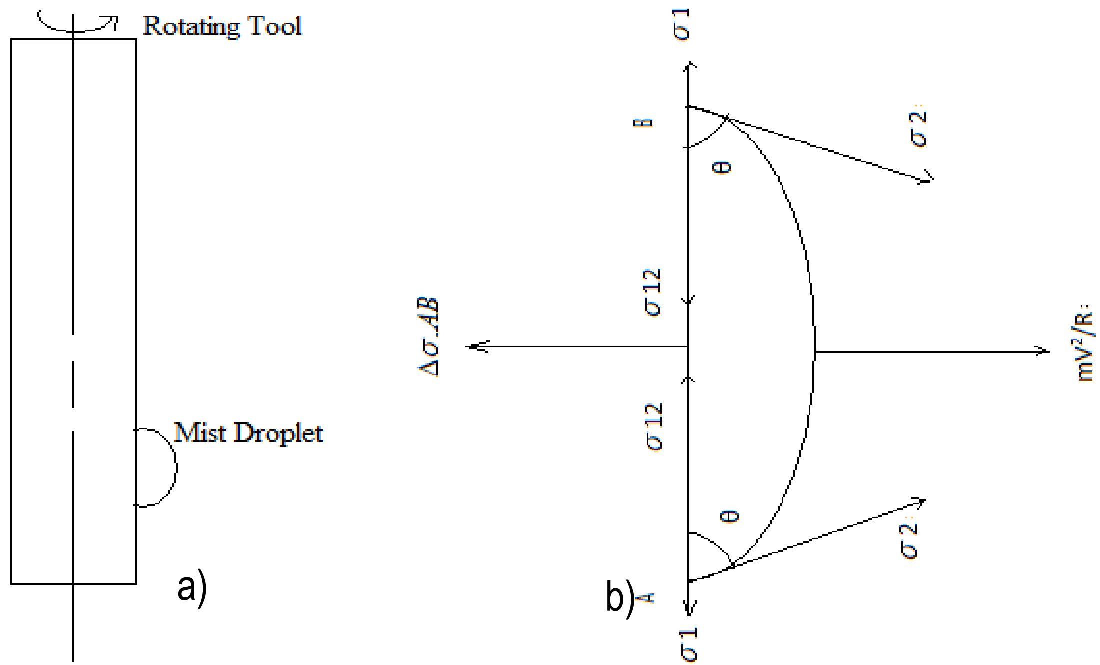
MACHINING: micromist





MACHINING: micromist





(a) Micro-droplet on a rotating tool;

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

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

m: mass of droplet

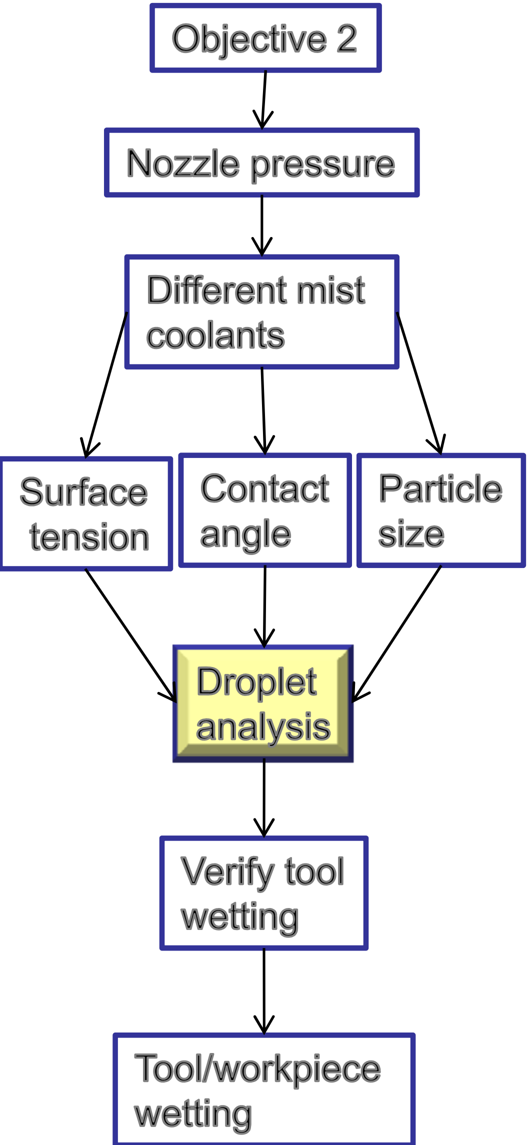
v: surface speed of tool

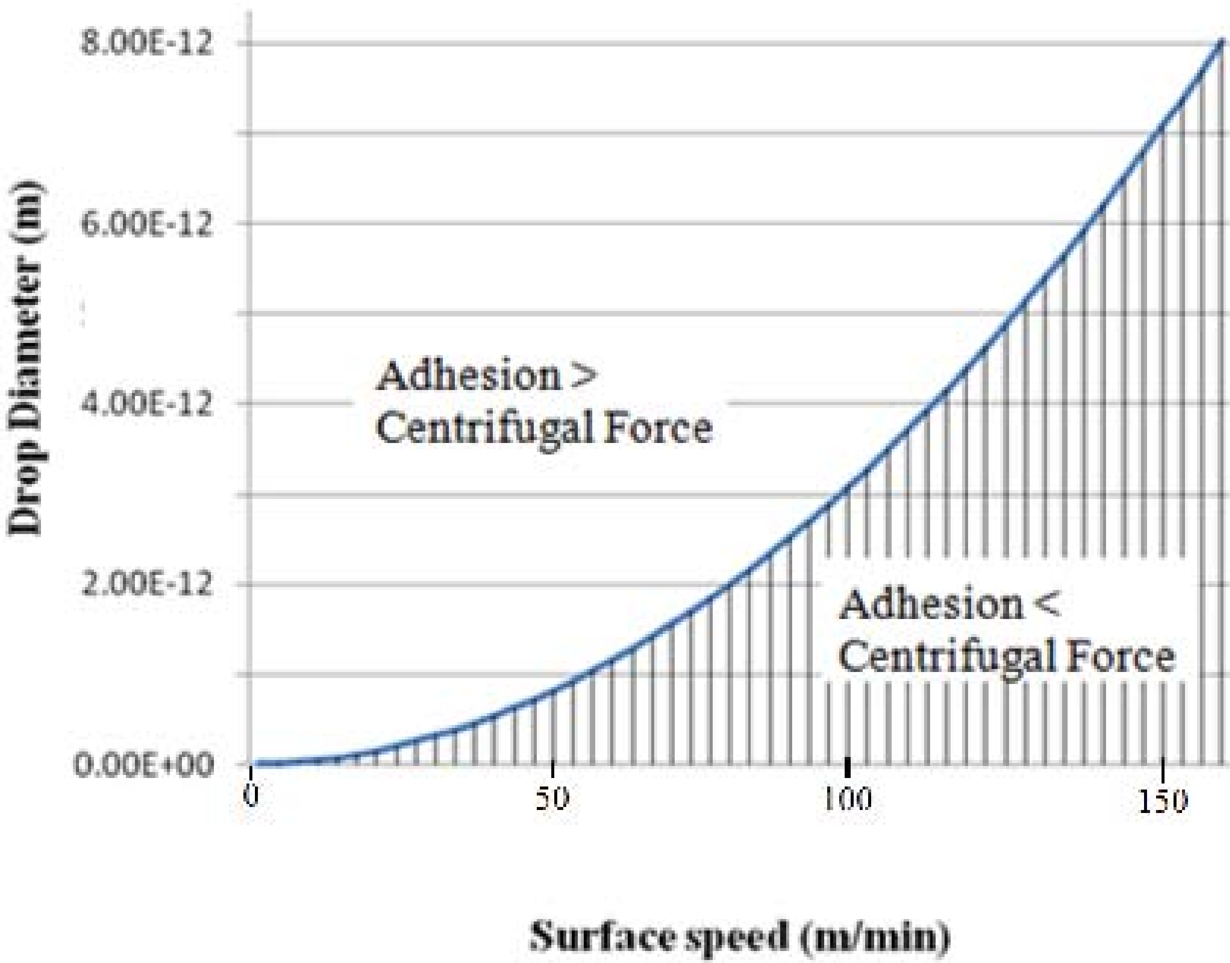
R: radius of tool

D: diameter of droplet

σ_2: surface tension of liquid

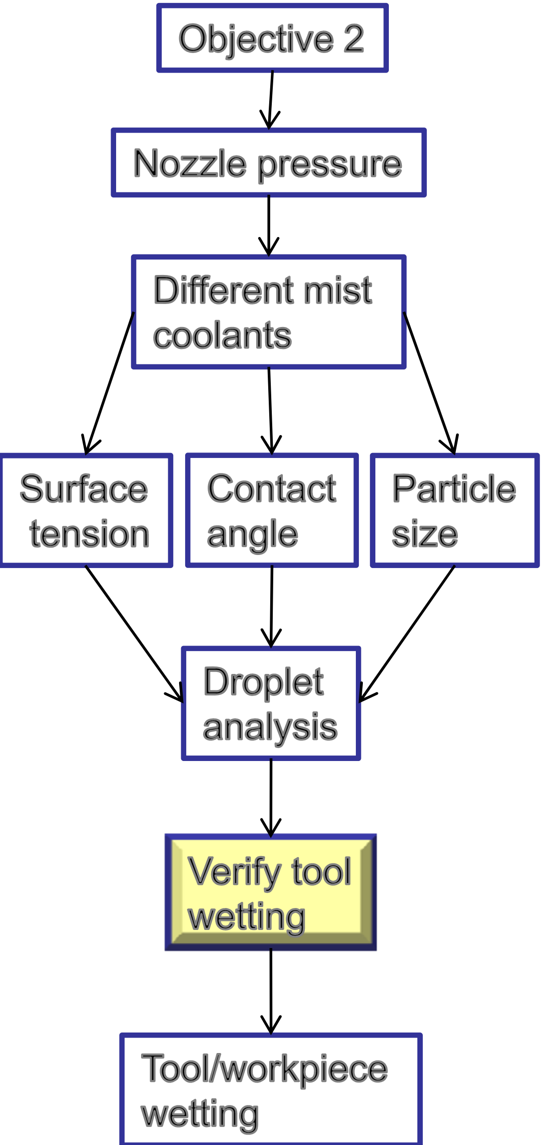
MACHINING: micromist





Balance of adhesion and centrifugal force on a 2210EP microdroplet

MACHINING: micromist

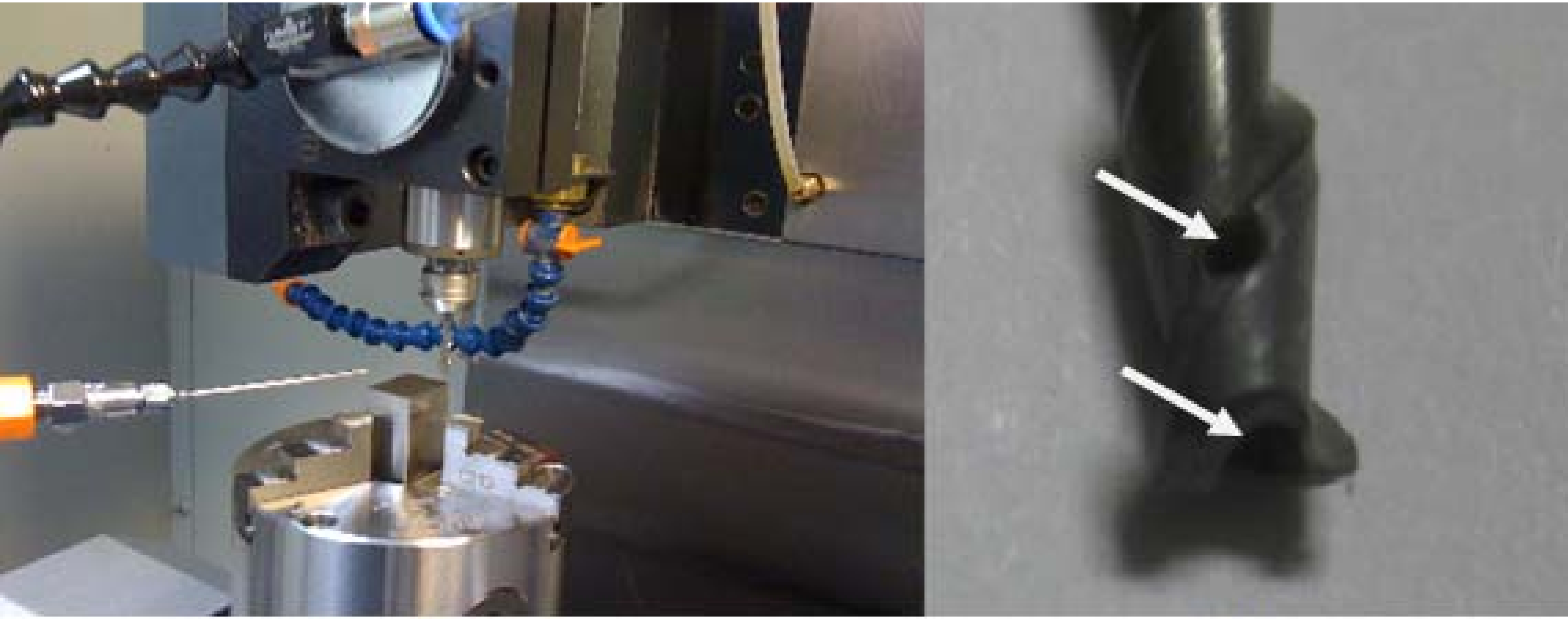


Parameters of tool wetting experiments:

- Tools are run from 0-500 m/min
- Tool diameter: 3.175mm, 12.7mm
- Air pressure: 3.197 to 3.39 bar
- Stroke length: 2.7 mm
- Stroke frequency: 12 strokes/min
- Volume flow rate of coolant: 3.33 x 10^{-9} mm^3/sec

APPROACH – OBJECTIVE # 2

Setup for validation of tool wetting



(a) (b)

(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?

↓

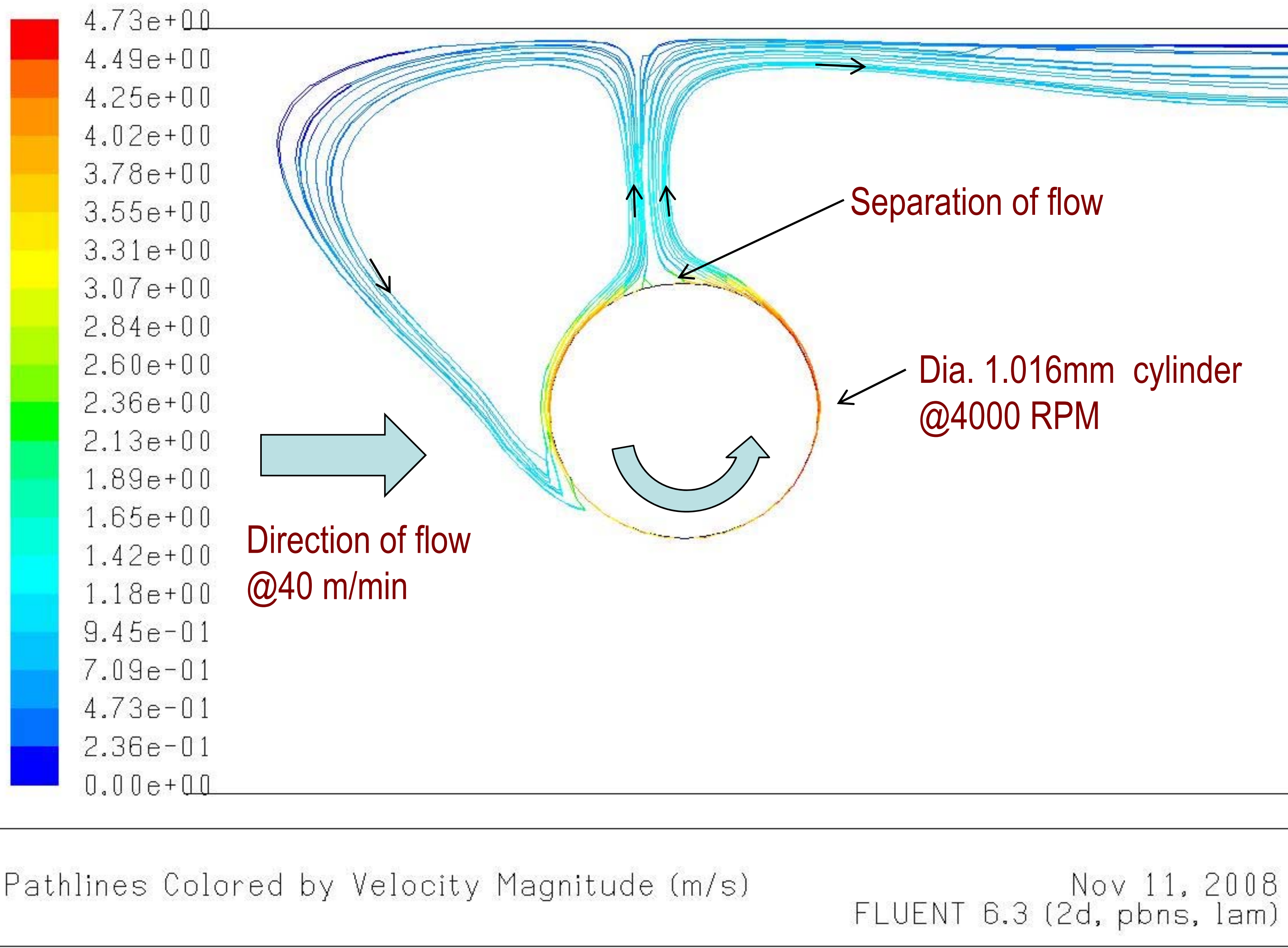
Particle trajectory

↓

CFD modeling

↓

Optimal tool/workpiece/ nozzle positions



RESULT: flow of micromist

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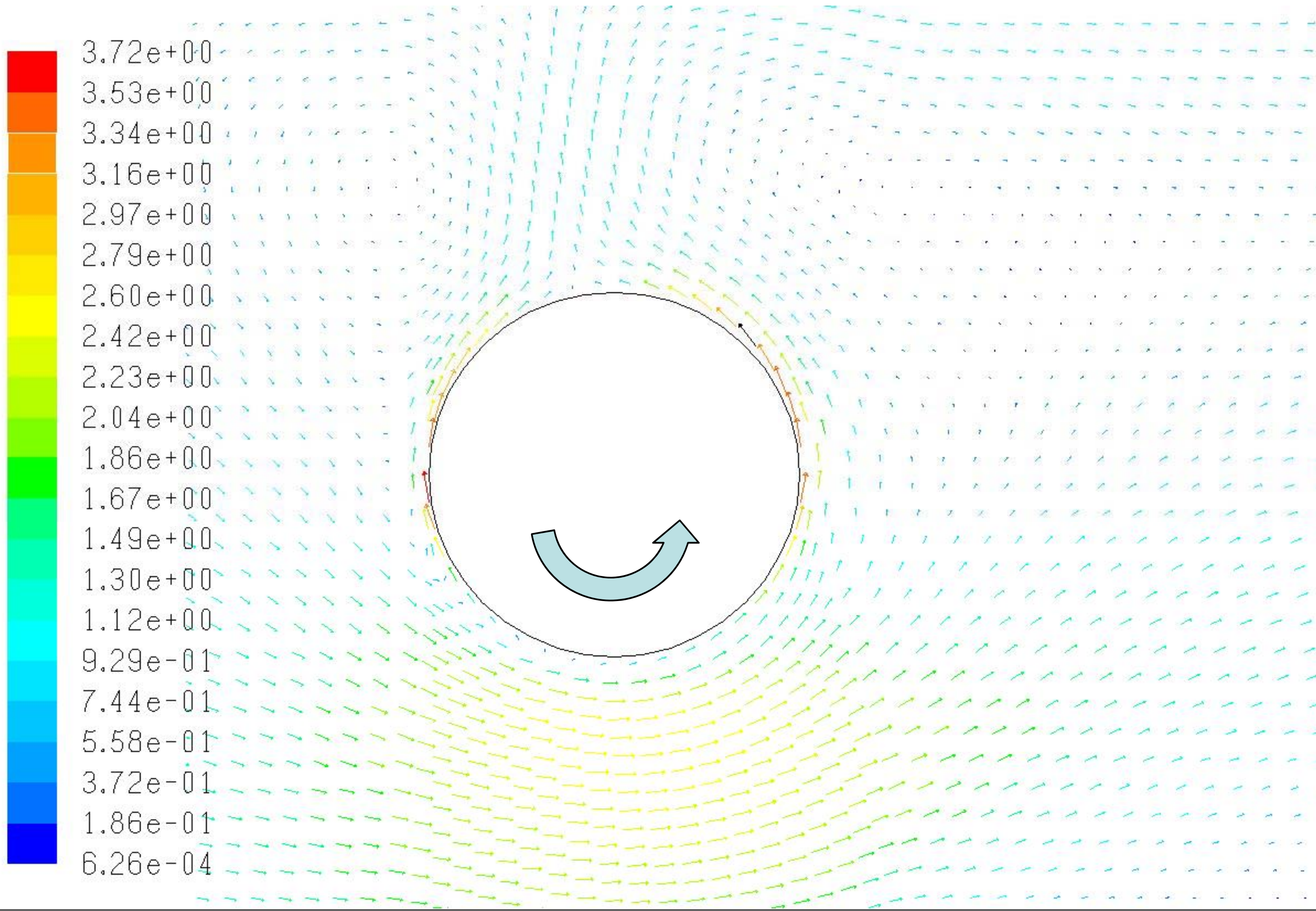
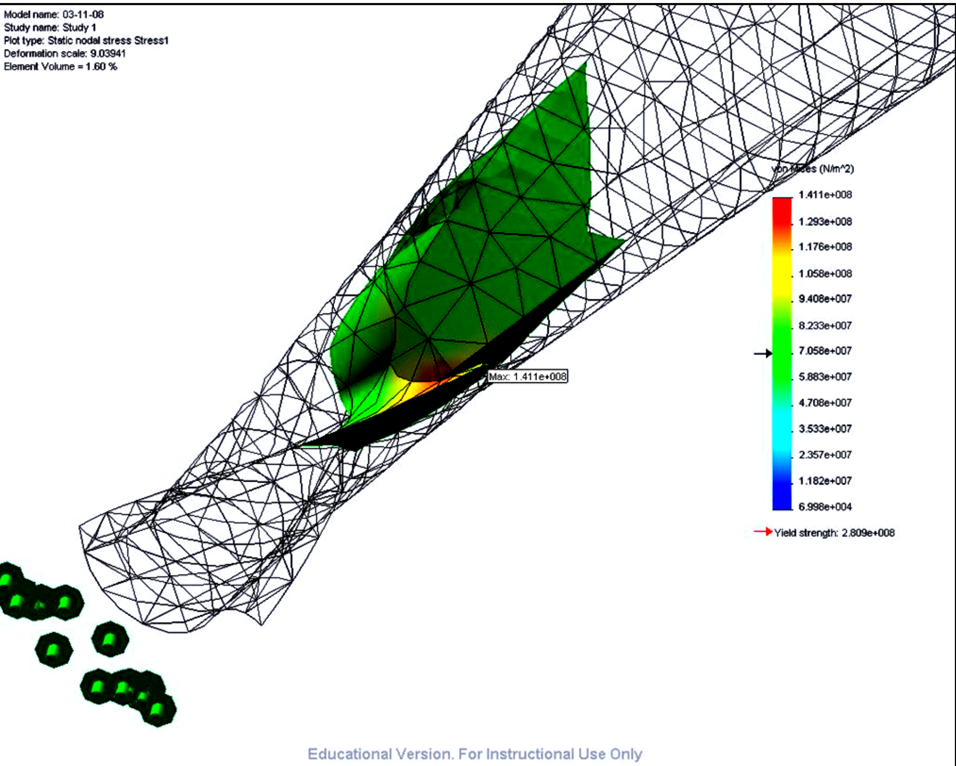
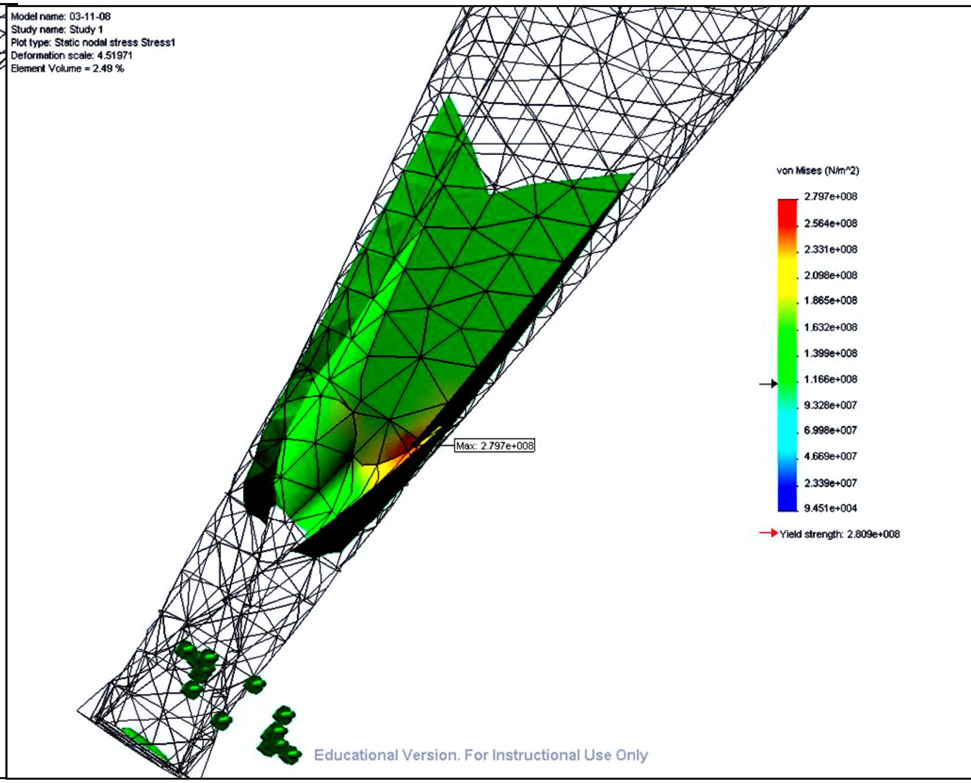


Velocity Vectors Colored By Velocity Magnitude (m/s) Nov 11, 2008
FLUENT 6.3 (2d, pbns, lam)

MICROMACHINING: tool deflection

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



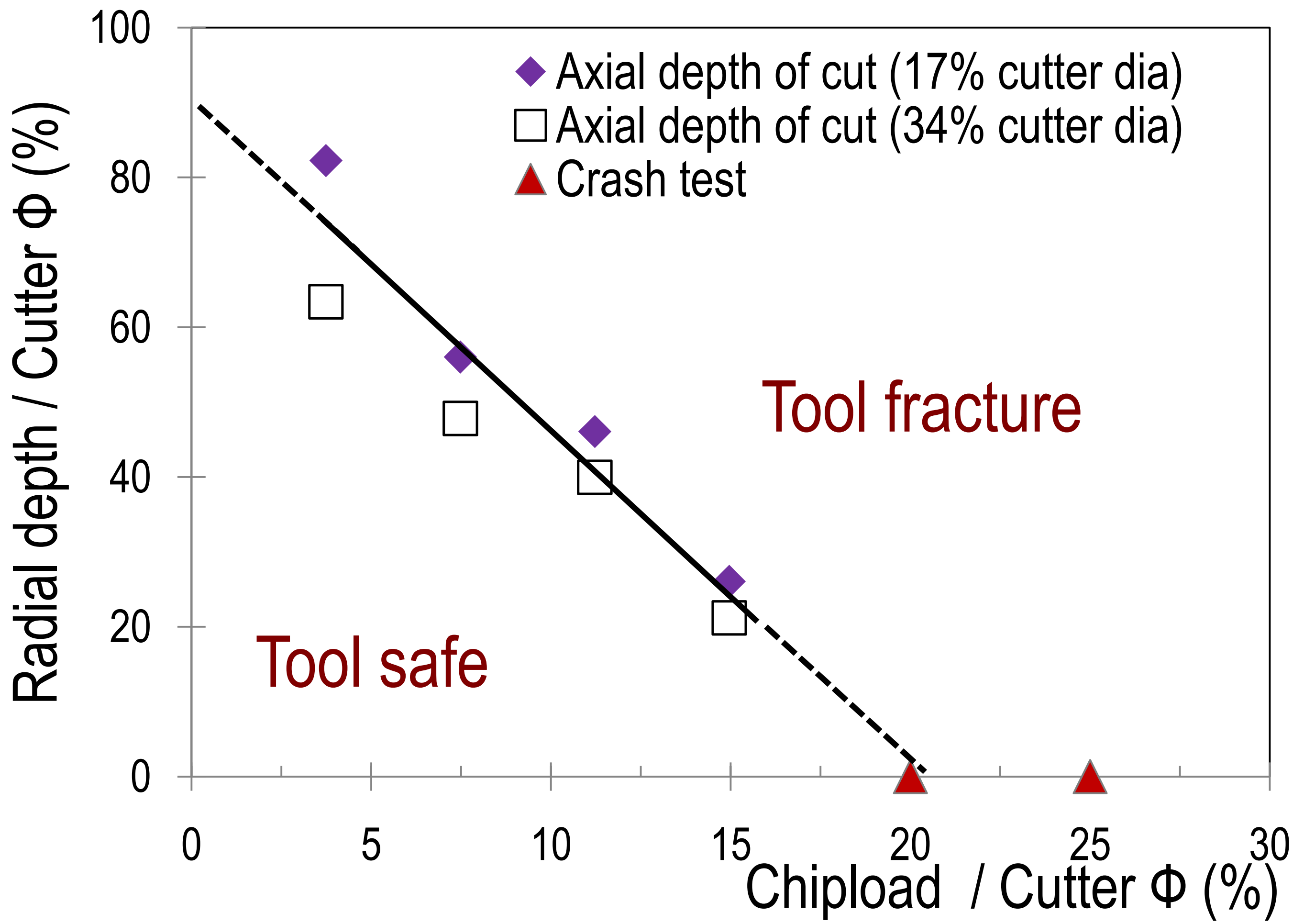


End deflection=17% tool diameter
Bending stress= 50% tool strength

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

Finite element analysis of bending stress on a micromilling tool.

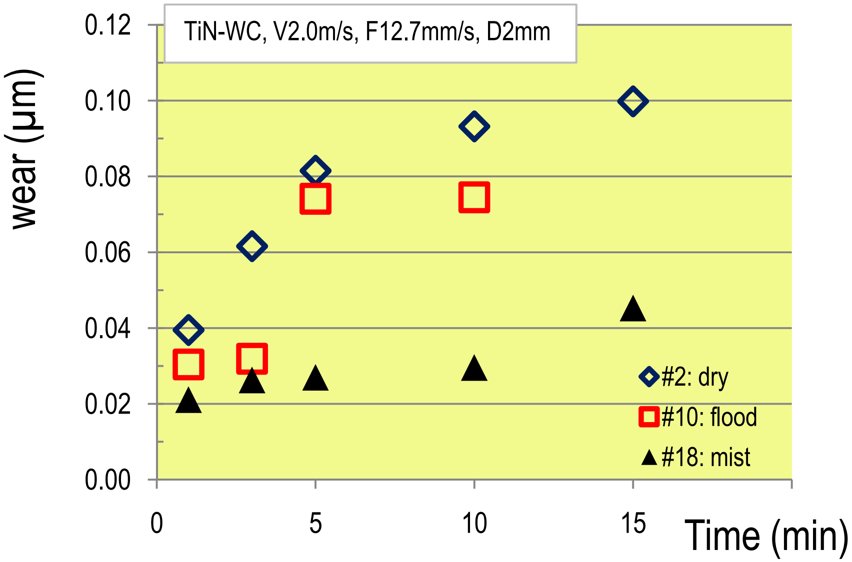
MICROMACHINING: limit of parameters

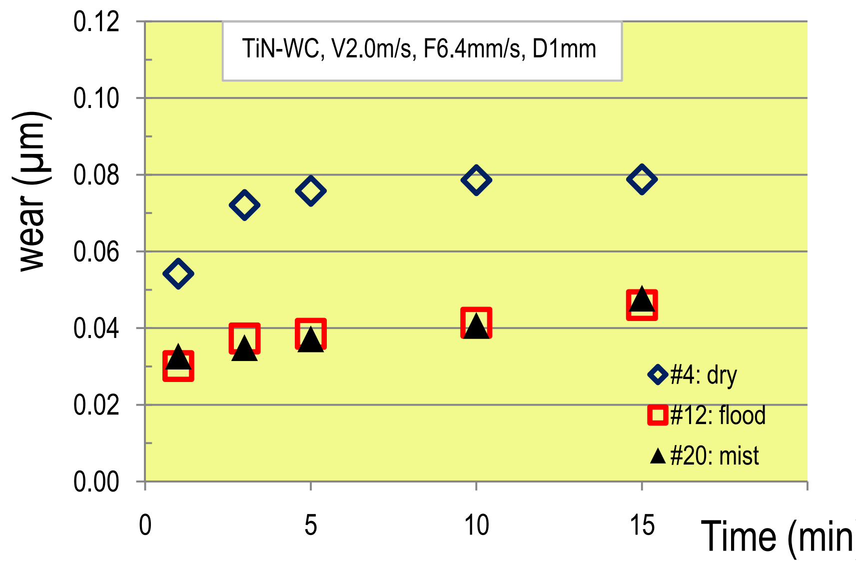


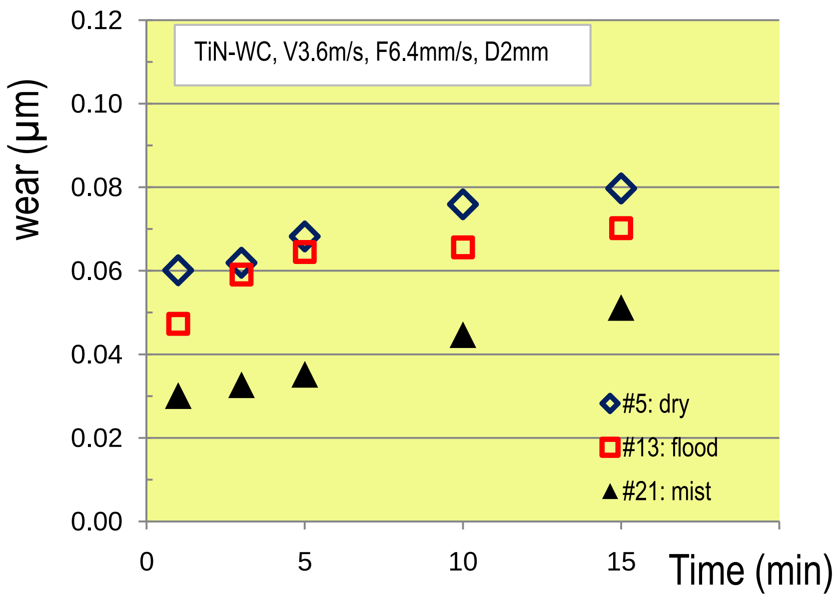
Catastrophic failure threshold of micromilling tools.

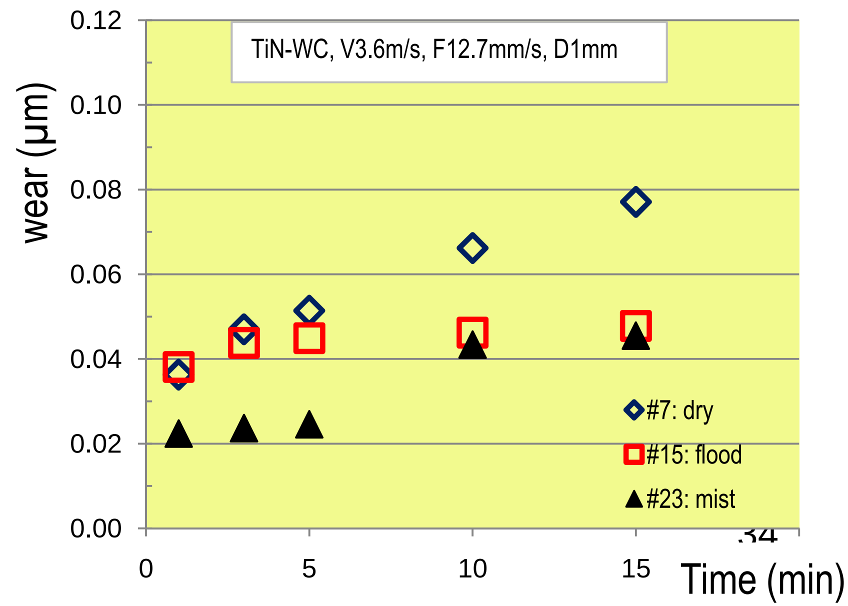
0.35mm (0.014 in) axial depth, dry , climb (down) side milling of 316L stainless steel.

MICROMIST: macromilling

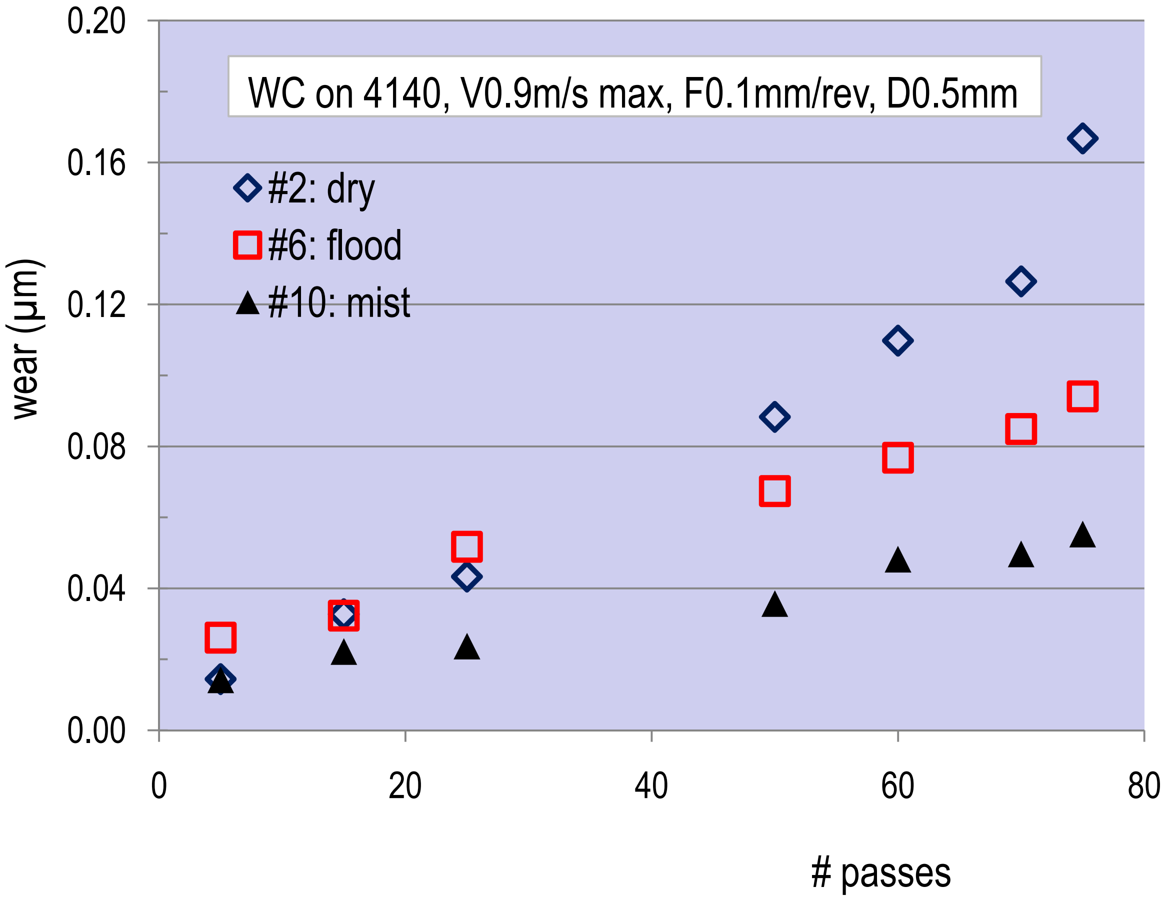


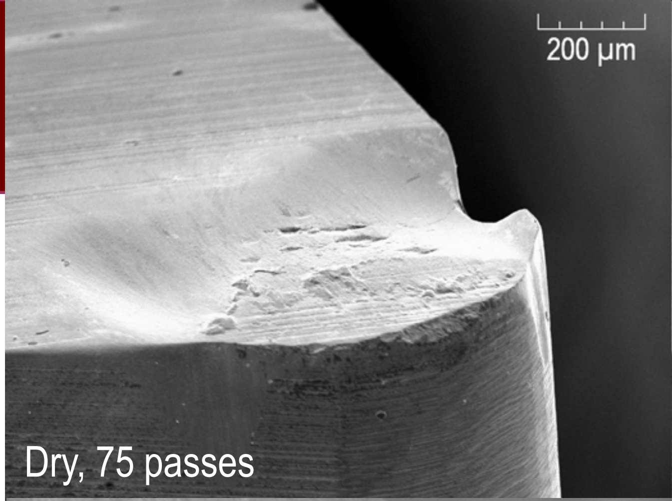


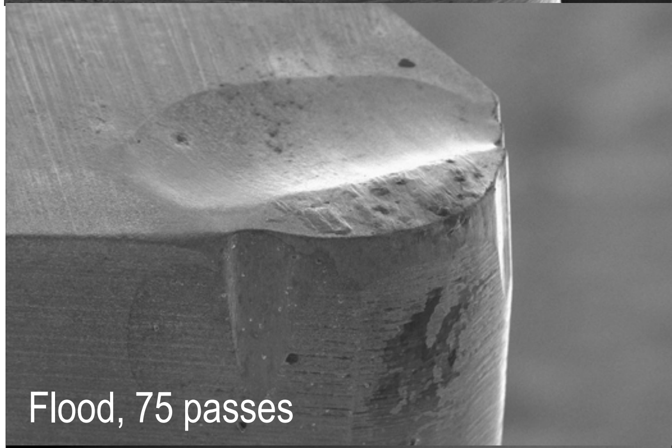


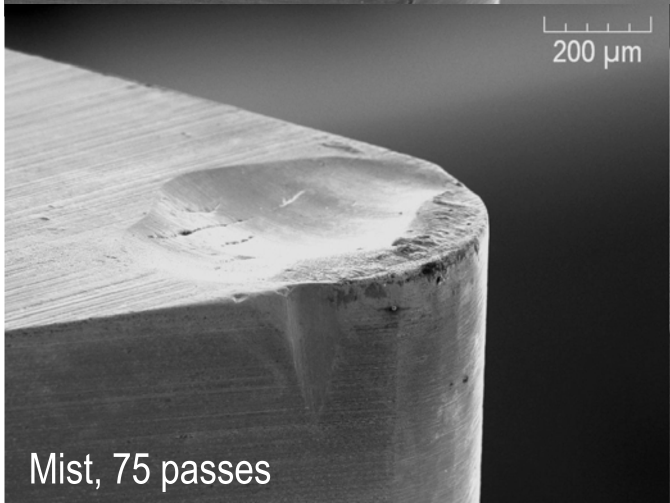


MICROMIST: macrofacing

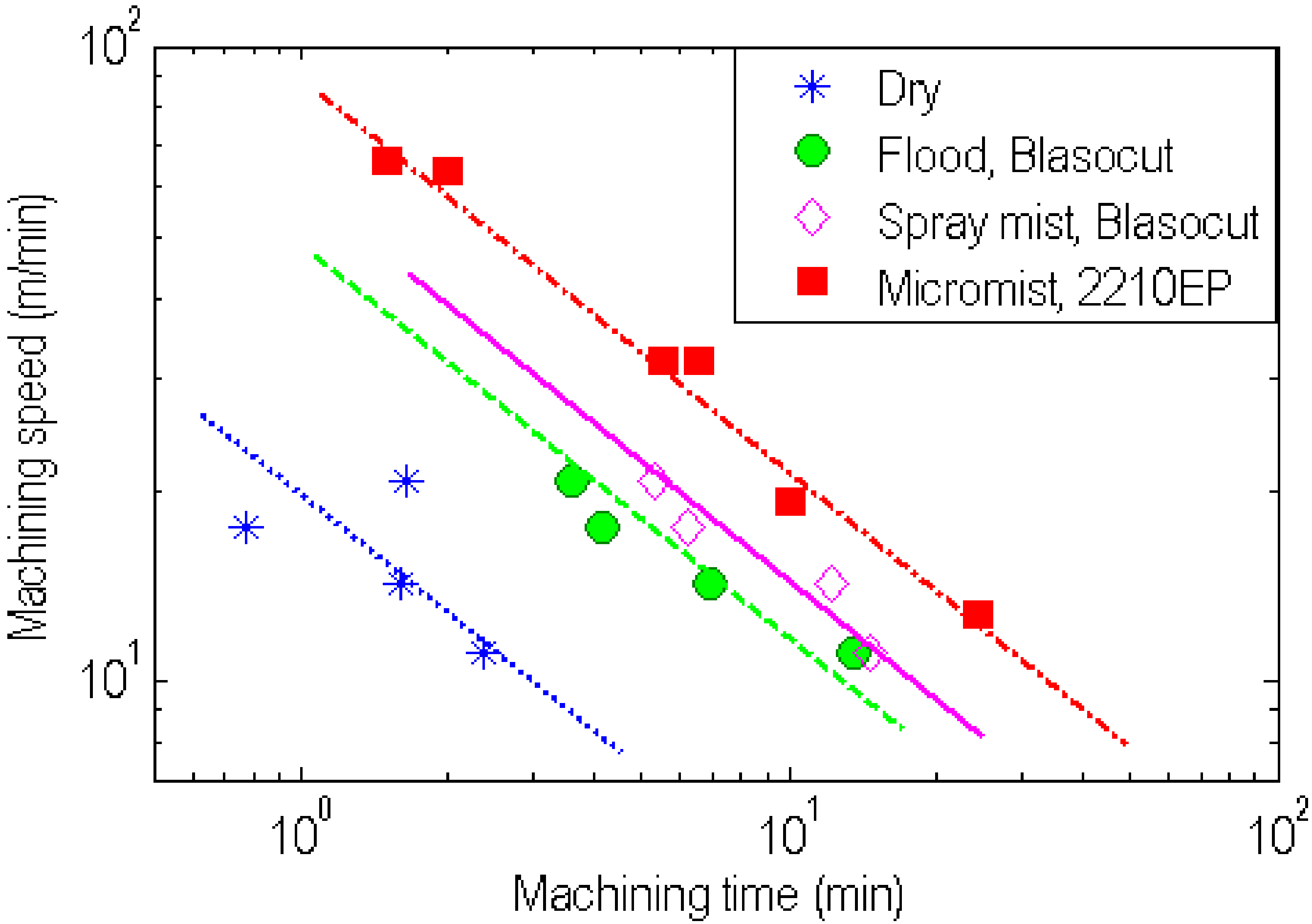








MICROMIST: micromilling



Micromilling of 316L stainless steel and effect of cutting fluids.

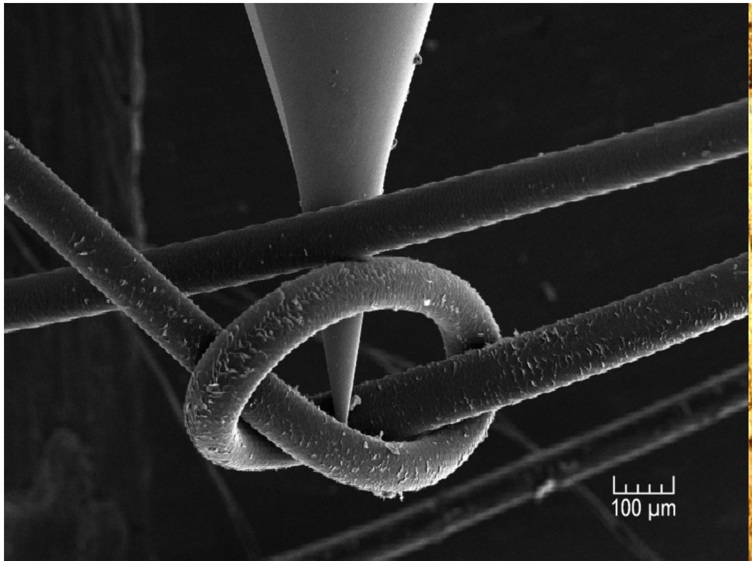
10 µm/tooth (0.0004 in/tooth), 0.35mm (0.014 in) axial depth, 0.56 mm (0.022 in) radial depth, climb (down) side milling

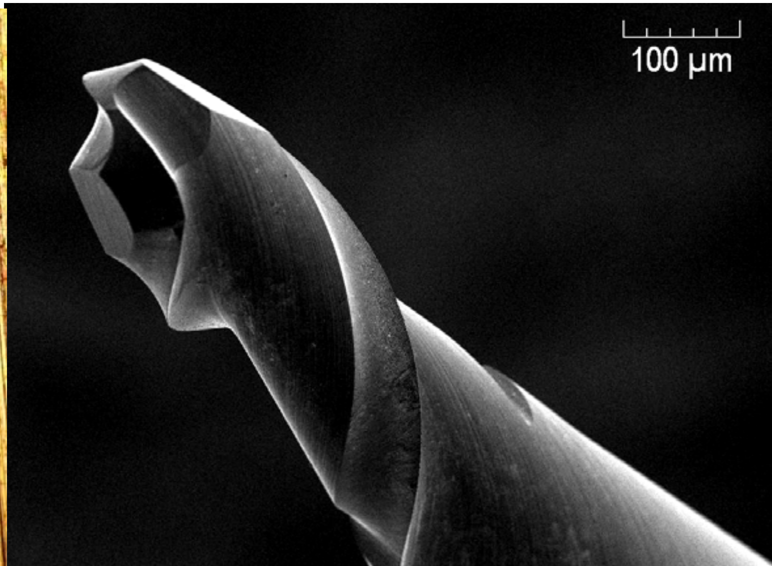
MICROMIST: summary

1) NSF-RET program
   - Promote collaboration among schools and industry
   - Encourage college grads to continue for higher degrees
2) Effective micromist must:
   - Penetrate and adhere to moving tool/workpiece.
   - Wet both tool and workpiece.
   - Avoid stagnant mist location.
3) Optimal micromist increases tool performance
   - Macromachining.
   - Micromachining.
4) Submicron mist particles
   - Contaminate other equipment.
   - Pose potential health issues.
   - Should be used with air cleaner unit.

MICROMIST: future works

1) Complete DOE experiment and compare with theoretical data
2) Compare economic advantages of dry, flood, and mist
3) Apply to machines at TSTC Waco and BMC Athens
4) Extend micromilling and include microdrilling studies using tool steel, aluminum, and titanium.
5) Optimize tool coating





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- Mr. Wally Boelkins, UNIST Inc.
- Mr. Patrick Anderson, PMT Inc.