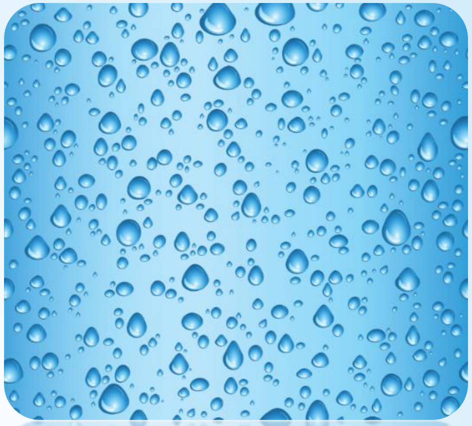
Experimental investigation of micromist for effective machining



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Experimental investigation of micromist for effective machining

- Understanding Minimum Quantity Lubrication (MQL)
- MQL research goals
- Imaging of the mist using Particle Image Velocimetry
- Drop let size optimization
  - Experimental set up
  - Analysis of experimental results
- Machining with MQL
  - Experimental setup
  - Analysis of experimental results
- Advantages and Benefits of MQL

Motivation for the study on MQL

- Over 2 billion gallons cutting fluid is used in 2002 (7-17% of total production cost)
- Purpose of cutting fluid : Coolant & Lubricant
- Minimum Quantity Lubrication (MQL)
  - Advantage
    - No maintenance and waste
    - Generated Chip can be remelted
    - Reduces flank wear in cutting tools
    - Better surface finish

Understanding Minimum Quantity Lubrication (MQL)

- **What is MQL ?**

Minimum Quantity Lubrication—the process of applying a minute amount of a quality lubricant directly into the cutting tool-work piece interface in order to facilitate cutting.

Lubrication is performed by an aerosol that is formed by oil droplets that are finely dispersed in an air stream.

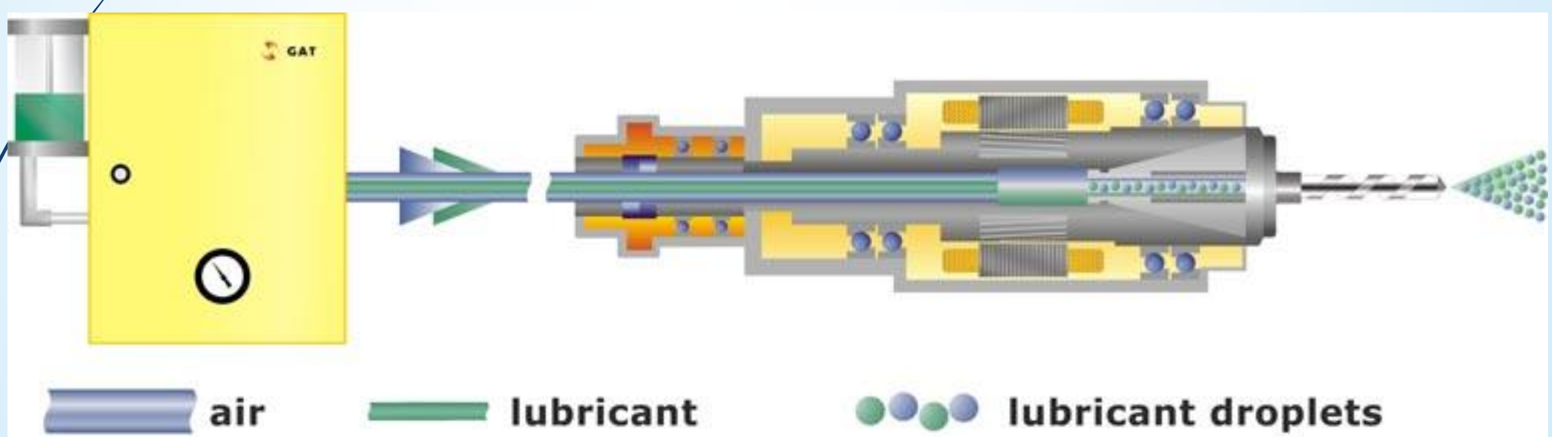
Minimal quantity lubrication (MQL) can be fed to the tool or workpiece in two different ways, internal or external:

- **Internal MQL**:
  with the internal lubrication method, compressed air or the aerosol is applied through the spindle, the tool holder and the tool directly at the point between tool and workpiece.

- **External MQL**:
  with the external lubrication method, the aerosol is supplied to the lubrication point from the outside through nozzles.

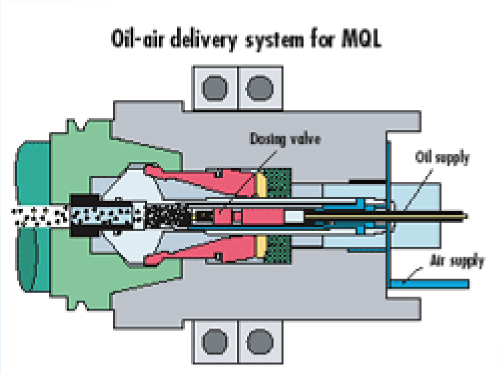
Understanding Minimum Quantity Lubrication (MQL)

MQL through Spindle



Understanding Minimum Quantity Lubrication (MQL)

MQL through External System



Understanding Minimum Quantity Lubrication (MQL)

- **MQL Applications:**

  Applications for machine tools includes milling, rolling, cutting, drilling, boring, forming among others.

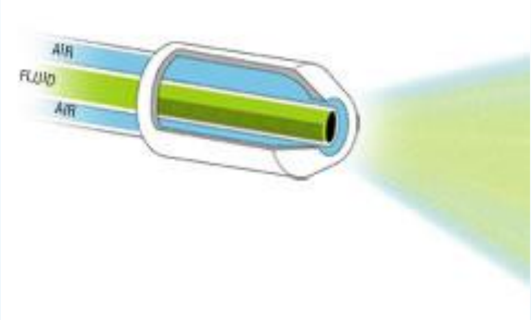
- **MQL reduces machining costs:**
  - Increased tool life, significant coolant reduction, increased surface finish quality, decreased maintenance and increased machine uptime
  - **Key disadvantages**
    - Does not remove chips
    - Not ideal for high production environment - Evaporation

Parameters that affect the MQL Process

- MQL Parameters which significantly influence the effectiveness of MQL machining are:
  - Droplet size (Oil mist size)
  - Droplet distribution: nozzle distance & wetting area
  - Air pressure & flow rate

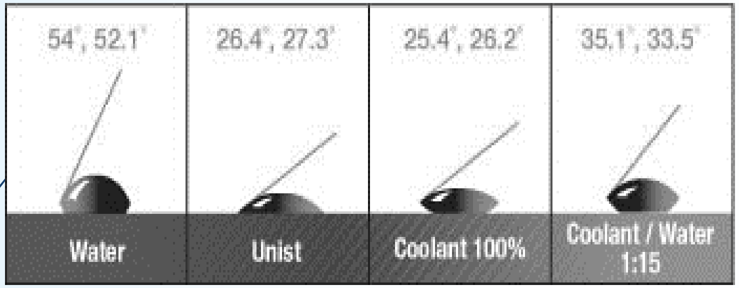
Methodology used in the Optimization of MQL process

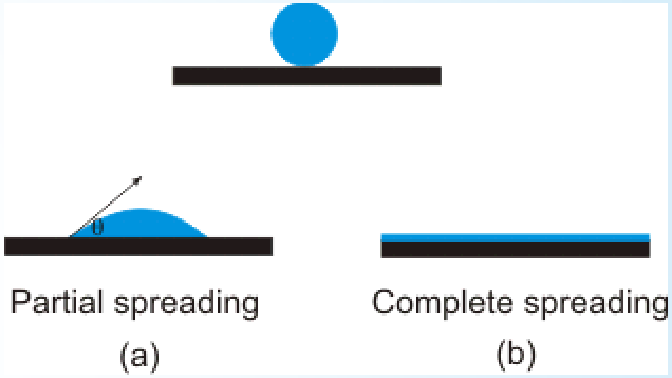
- Optimized Process Parameters
  - Droplet size and distribution
  - Air pressure and Flow rate
  - Distance between the nozzle and workpiece-tool interface
  - Quantity of lubricant dispensed
  - Quality of Lubricant (wetting angle)

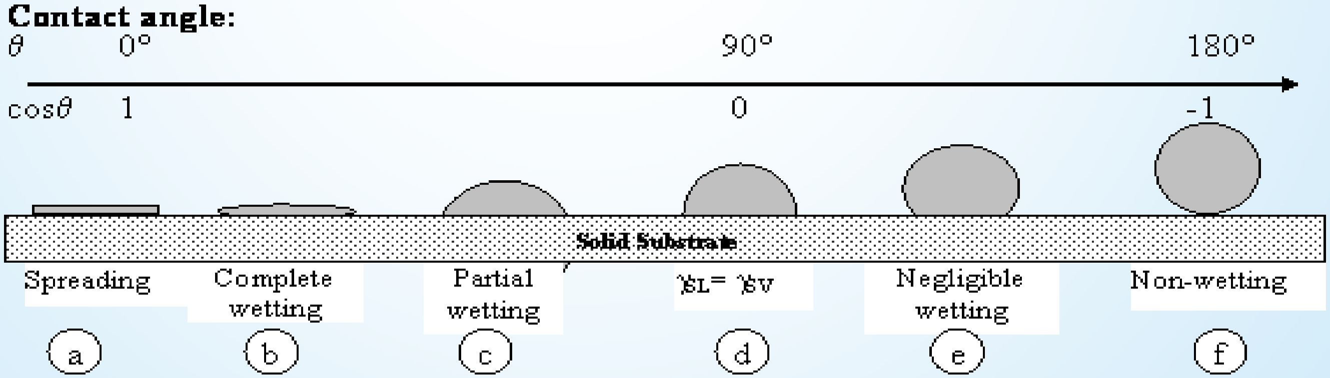


Critical Element of MQL - Lubricant

- Workpiece surface wetting







Critical Element of MQL - System Performance

- Maintain even thin film of oil droplets on the machining surface and cutting tool.
- Precise and repeatable operation of the MQL application system.
- Maintain Oil and air separate until the point of ejection for the consistent creation of mist / flow
- Avoid excessive misting by proper control of air flow.

Critical Element of MQL – Based on the Machining System

- The proper application system depends on the operation, variations in the material size and shape, and the design of the machine.
- Chip Removal
  - Orienting the work so the chips are moved out by gravity
  - In some CNC machines (HCNCs), the chips naturally fall down vertically and can be removed from the system.
  - An air blow-off nozzle can be used to remove chips in situations where chip removal is critical.
  - A programmable and intermittent air blast can effectively aid in chip removal, and help to eliminate the possibility of re-cutting a chip.
  - Other strategies for chip removal include using MQL specific tooling and vacuum systems to remove the chips. Ultimately, the solution in any particular situation will be as unique as the job itself

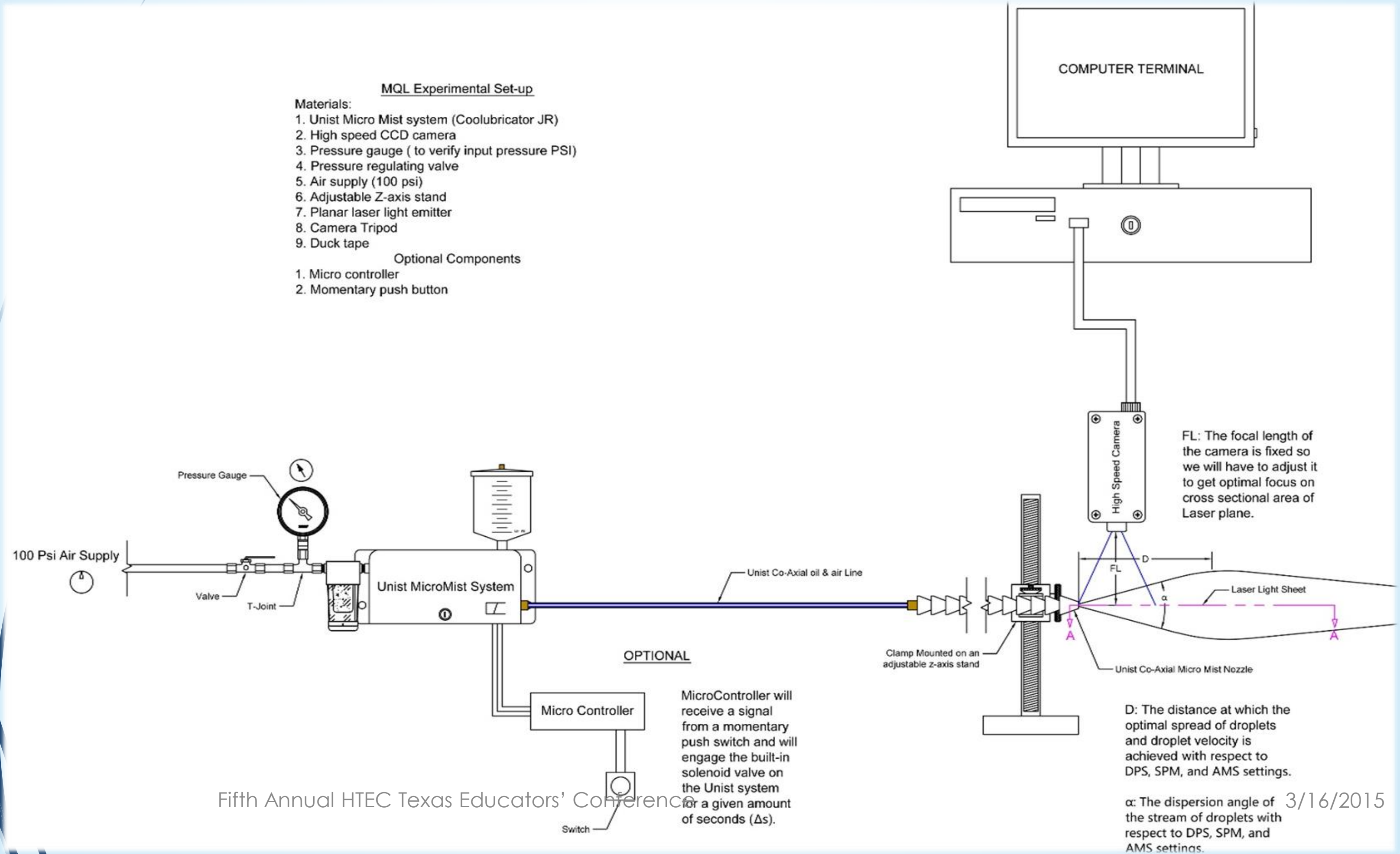
MQL Research Goals

- To design and conduct various experiments to characterize MQL in order to determine the optimal parameters for different machining conditions.
- Study several machining operations with different cooling conditions to analyze the effects of MQL on tool wear, surface roughness and chip breakage.

The MQL System

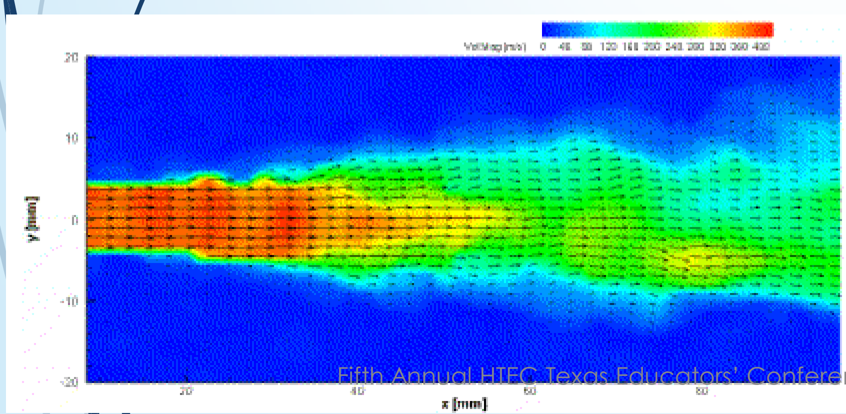
- The MQL system used was a Unist Coolubricator Jr.

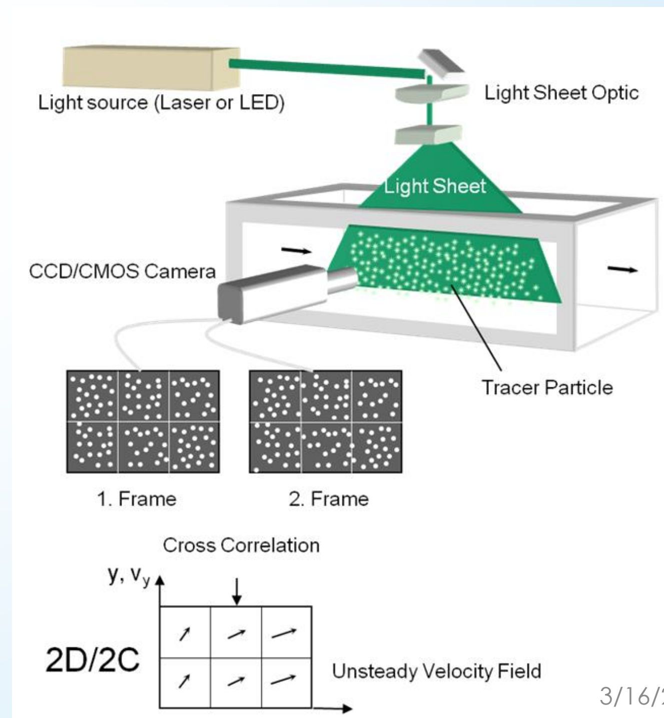
Experimental Set-up: Particle Image Velocimetry



Imaging of the mist using Particle Image Velocimetry

- Planar particle image velocimetry (PIV) was applied in order to measure the velocity field of the jet of MQL at the moment of ejection.

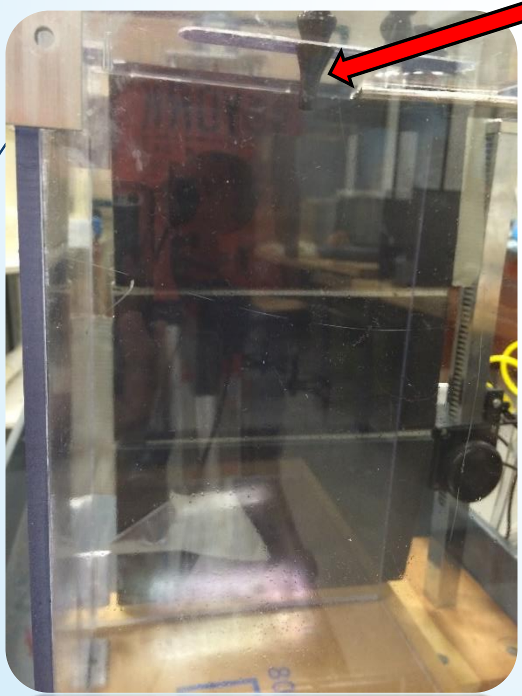


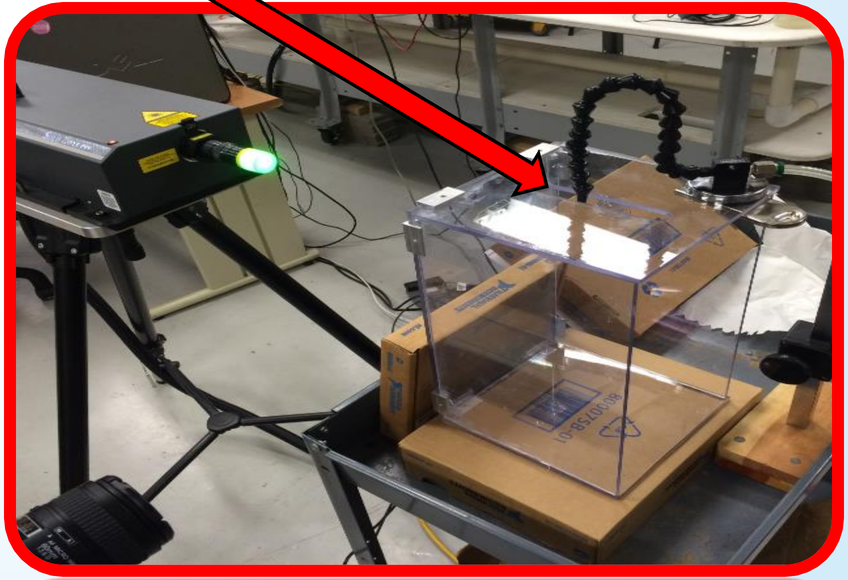


PIV Test Set-Up

- *Setup used during the experiment. Laser sheet generated by equipment in the top left and photographs caught by the high speed camera in the bottom left corner.*

Nozzle





PIV System Results

- The PIV System provided great results when it came to the trajectory and velocity of the air stream coming out of the nozzle.

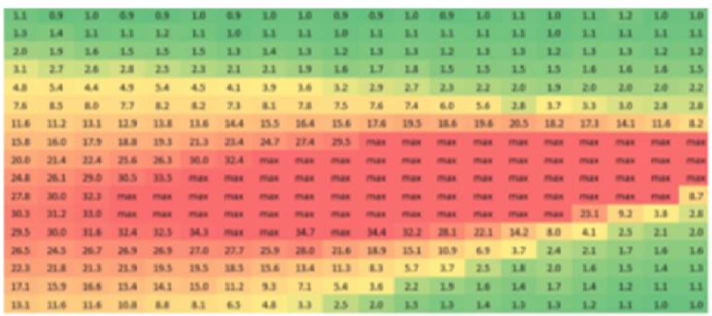


Fig. 4: Air speed map in front of the nozzle. Each data block is 10x5mm, 300 kPa nozzle pressure, 128 m/s nozzle speed. max: more than 35m/s

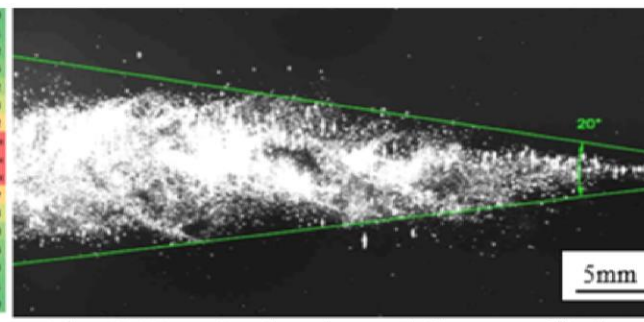
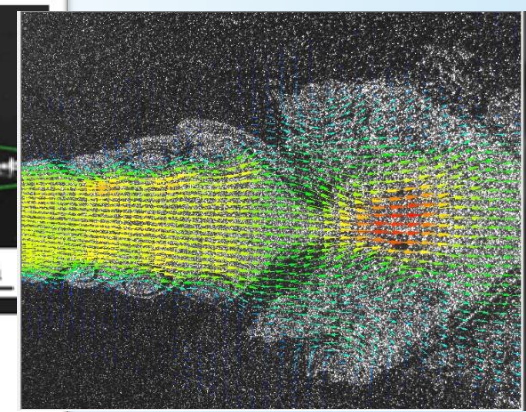
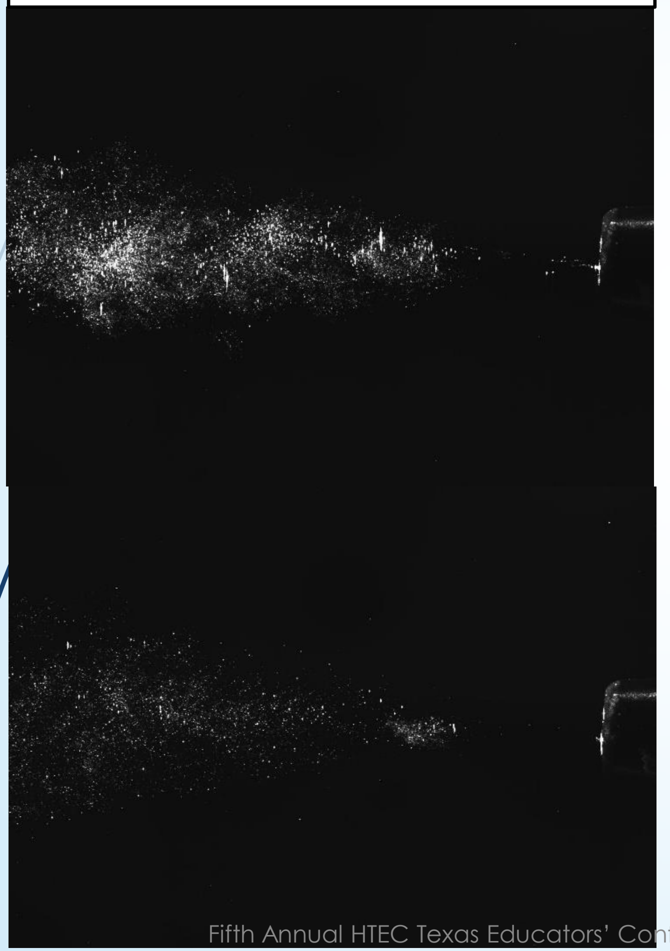


Fig. 5: Droplet density and flow profile by particle image velocimetry. 480 kPa input pressure, 8 strokes/min

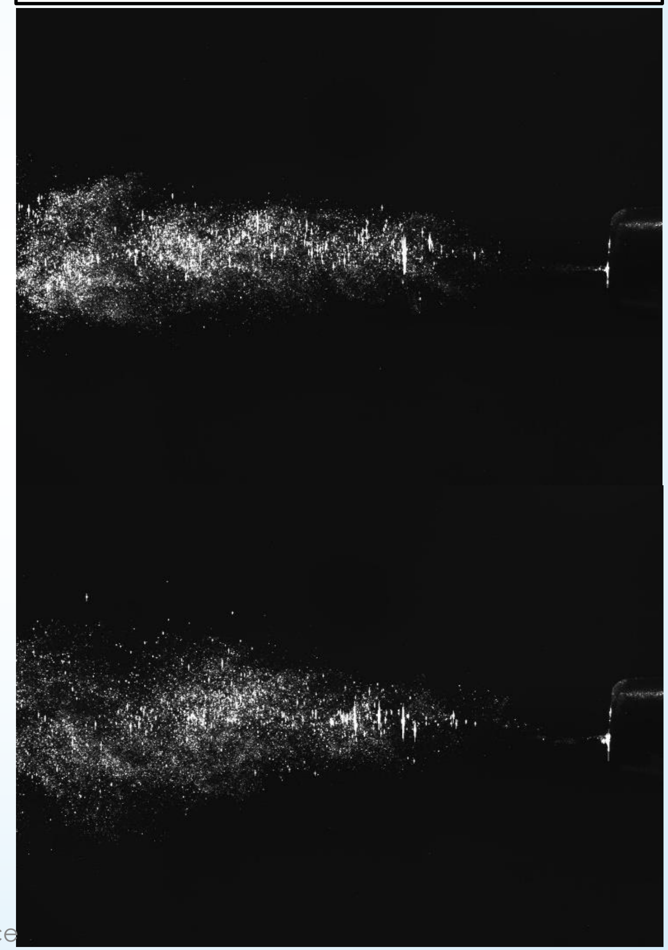


PIV System Results Cont.

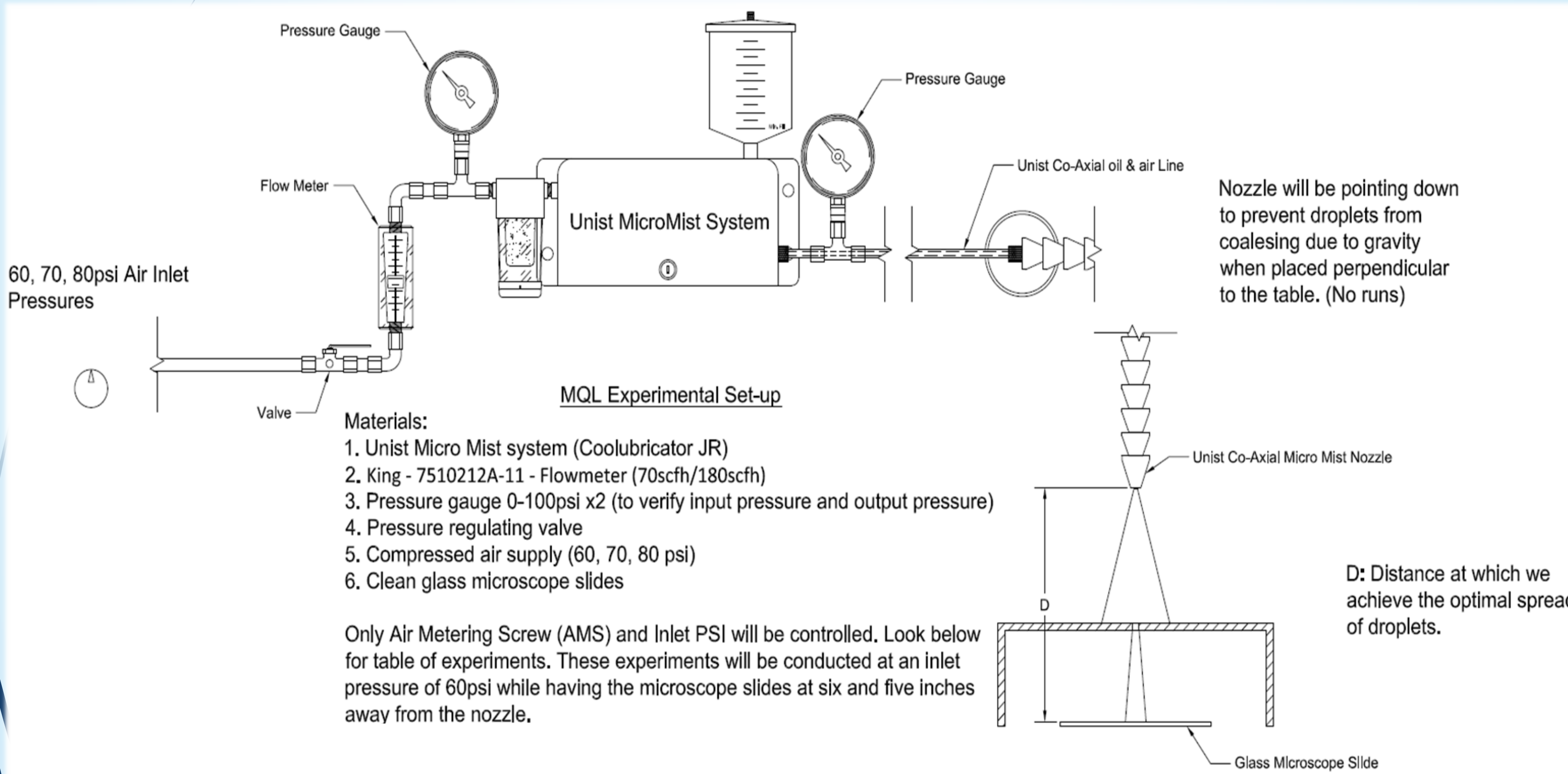
Pictures cycle start/end



Pictures Mid Cycle



Experimental Set-up: Droplet Sizes



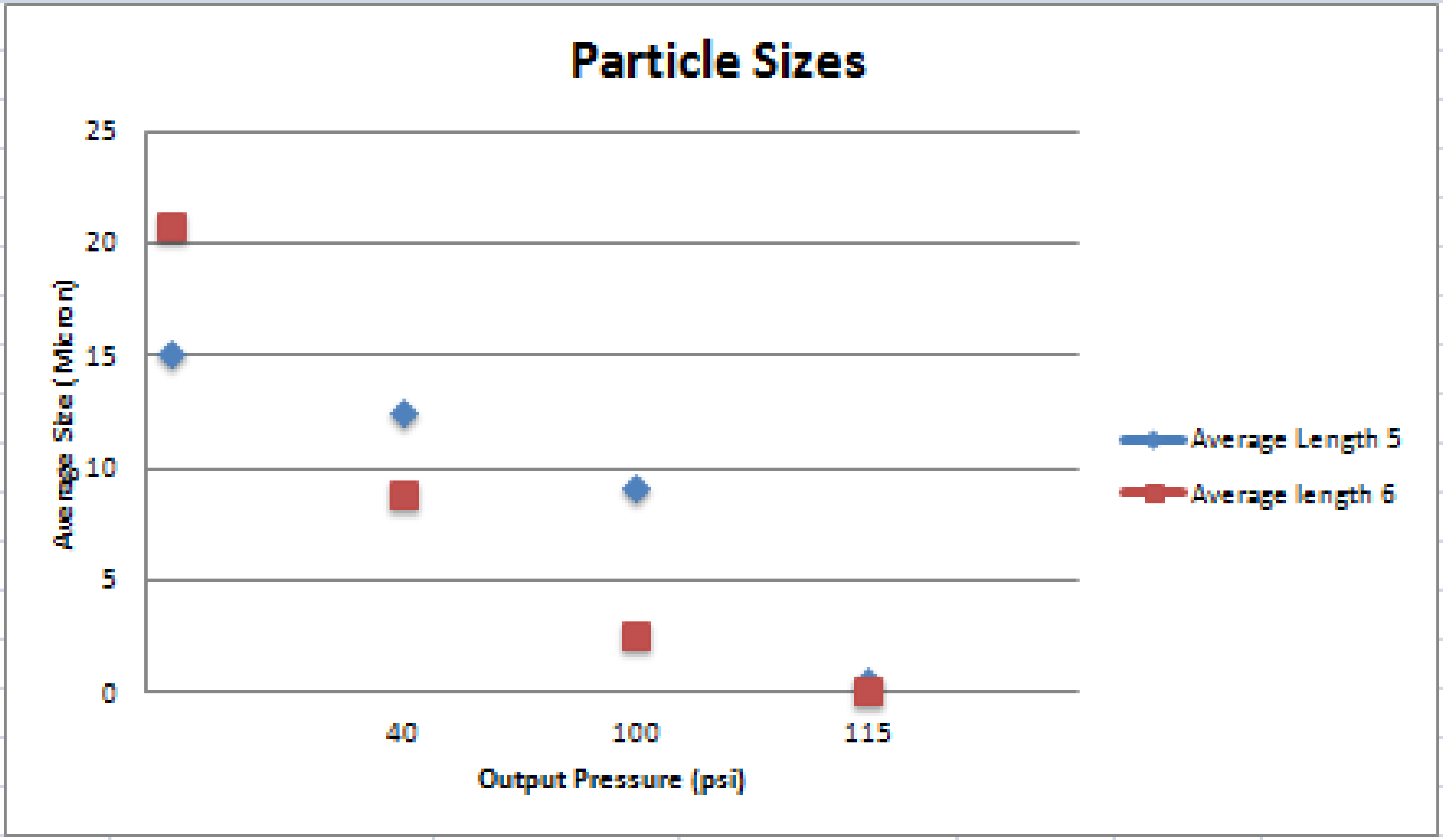
Results: Droplet Sizes

Extra Information			
Air Cap Screw Turns	Input Pressure (Psi)	Output Pressure (Psi)	Air Flow (scfh)
0.5	60 psi	OR	OR
1		OR	18
1.5		10	40
2		37	98
2.5		43	115
3		45	120
0.5	70 psi	OR	OR
1		OR	20
1.5		13	42
2		42	100
2.5		50	120
3		52	125
0.5	80 psi	OR	6
1		OR	20
1.5		15	48
2		46	102
2.5		57	128
3		60	130

Results: Droplet Sizes

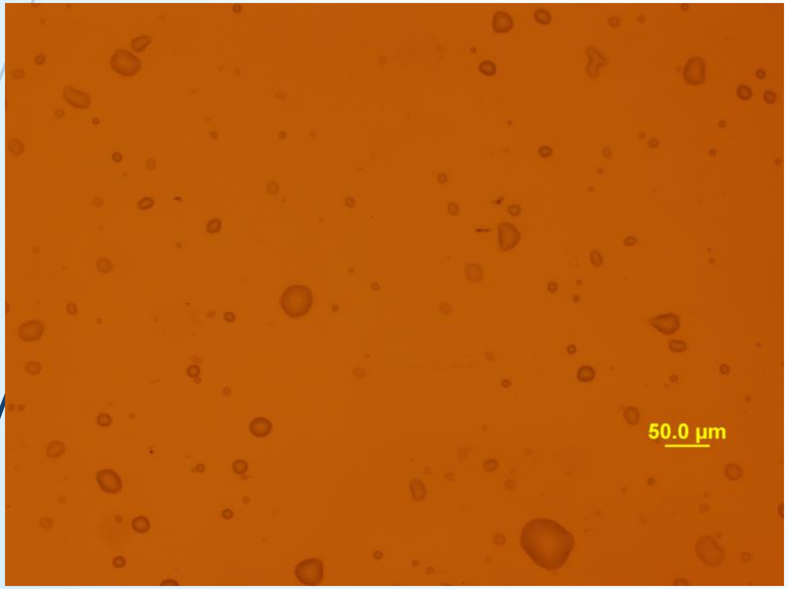
Mist Particle Sizes									
Distance (in)	Air metering screw turns	Input Pressure (psi)	Output Pressure (psi)	Air Flow (scfh)	Droplet size (µm)	Droplet Height (µm)	Droplet Volume (µm^3)	Avergae size (µm)	Average Height (µm)
5	1	60	?	18	15.7	4.4	470	15.2	3.88
					17	4.1	501		
					13.4	3.8	296		
					15.3	4	401		
					14.6	3.1	275		
	1.5		10	40	11.9	2.4	140	12.54	2.54
					12.4	2.5	159		
					12.3	2.4	149		
					13	2.6	181		
					13.1	2.8	200		
	2		37	98	11	2.2	110	9.22	1.86
					9.5	1.8	66		
					10	2	82		
					8	1.8	48		
					7.6	1.5	35		
	2.5		43	115	1>	?	0	1>	?
					1>	?	0		
					1>	?	0		
					1>	?	0		
					1>	?	0		
6	1	60	?	18	21	3	533	20.8	3.14
					20	3.5	572		
					21	3.4	609		
					20.5	3	509		
					21.5	2.8	519		
	1.5		10	40	10.1	2	84	8.8	2
					10.6	2.3	107		
					7.8	1.8	46		
					8.3	2.5	75		
					7.2	1.4	29		
	2		37	98	3.4	?	0	2.66	?
					2.8	?	0		
					2.6	?	0		
					2.2	?	0		
					2.3	?	0		
	2.5		43	115	1>	?	0	1>	?
					1>	?	0		
					1>	?	0		
					1>	?	0		
					1>	?	0		

Particle Size as a function of distance

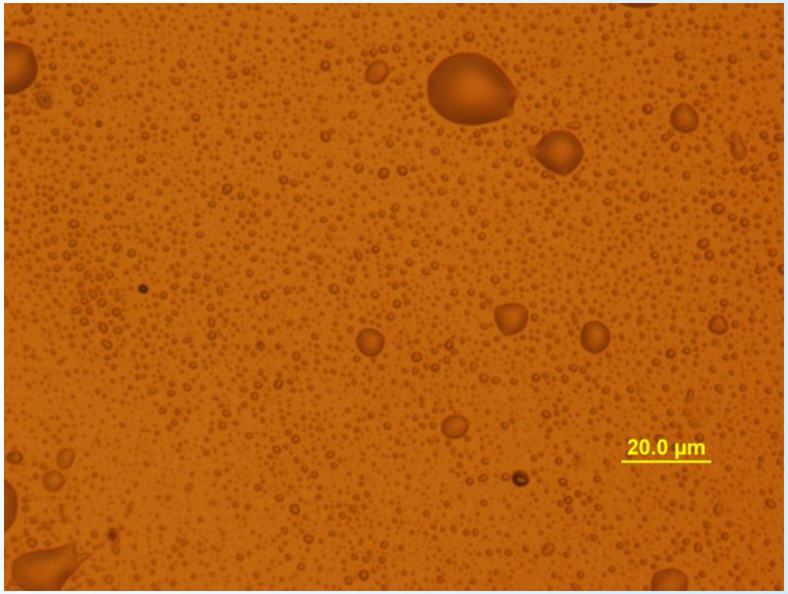


Droplet Analysis Cont.

- Droplet sizes under two different MQL settings

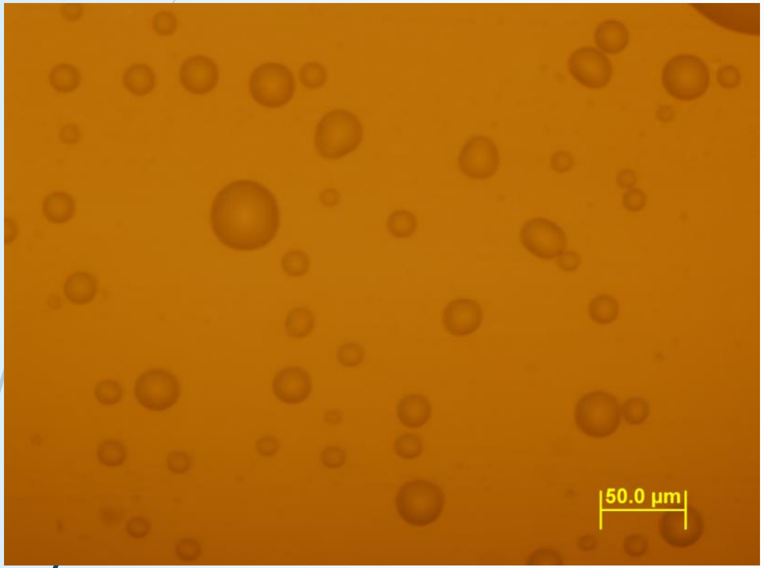


60 psi at 5 inches away

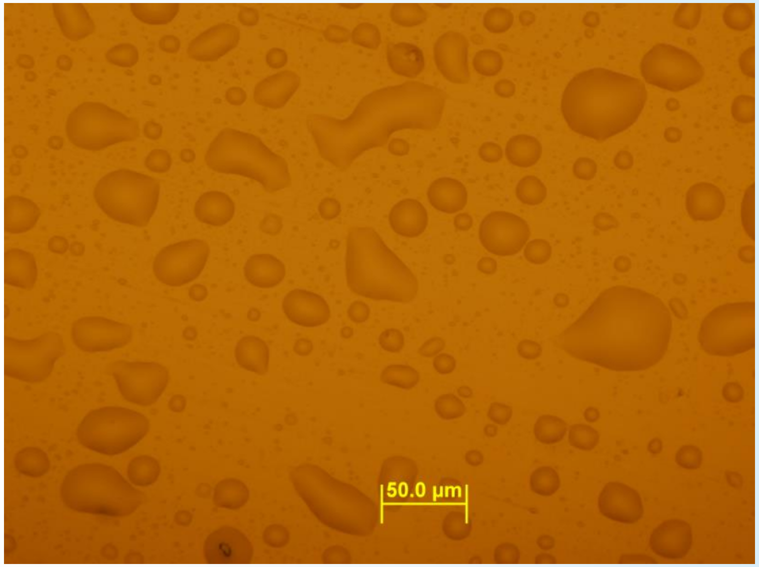


60 psi at 6 inches away

Droplet Analysis Cont.



100 psi at 5 inches away



100 psi at 8 inches away

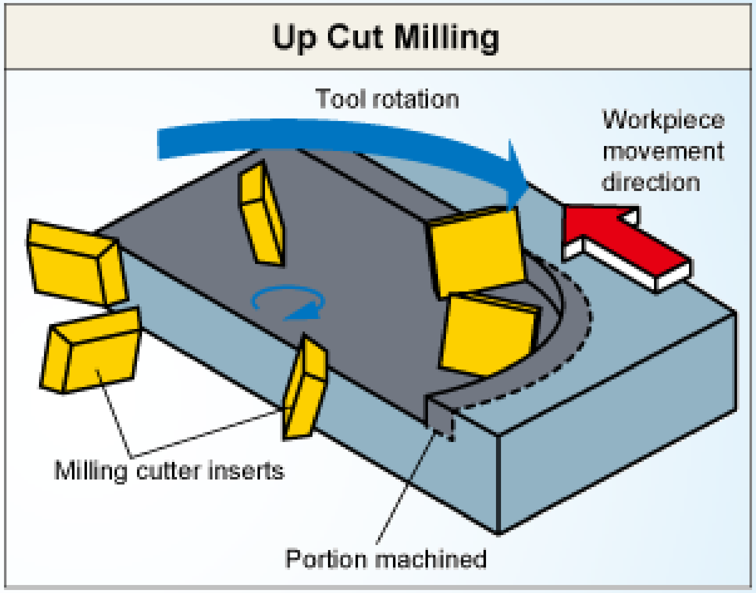
MQL Process Parameters for optimal performance

- Distance between nozzle and workpiece/tool interface (D) = 6 inches
- Air pressure = 60 psi
- Flow rate =
- Quantity of lubricant dispensed =

Performance of Machining with MQL - Study

- Machine several samples of commonly used tool steel (A2) with a face mill tool inserted with Face Milling Inserts from Kyocera (Part No. WNMG080404HQ) TN60
- A2 tool steel is used for blanking, forming, and trim dies, stamping dies, coining dies, thread roller dies, knurls, knurling tools, mandrels, master hobs, cold forming tools, spindles, shear blades, slitter blades, molds, punches, block and ring gauges, punch plates, reamers, brick mold liners, forming rolls, etc.

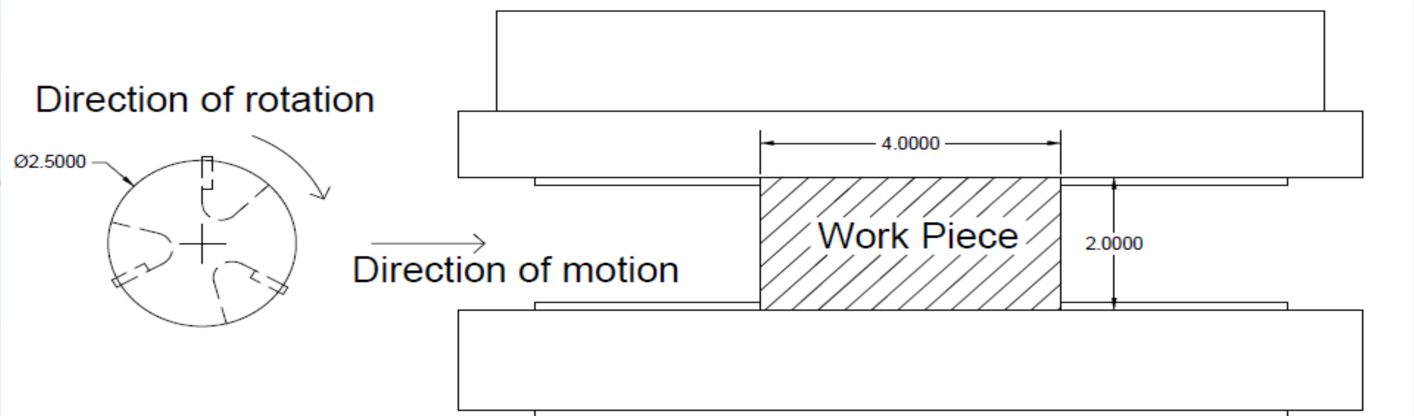
Machining : Surface Roughness Analysis

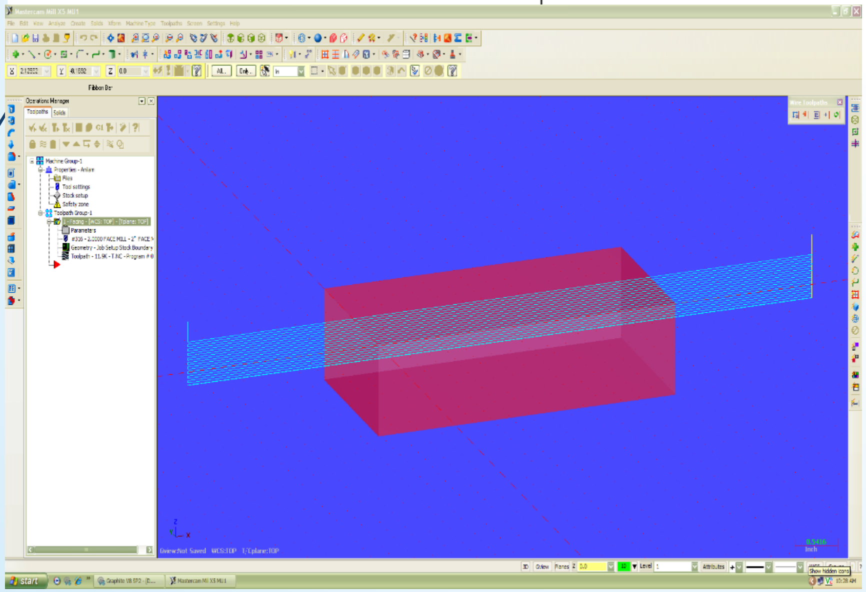


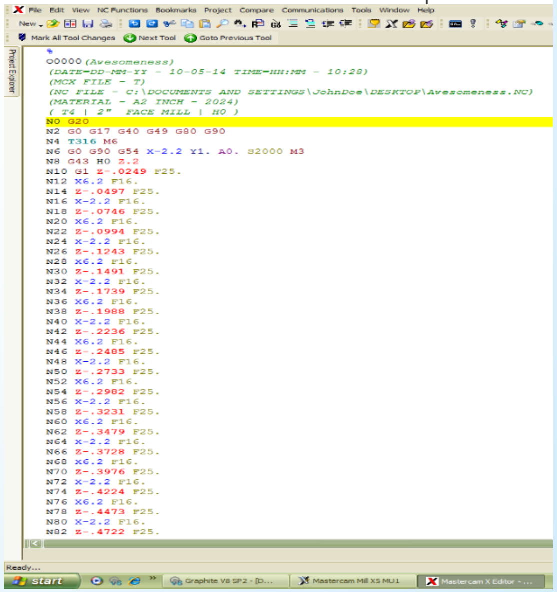
Experiment Set-up: Surface Roughness Analysis

- Material being machined: A2 Tool Steel
- Cutting inserts (x9): Kyocera TN60 Tungsten Carbide Face Milling Inserts
- Machine : Fryer MB-14 Milling machine with Anilam 3300 MK control system
- Machine parameters :
  - Feed: 16 IPM
  - Step-down: 0.025" (rough cut)
  - Finish pass: 0.003"
  - RPM: 2000
  - Step-Over: N/A
- Tool:
  - 2" DIA Face Mill with 3 cutting inserts

Experimental Set-Up

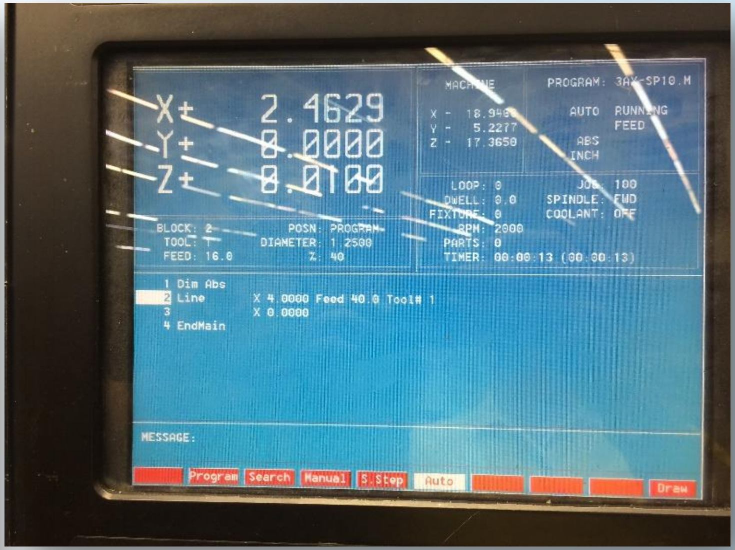




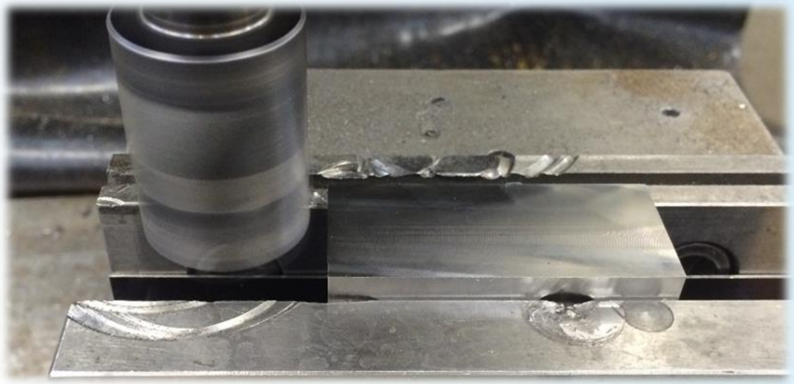


Machine

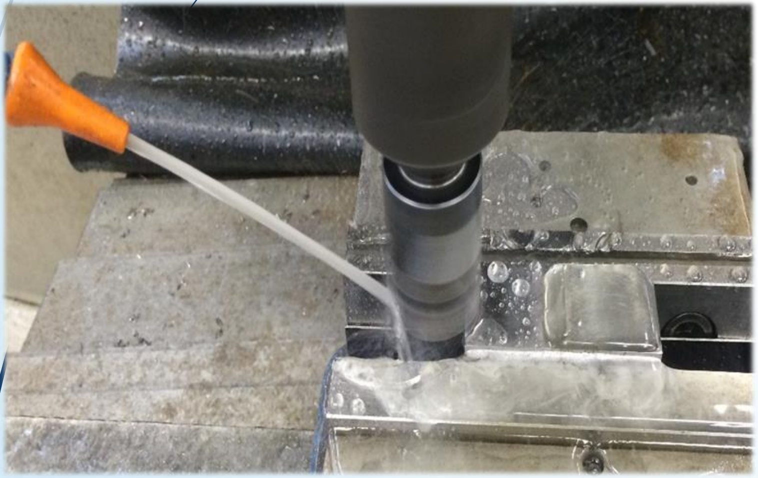

ANILAM 3300 MK
X- 18.1439
Y+ 0.0000
Z+ 0.0000
MACHINE
PROGRAM:
MANUAL HALTED
IN-POSN FEED
ABS
INCH
MESSAGE:
Message Program Edit Manual S.Step Auto MDI Tool Exit
X Y Z
CLEAR
ENTER
F1 F2 F3 F4 F5 F6 F7 F8 F9 F10


X+ 2.4629
1 Dim Abs
2 Line X 4.0000 Feed 40.0 Tool# 1
X 0.0000
4 EndMain
MESSAGE:
Program Search Manual S.Step Auto Draw

Experimental Set-Up - Machining



Dry Machining



Flood Cooling

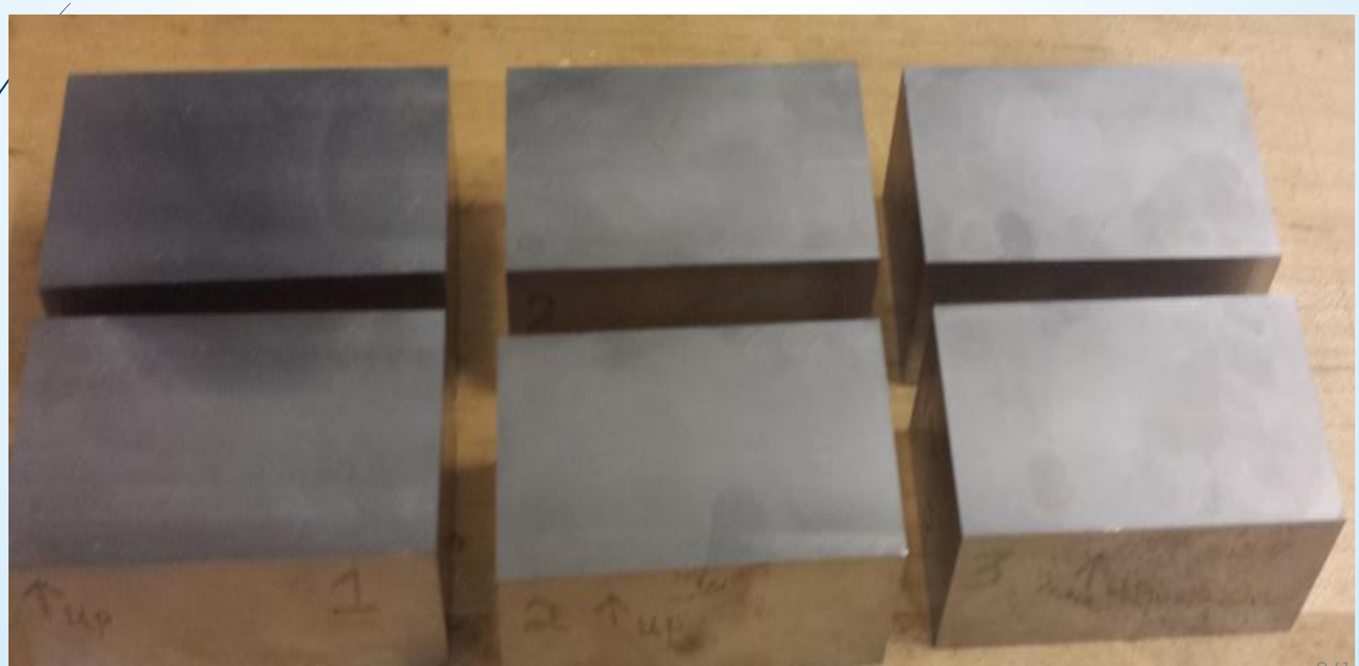
MQL

Surface Roughness measurement

- The equipment includes a Taylor Hobson Surtronic 25 portable surface roughness tester with a .5um probe, a measuring microscope, and a reference surface roughness sample to ensure proper calibration of surface roughness tester.

Machining Comparison

- *Blocks machined by different lubrication methods. Left blocks-Dry machining, middle blocks-MQL, and right blocks-flood lubrication.*



Dry Machining **MQL** **Flood Cooling**

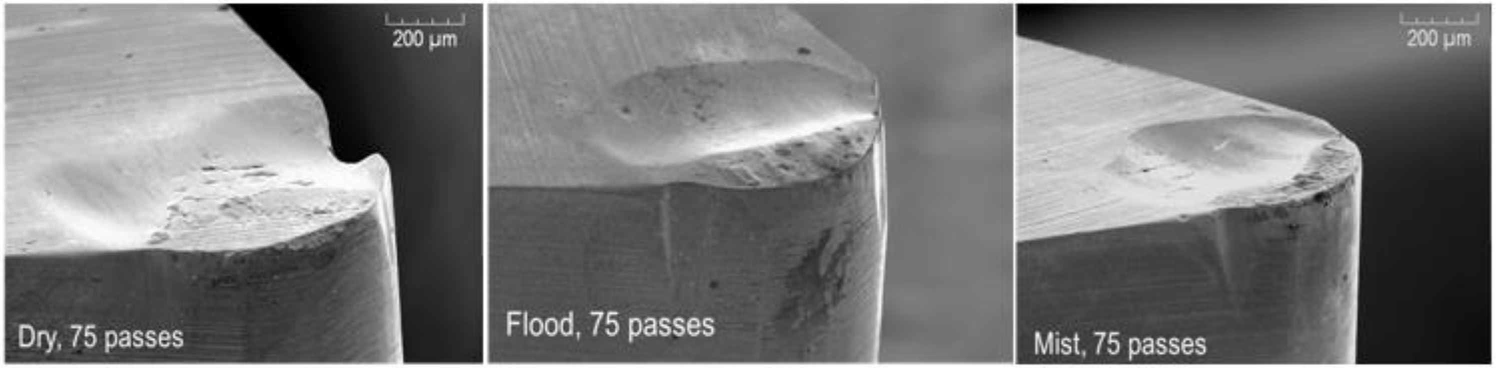
Results: Surface Roughness

- *Surface roughness measurements obtained from the surtronic tester.*

Dry Machining	Block 1	1.22 um	1.31 um	1.27 um	1.37 um
	Block 2	1.18 um	1.35 um	1.33 um	1.40 um
MQL	Block 1	0.92 um	0.96 um	0.88 um	0.86 um
	Block 2	0.92 um	0.87 um	0.91 um	0.84 um
Flood Lubrication	Block 1	1.84 um	1.94 um	1.64 um	1.60 um
	Block 2	1.86 um	1.82 um	1.73 um	1.53 um

Advantages - Improved Cutting Performance/Tool life

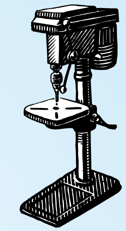
- Here are three Tungsten Carbide cutting inserts used under the same machining conditions but with three different cooling/lubricating conditions. Air, Flood Coolant and MQL.



(a) (b) (c)

SEM pictures of facing tools after 75 facing passes in (a) air, (b) flood coolant, and (c) MQL with 2210EP lubricant, 0.022 cc/min, 250 kPa nozzle pressure, 6 mm nozzle distance.

Benefits



- Reduction of coolant use (ml instead of liters) $$$
- Use of ecofriendly vegetable based oil coolant
- Elimination of Chip cleaning process (Chips are worth more money since they don't have to be cleaned)
- Tool Life increase of up to 500%
- Coolant health hazards are eliminated

A formula was developed

Machining + MQL =

Acknowledgements

- **Dr. Wayne N.P. Hung**

  Department of Engineering Technology & Industrial Distribution Department of Mechanical Engineering

  Texas A&M University College Station, Texas 77843, USA

- The **Unist Corporation** for donating all the MQL equipment for testing and for providing valuable insight into the use and efficiency of MQL.

Thank you!