Water Erosion Resistant Surface Treatments Using Laser Peening and Low Plasticity Burnishing

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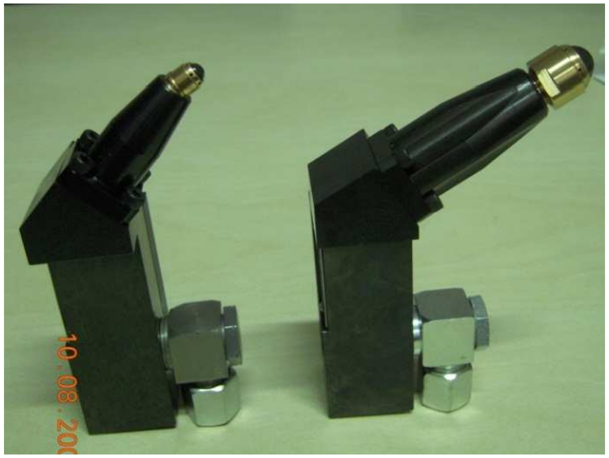
Outline

- LPB Process
- DOE Analysis for LPB
- Residual Stress Measurement
- Water Erosion Rig Test
- Future Work

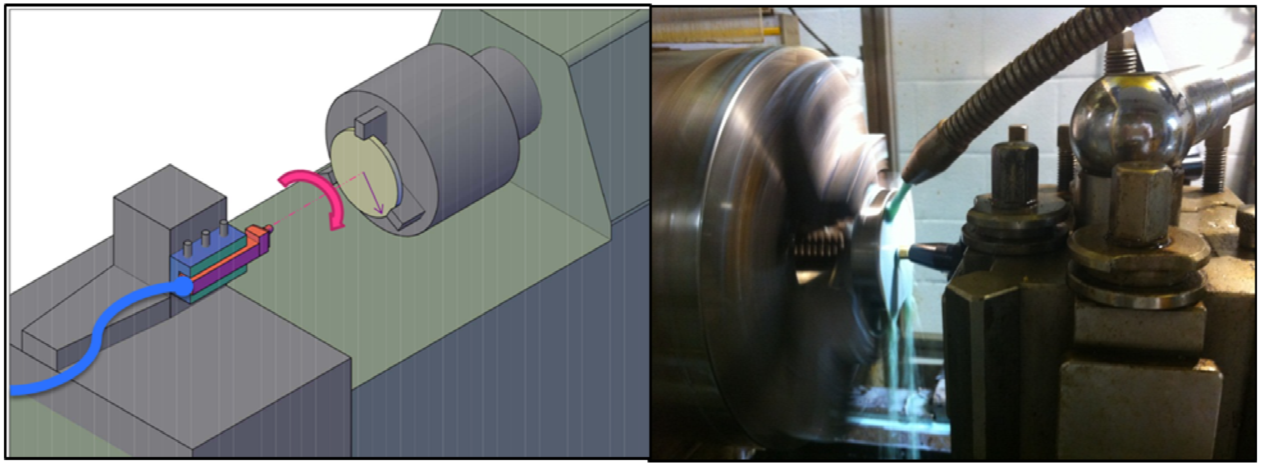
Low Plasticity Burnishing

Ecoroll Burnishing Equipment



Ecoroll Burnishing Tool

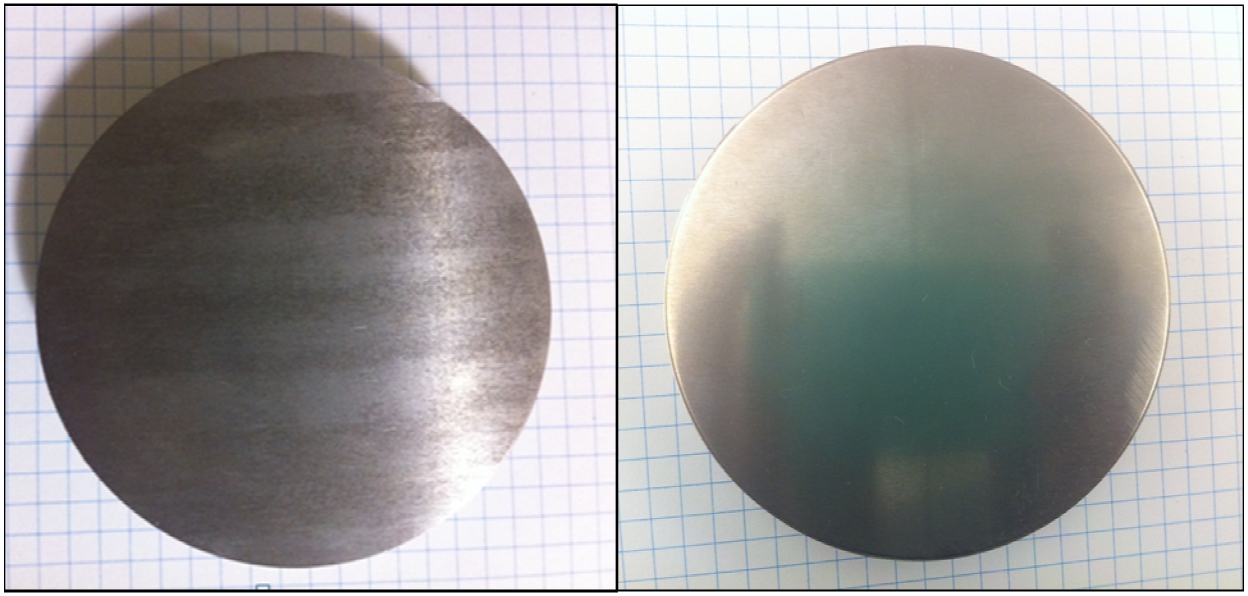
Low Plasticity Burnishing



a) LPB Process

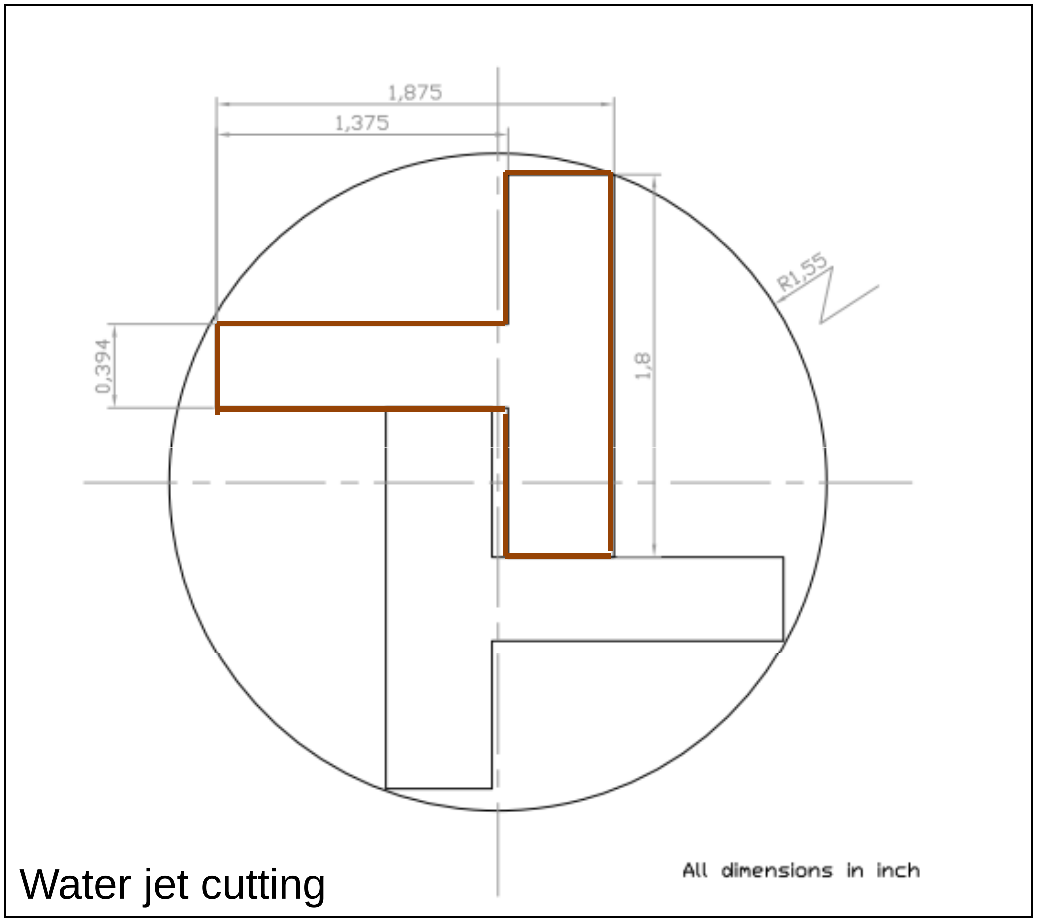
b) LPB Tool

Low Plasticity Burnishing



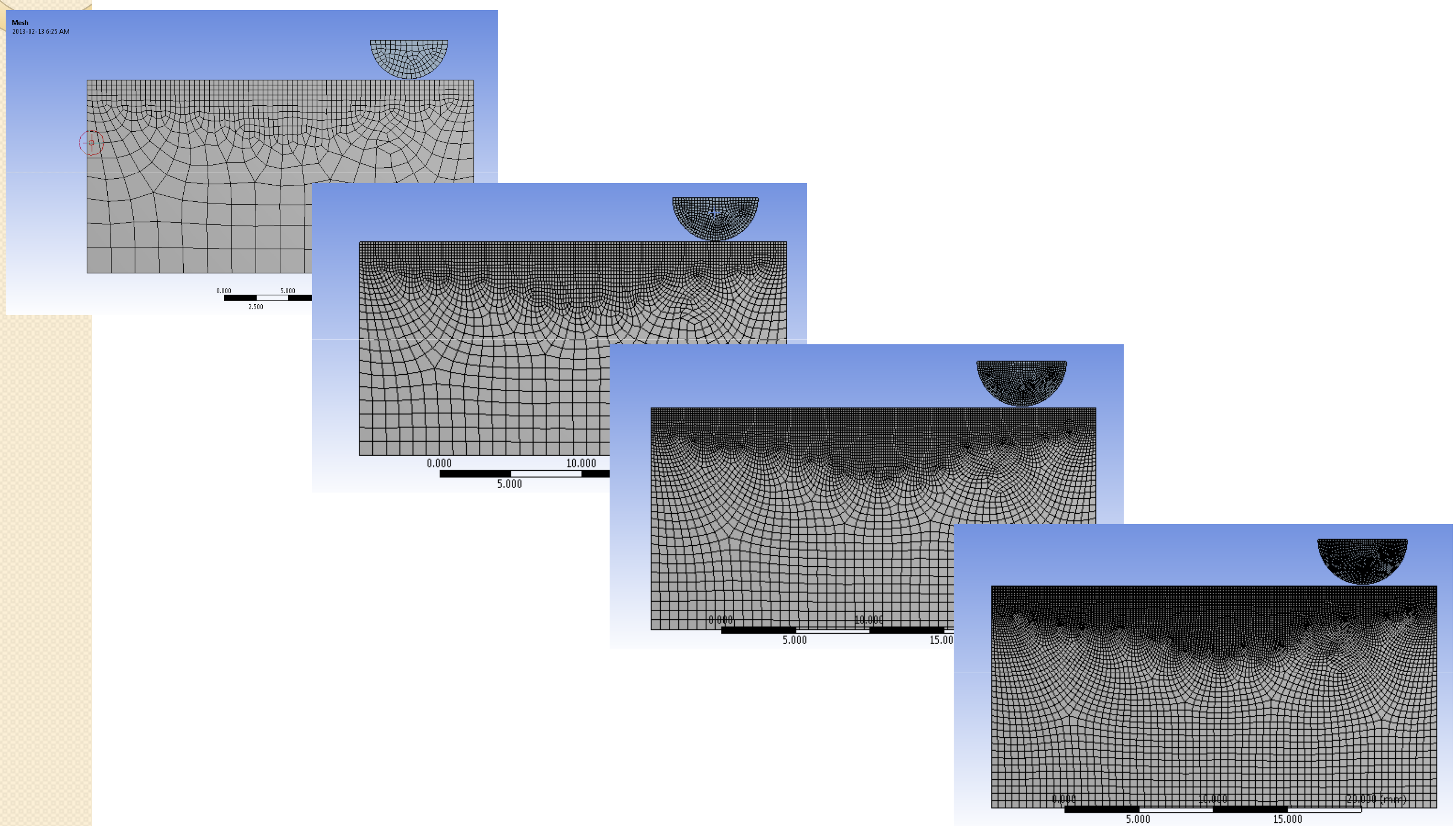
a) Ti64 disk before LPB b) Ti64 disk after LPB

Cutting Pattern of LPB Disk



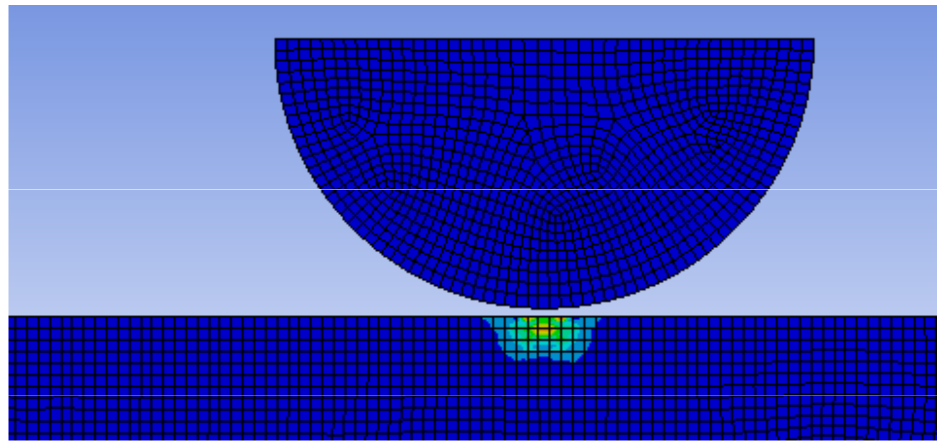
D=3.1 inch   T= 0.625 inch

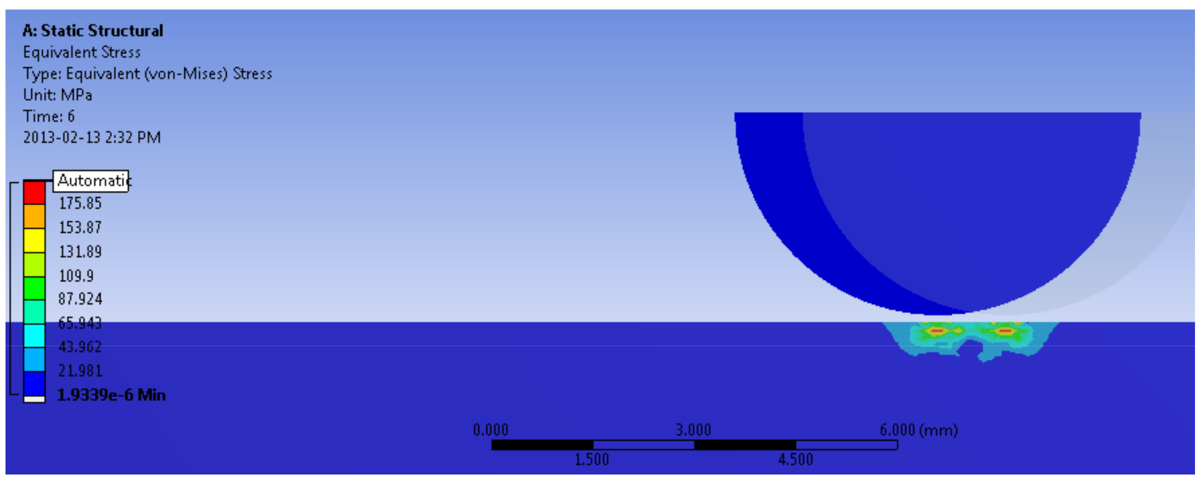
Modeling of LPB Process



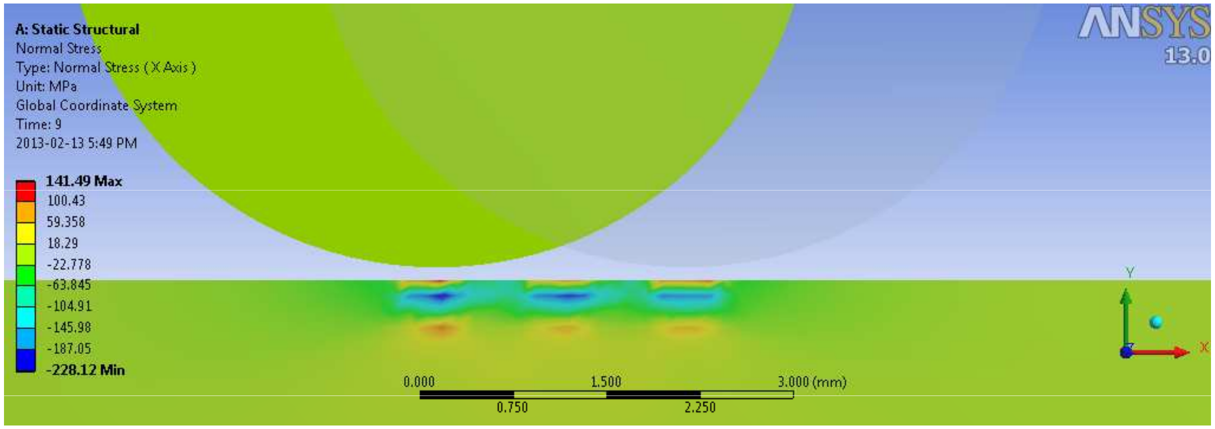
Preliminary Modeling of LPB Process

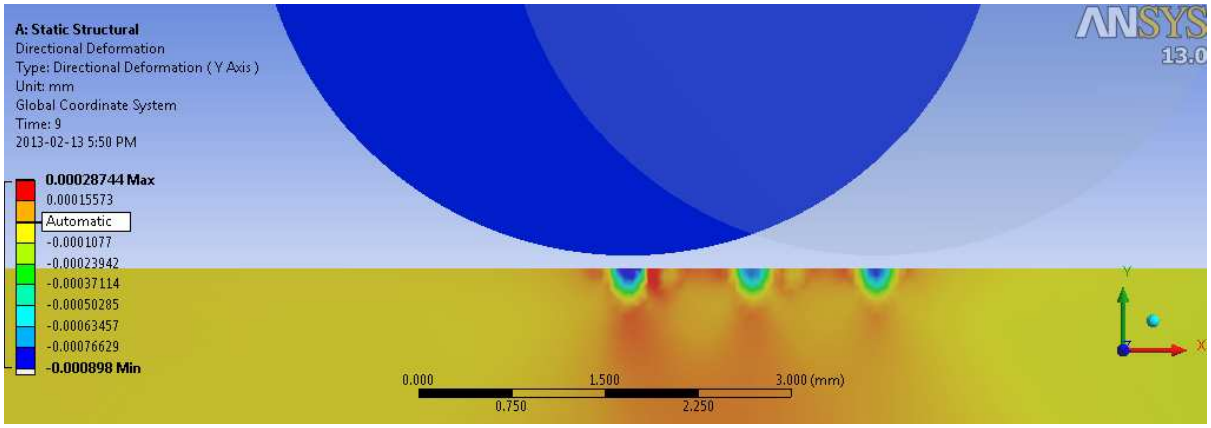
Pressure: 200Bar
Feed: 1mm/sec



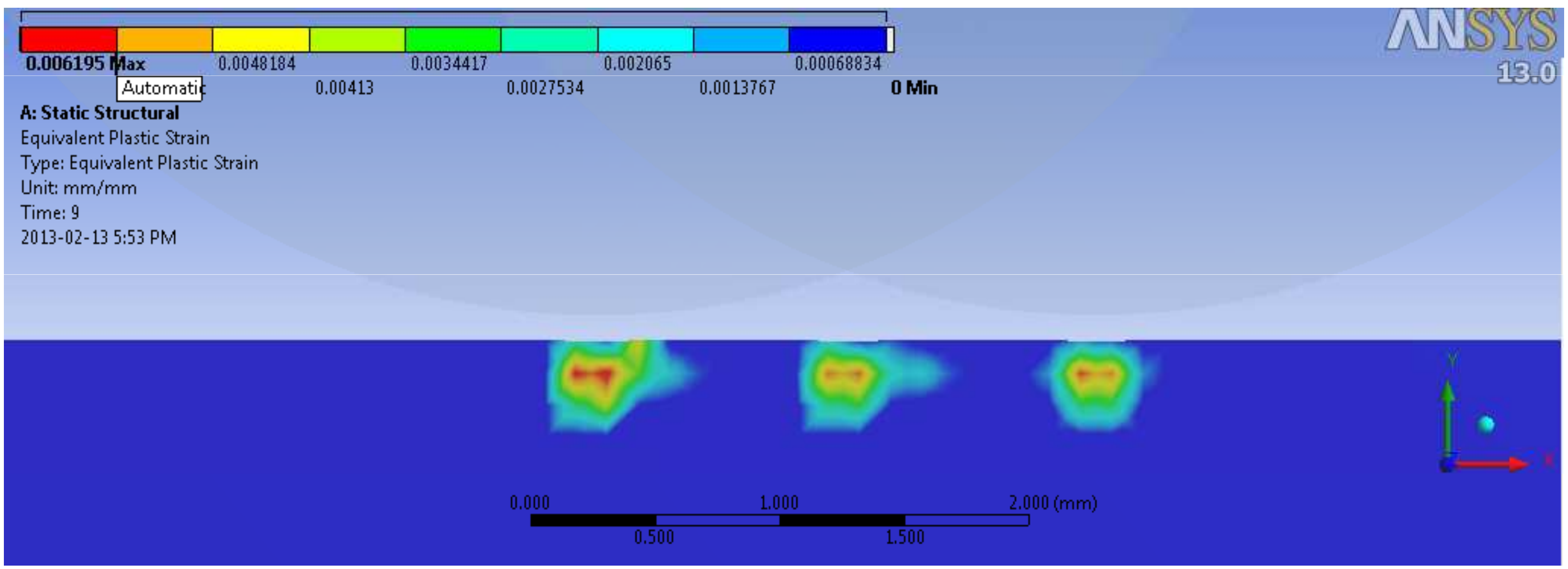


Progress of Residual Stresses during LPB

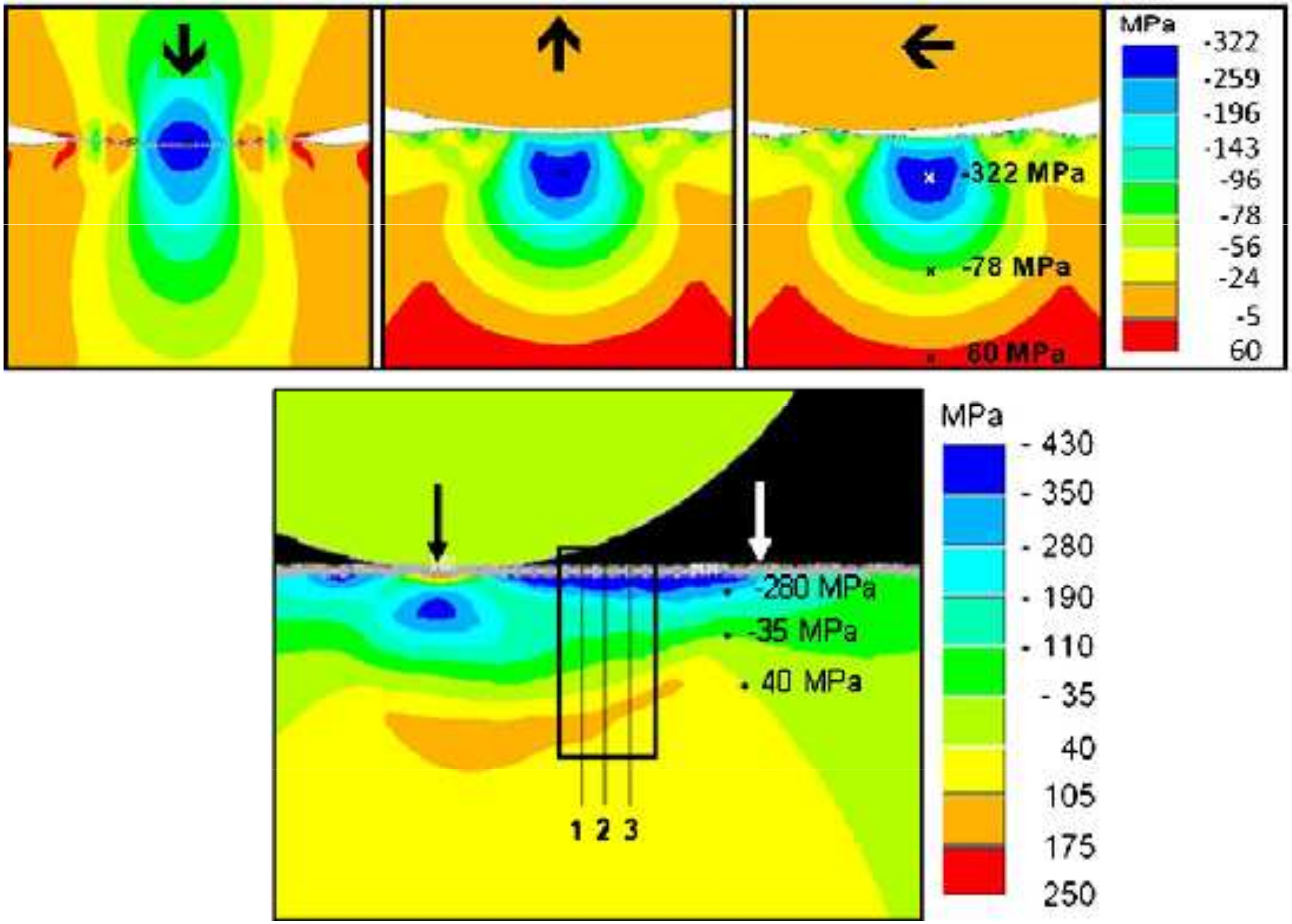




Plastic Strain

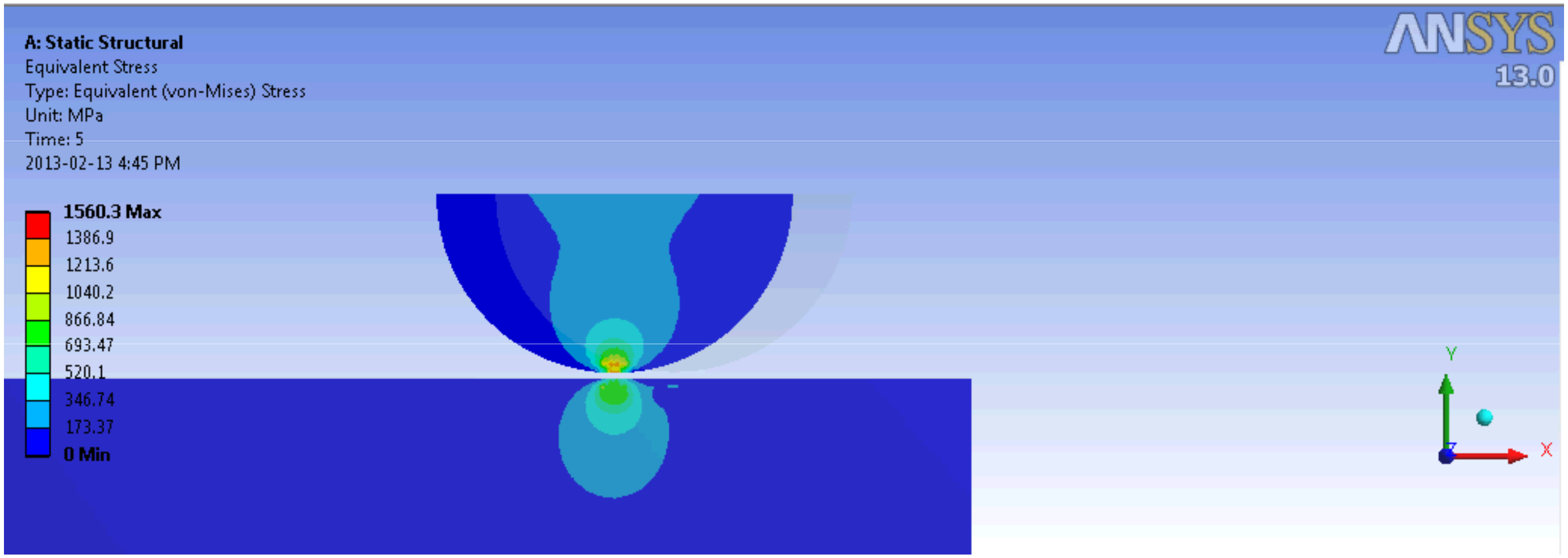


LPB modeling from Literature

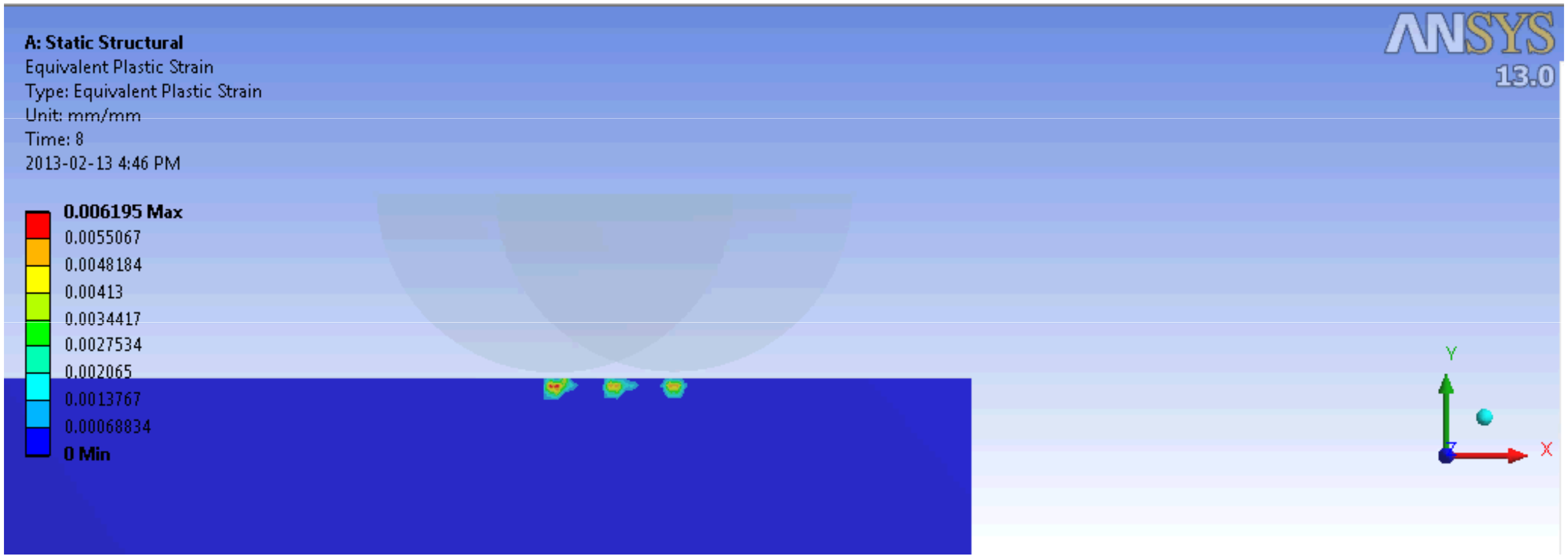


Preliminary Modeling of LPB process

Preliminary Modeling of LPB process



Preliminary Modeling of LPB process



DOE for LPB

Factors \ Levels	High(+)	Low(-)
A: Spindle Velocity(r/min)	150	75
B: Feed(mm/r)	0.20	0.06
C: No. of passes	3	1
D: Pressure(bar)	200	100

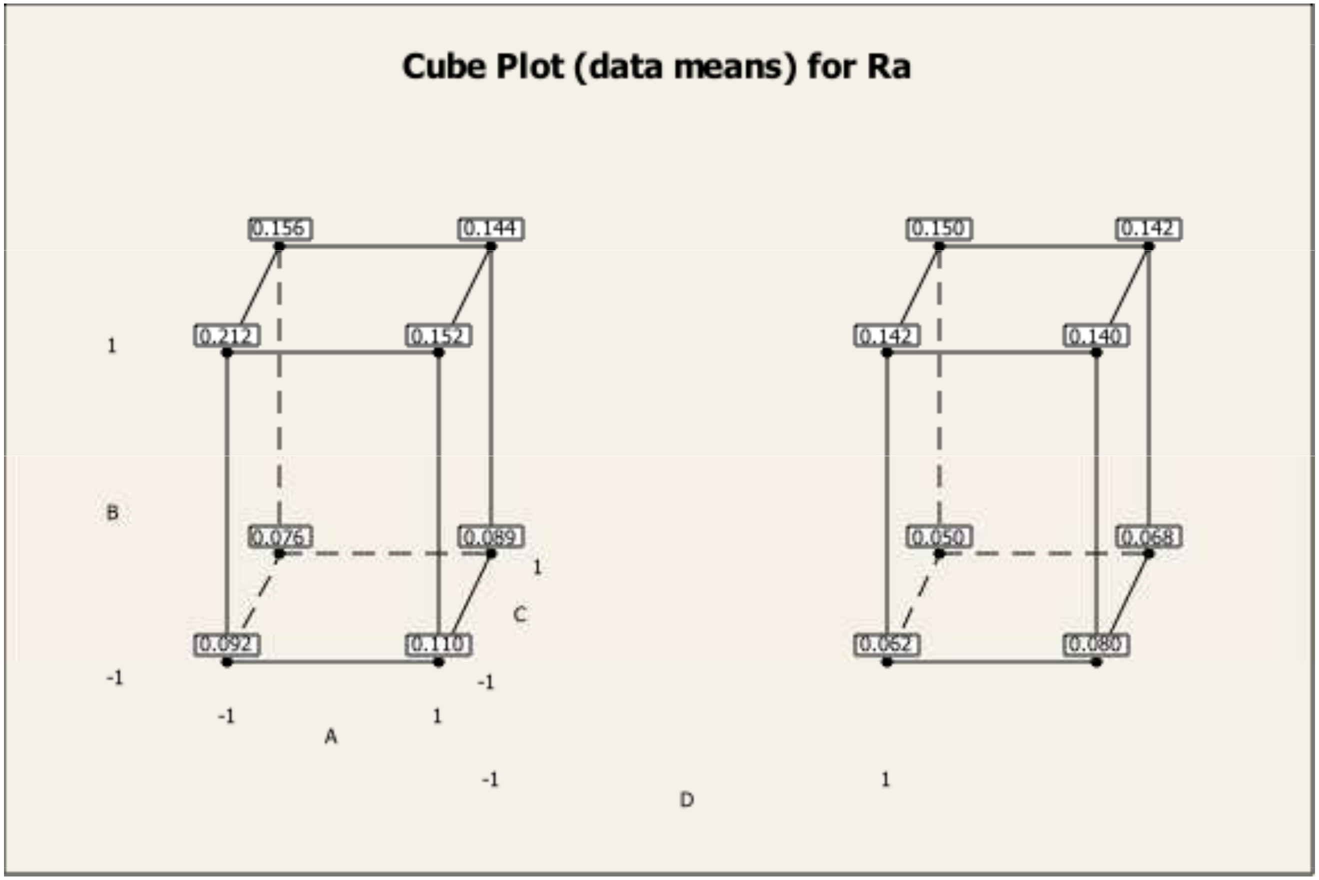
Design Table (randomized)

Run	A	B	C	D
1	+	+	-	-
2	+	-	+	-
3	+	+	+	-
4	+	-	+	+
5	+	-	-	-
6	+	+	-	+
7	+	-	-	+
8	-	+	+	+
9	-	-	-	-
10	-	-	+	+
11	+	+	+	+
12	-	+	-	-
13	-	-	+	-
14	-	+	-	+
15	-	-	-	+
16	-	+	+	-

2-level Full factorial design: 16 runs of experiments

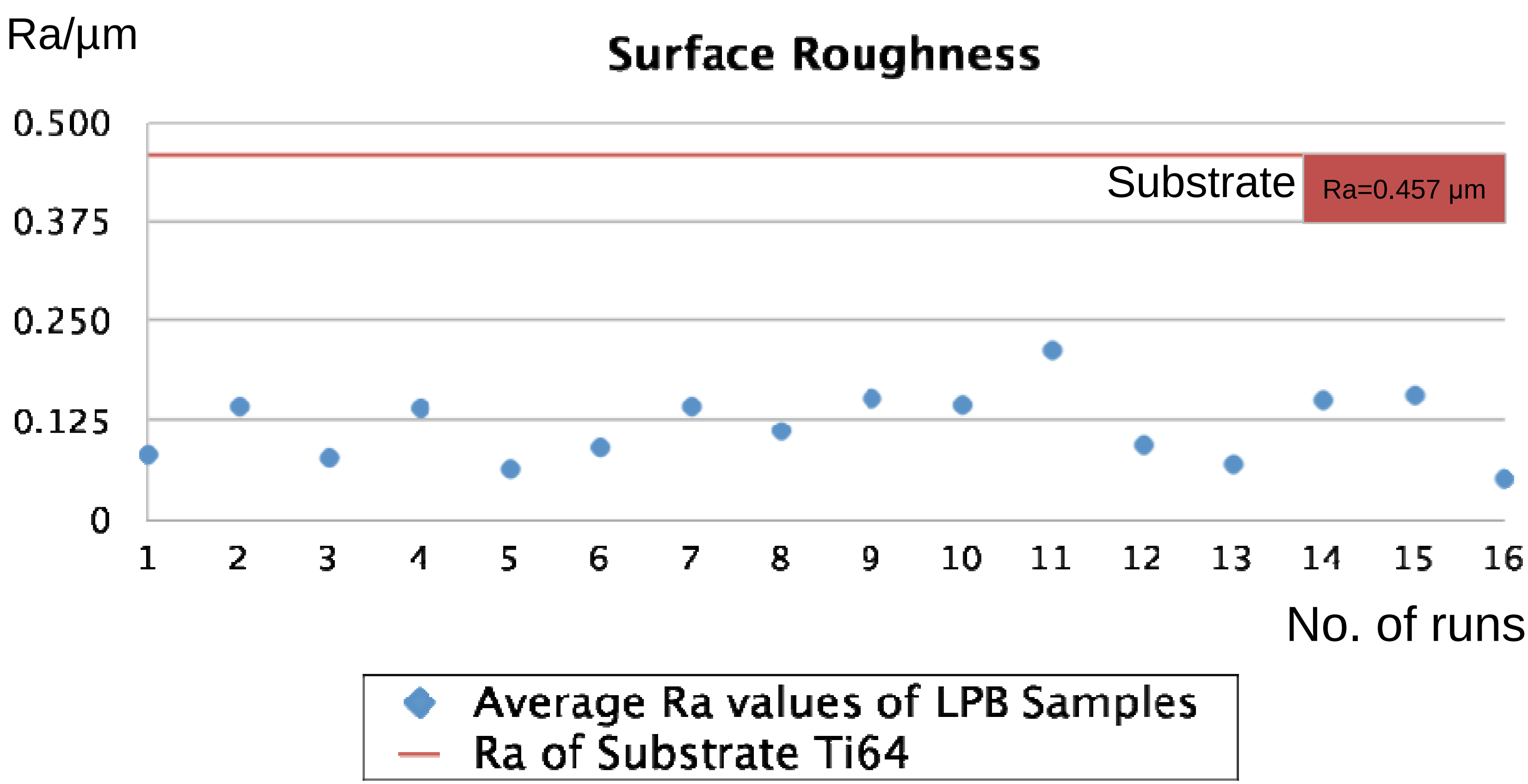
Analysing Software: Minitab

Surface Roughness(Ra)

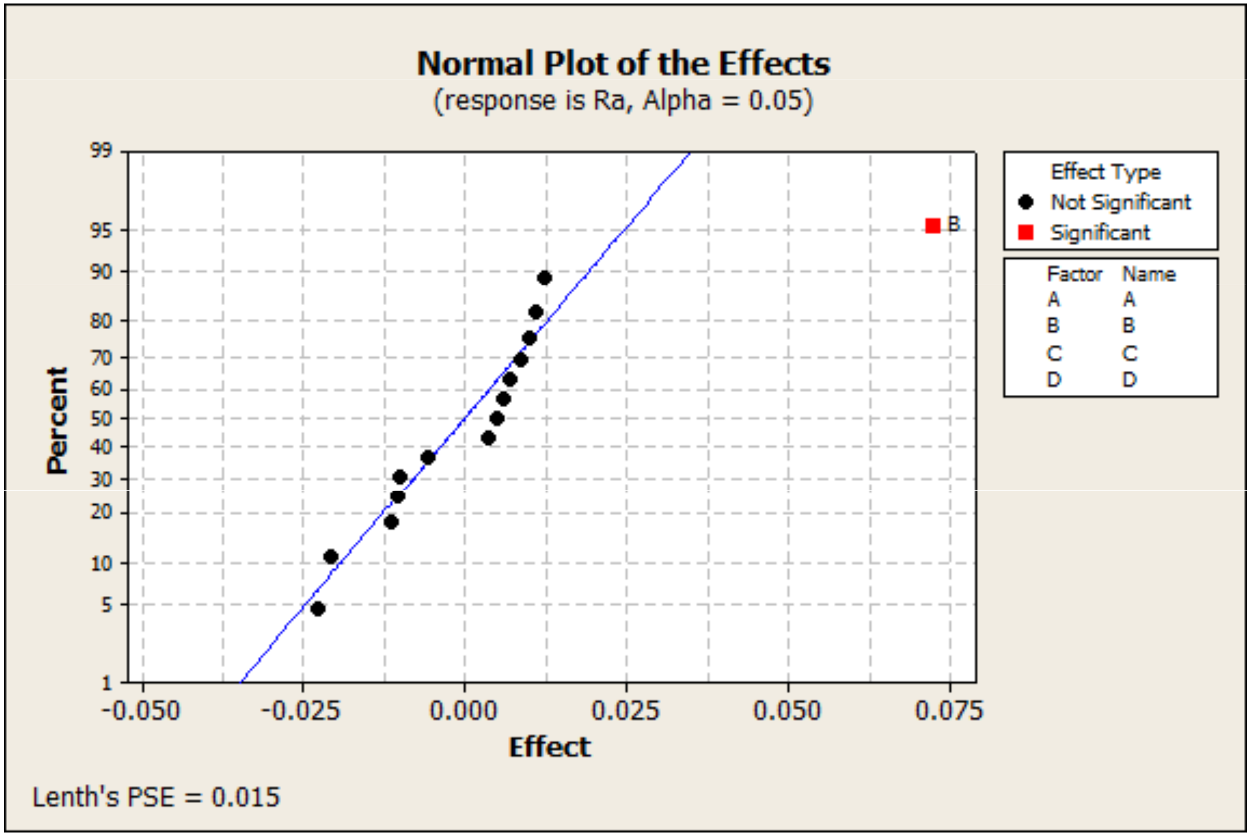


Surface roughness of the substrate: Ra = 0.326 micrometer

Surface Roughness(Ra)



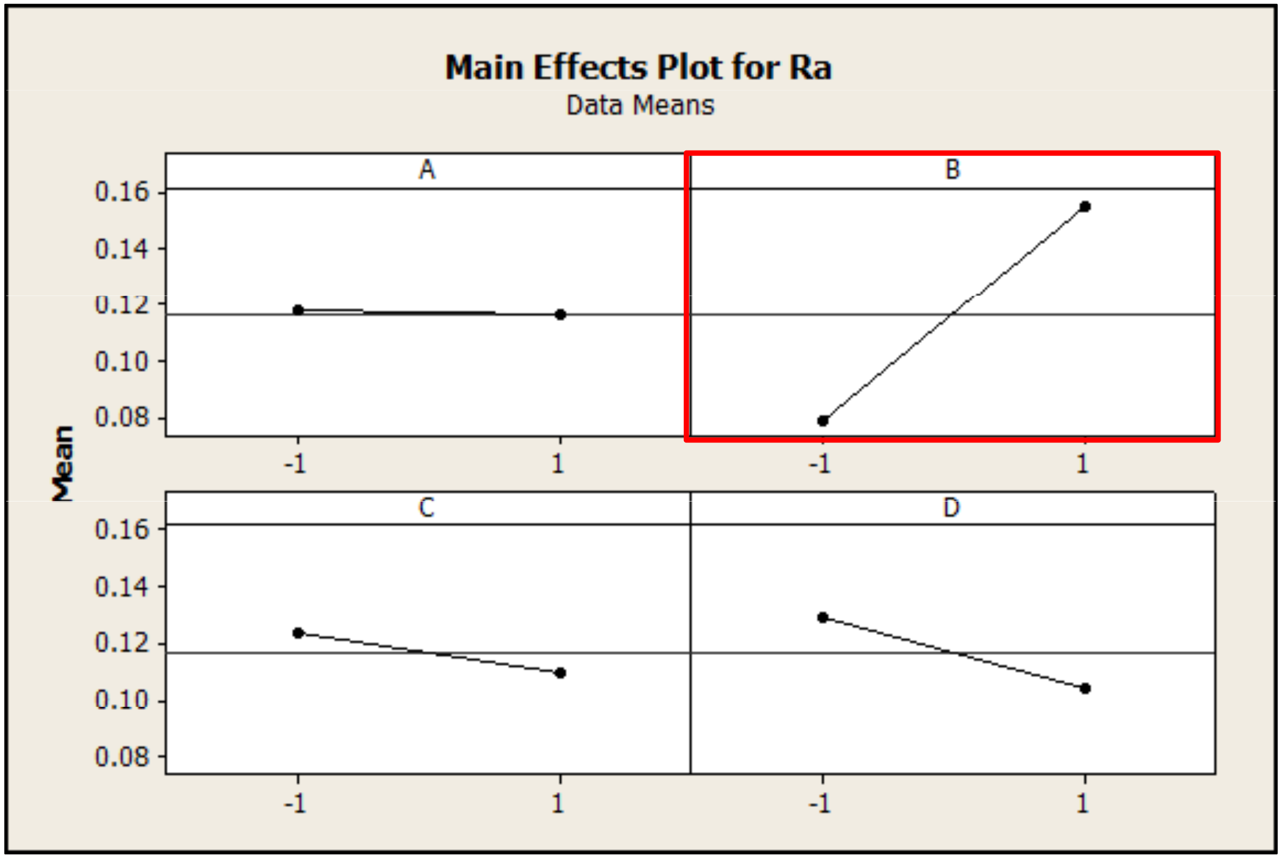
Surface Roughness(Ra)



Ra: Arithmetical Mean Roughness

A: Spindle Velocity
B: Feed
C: No. of Passes
D: Pressure

Surface Roughness(Ra)



Surface Roughness(Ra)

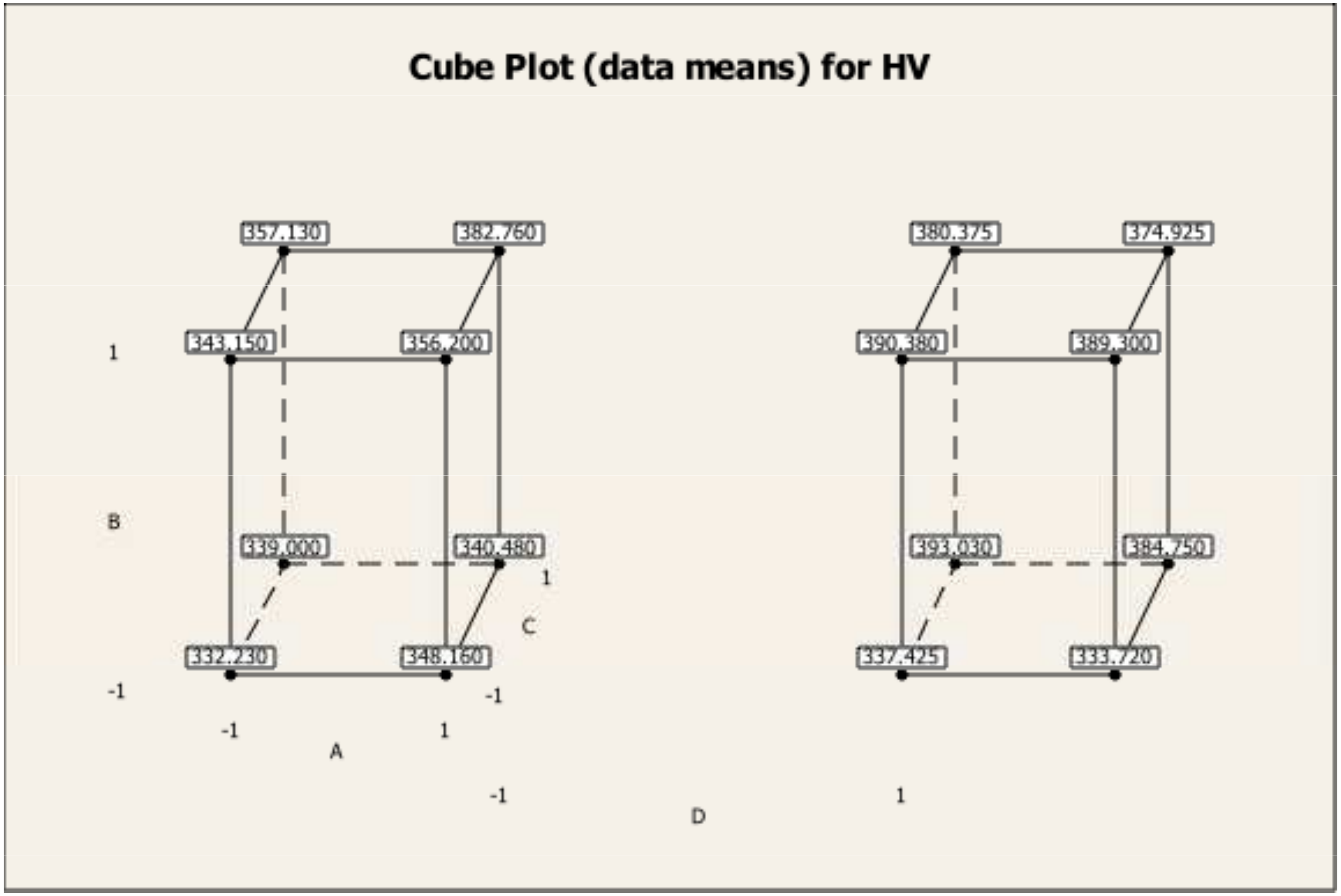
Estimated Effects and Coefficients for Ra (coded units)

Term	Effect	Coef
Constant		0.11456
A	-0.00587	-0.00294
B	0.07237	0.03619
C	-0.01038	-0.00519
D	-0.02063	-0.01031
A*B	-0.02262	-0.01131
A*C	0.00862	0.00431
A*D	0.01238	0.00619
B*C	0.00487	0.00244
B*D	0.00612	0.00306
C*D	0.00688	0.00344
A*B*C	0.00987	0.00494
A*B*D	0.01112	0.00556
A*C*D	-0.01013	-0.00506
B*C*D	0.00362	0.00181
A*B*C*D	-0.01138	-0.00569

Conclusion: In order to have a much smoother surface, it's better to set the feed at the low level.

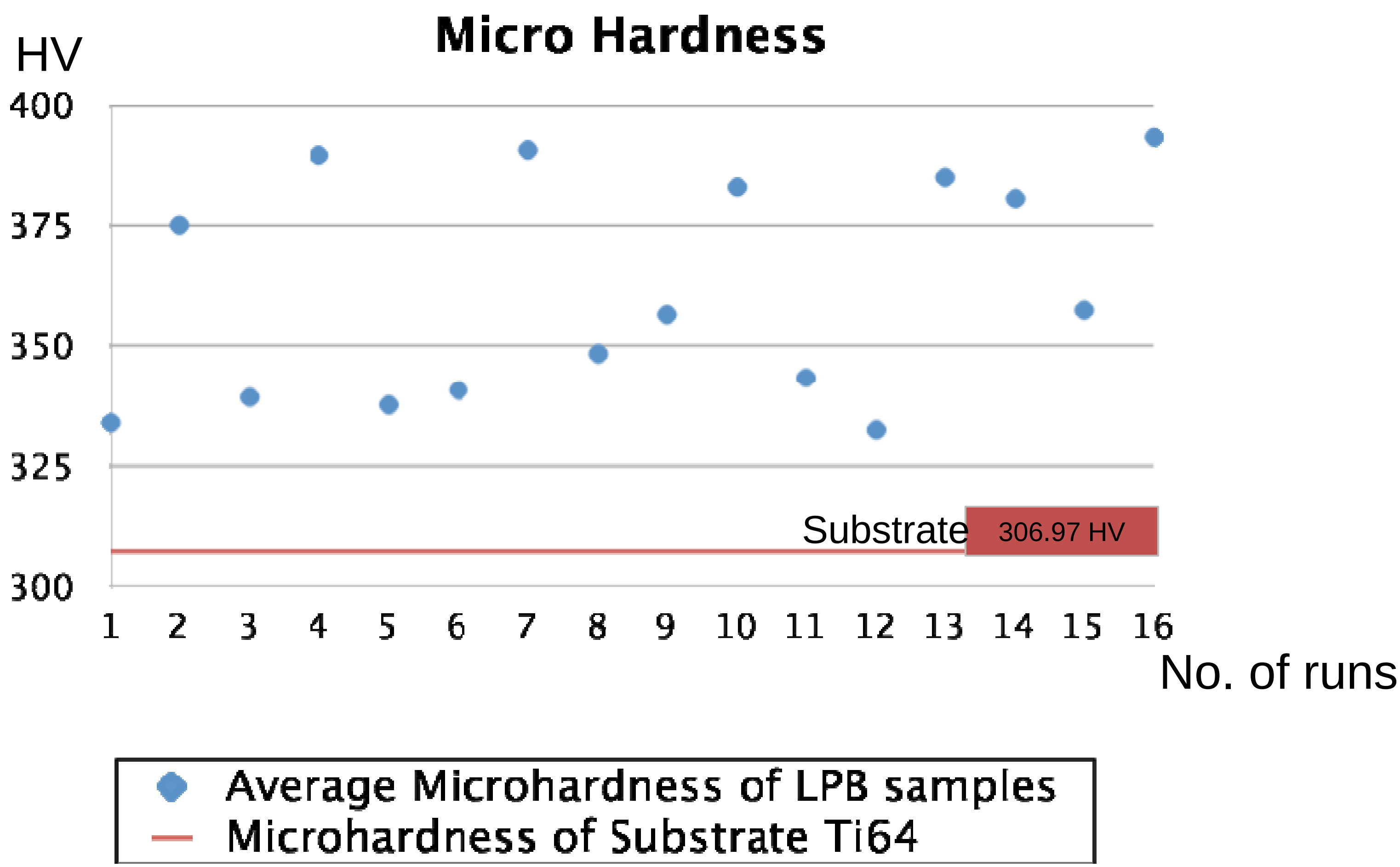
FEED ↓ → **RA** ↓

Microhardness(HV)

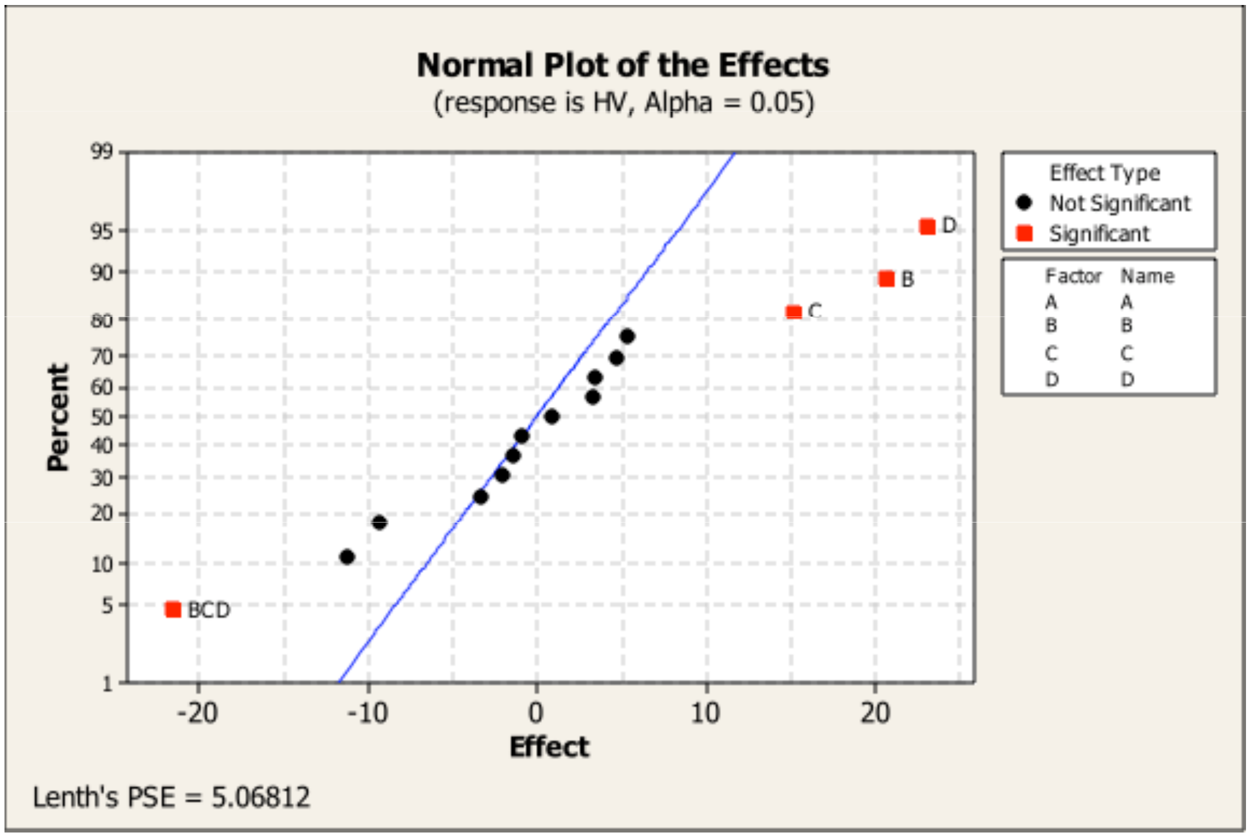


Surface hardness of the substrate: 300.317HV

Microhardness(HV)



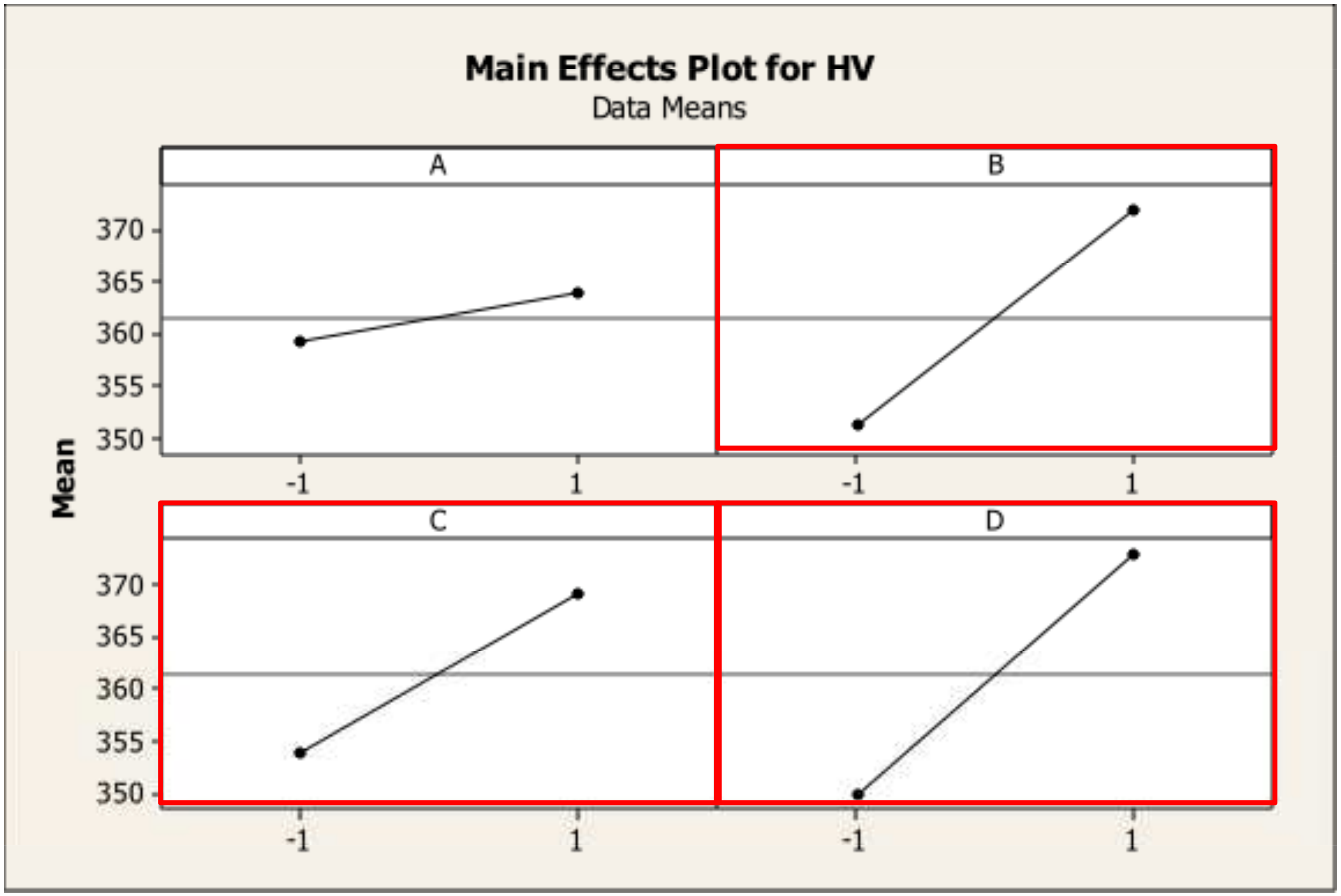
Microhardness(HV)



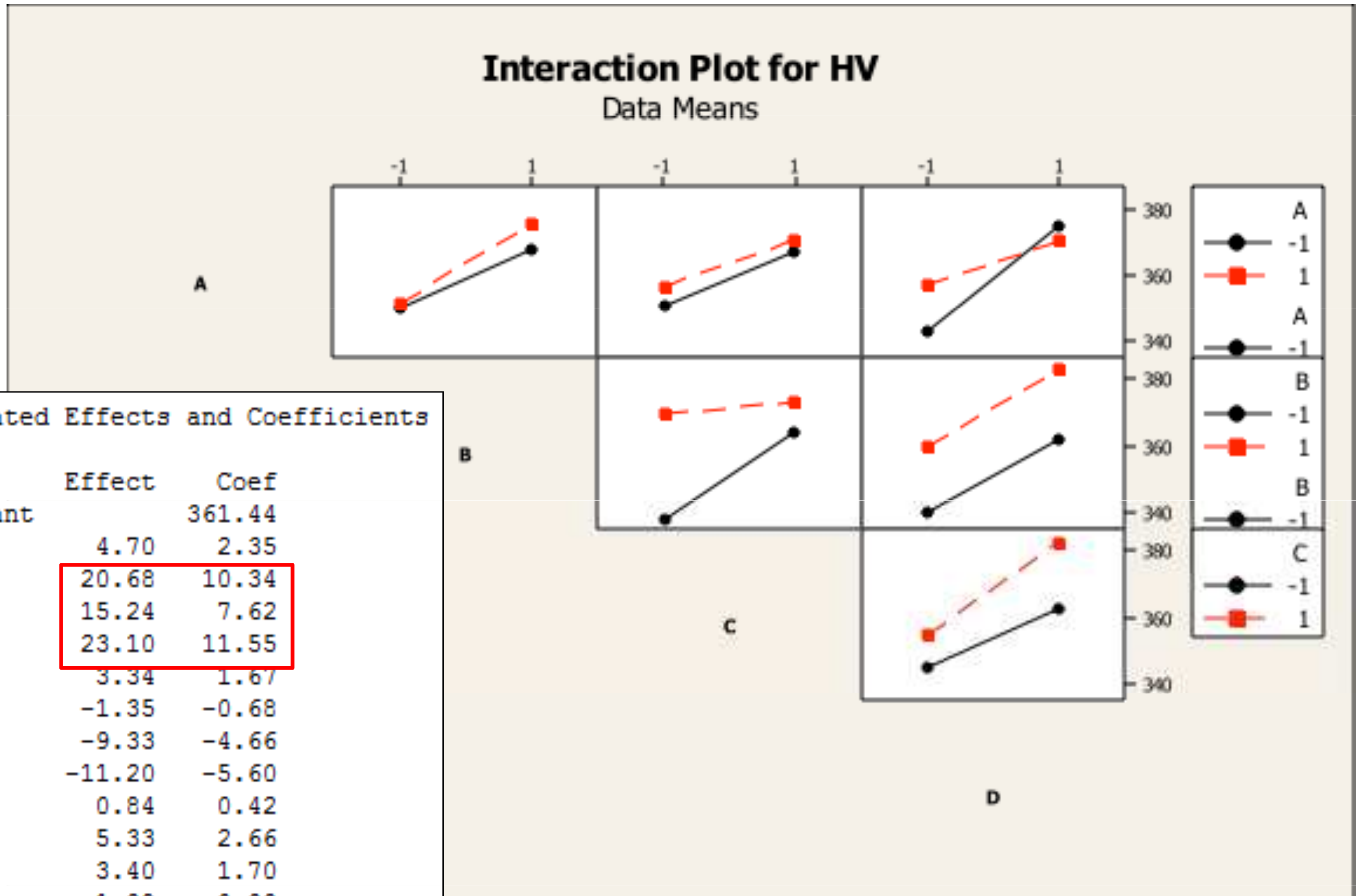
Vickers Hardness Parameters: Load: 50g ; Time: 15s

A: Spindle Velocity B: Feed C: No. of Passes D: Pressure

Microhardness(HV)



Microhardness(HV)



Estimated Effects and Coefficients

Term	Effect	Coef
Constant		361.44
A	4.70	2.35
B	20.68	10.34
C	15.24	7.62
D	23.10	11.55
A*B	3.34	1.67
A*C	-1.35	-0.68
A*D	-9.33	-4.66
B*C	-11.20	-5.60
B*D	0.84	0.42
C*D	5.33	2.66
A*B*C	3.40	1.70
A*B*D	-1.98	-0.99
A*C*D	-0.88	-0.44
B*C*D	-21.56	-10.78
A*B*C*D	-3.35	-1.68

Residual Stress Measurement

Incremental Center Hole-Drilling Method

- Combined with Strain Gage
- Combined with Digital Image Correlation

Hole-Drilling Strain Gage Method

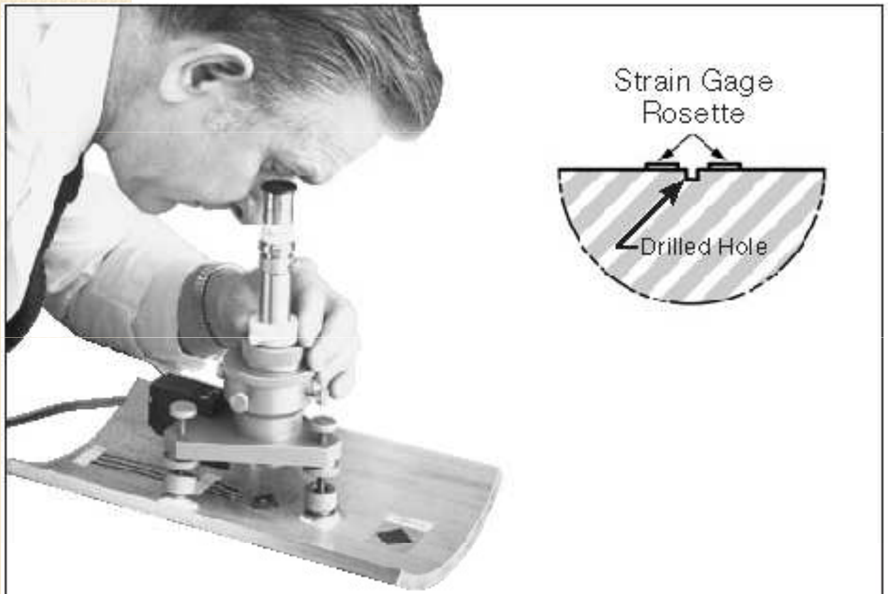
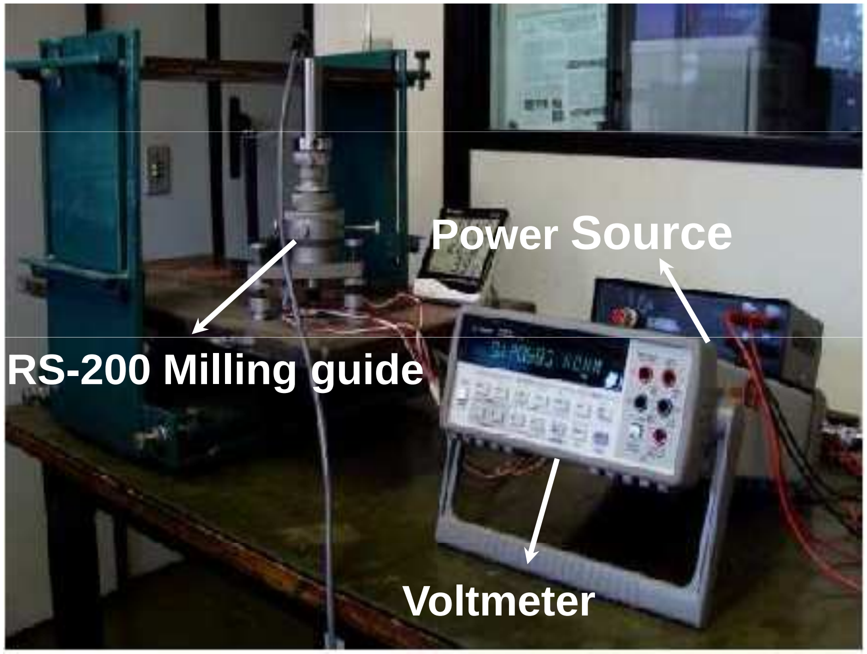


Figure 1. Hole-Drilling Strain Gage Method



Hole-Drilling Strain Gage Method

$$\varepsilon = \frac{\Delta R / R}{K}$$

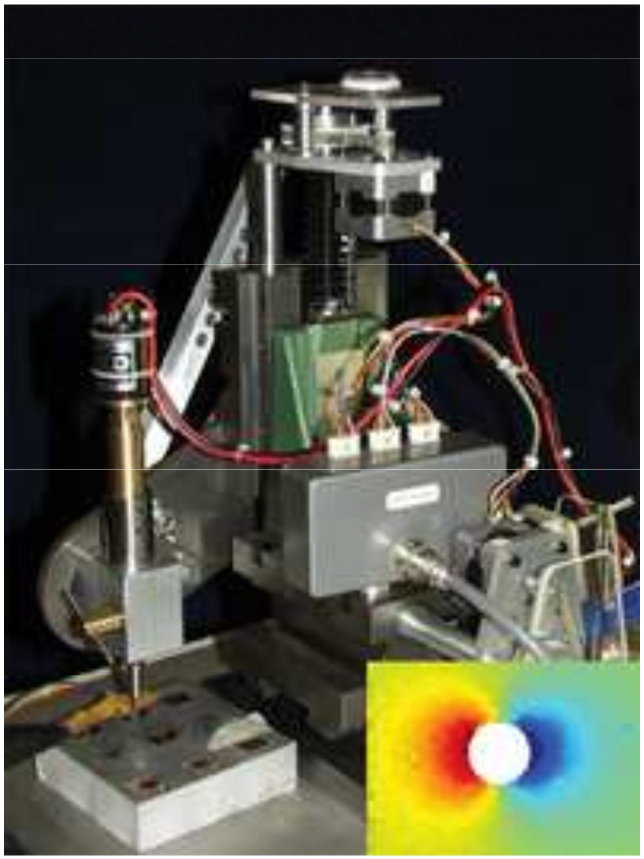
Where:

$\Delta R = R_f - R_i$ (Ohm) for each drilling increment;

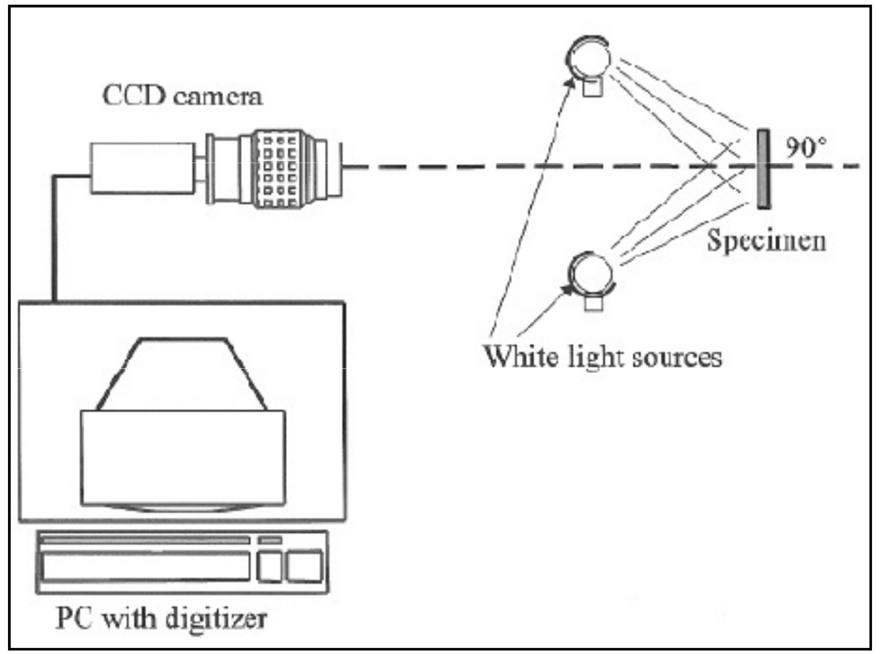
R_i is the reading of the resistance strain gage before the first drilling increment;

R_f is the reading of resistance strain gages for each drilling increment.

Incremental hole-drilling combined with DIC



NPL, in partnership with Airbus, AWE, Stresscraft,British Energy and LA Vision has demonstrated the world's first application of using DIC for the measurement of residual stress with the incremental hole drilling technique.



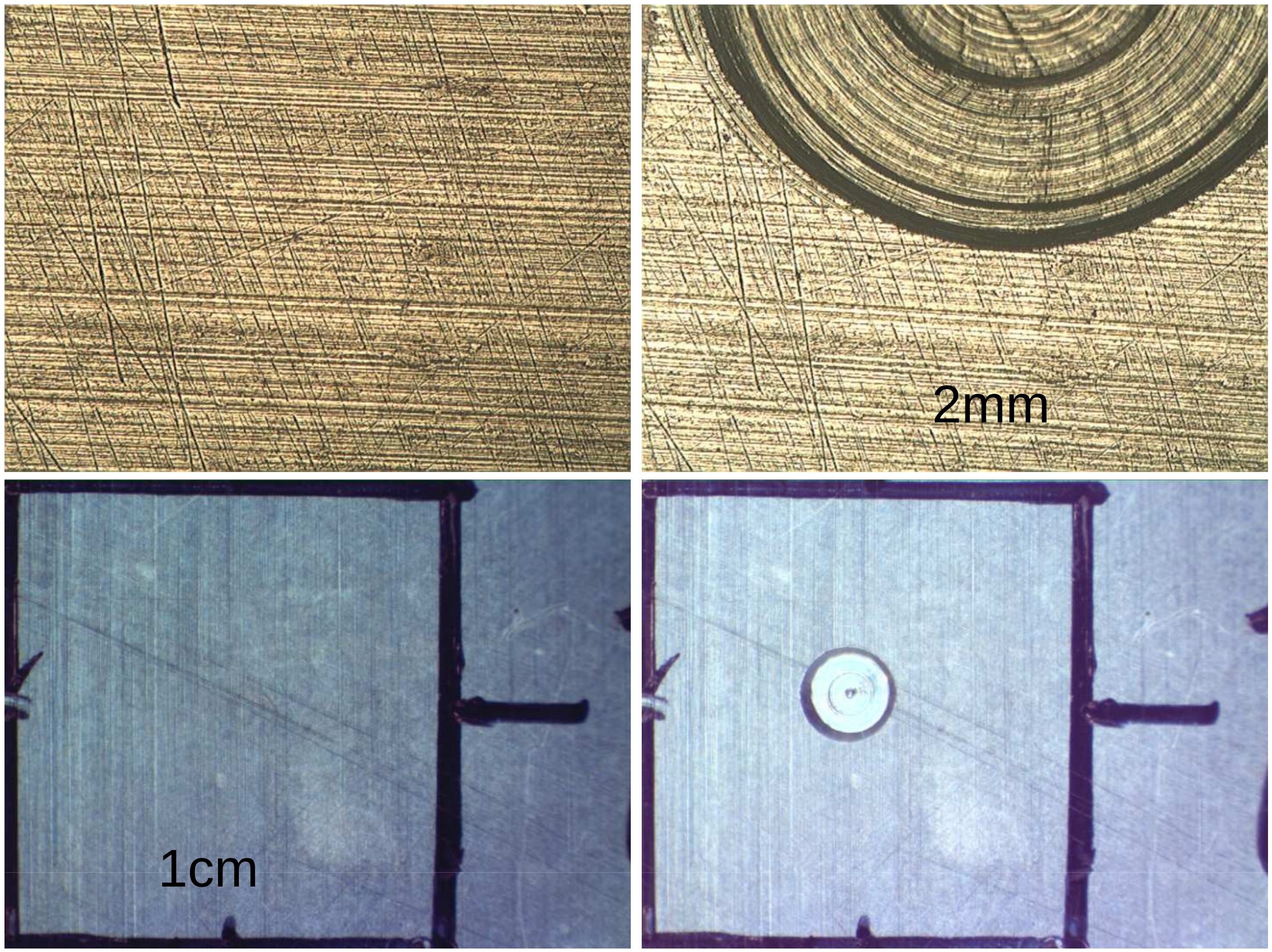
Schematic arrangement used for 2-D Digital Image Correlation (from Sutton et al.)

Incremental hole-drilling combined with DIC

Before drilling | After drilling

#1

#2



Features of Strain Gauge and Optical Measurements

Strain Gauge Measurements	Optical Measurements
• Moderate equipment cost, high per-measurement cost	• High equipment cost, moderate per-measurement cost
• Significant preparation and measurement time	• Preparation and measurement time can be short
• Small number of very accurate and reliable measurements	• Large number of moderately accurate and reliable measurements
• Stress calculations are relatively compact	• Stress calculations can get quite large
• Modest capabilities for data averaging and self-consistency checking	• Extensive capabilities for data averaging and self-consistency checking
• Relatively rugged, suitable for field use	• Delicate, more suited to lab use
• Sensitive to hole-eccentricity errors	• Hole eccentricity can be corrected

Incremental Center Hole-Drilling Method

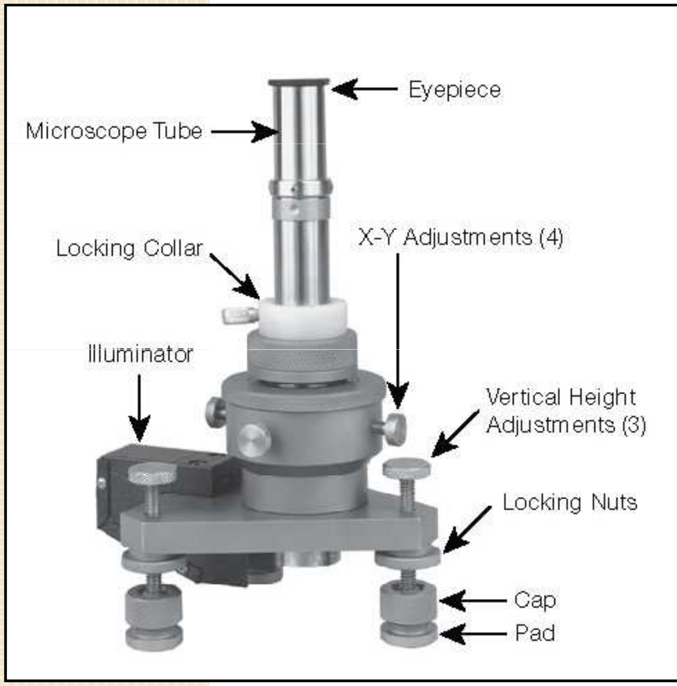
- **Challenges:**

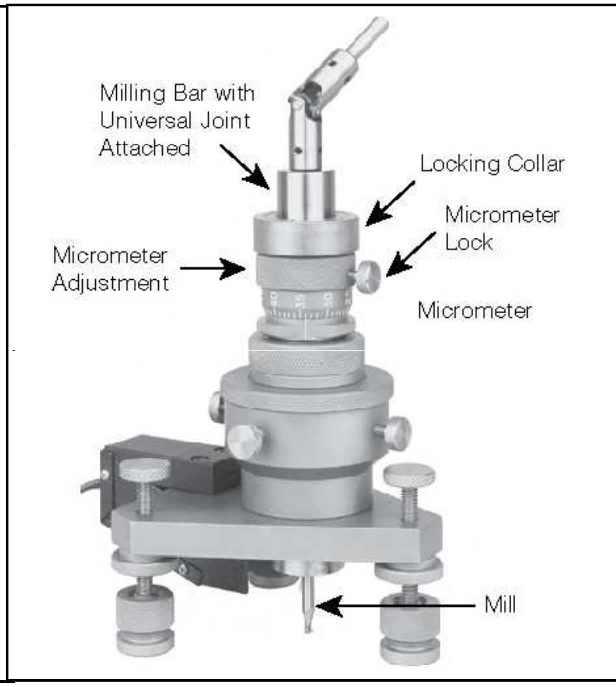
➢ High speed(up to 400000rpm) drilling should be used for Ti64 alloy.

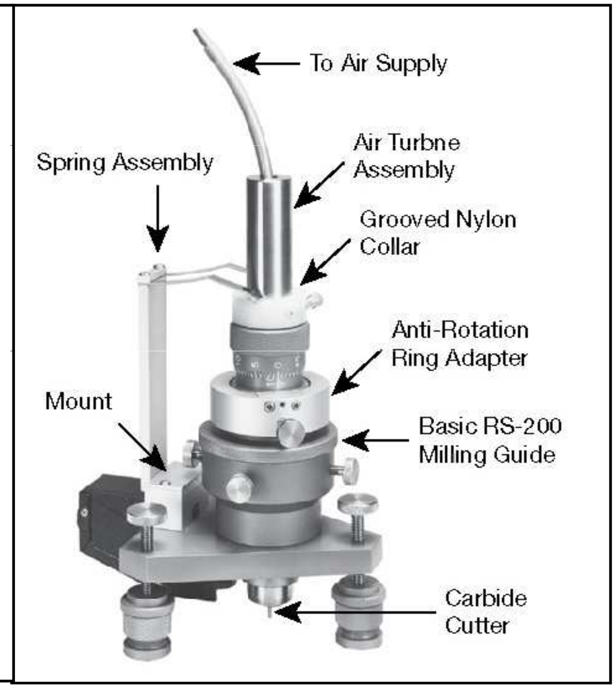
➢ Strain gage measurement result is sensitive to hole-eccentricity errors.

➢ The testing specimen should not be moved from the camera during the hole-drilling DIC process.

Incremental Center Hole-Drilling Euipment







Vishay Company

Water Erosion Rig Test

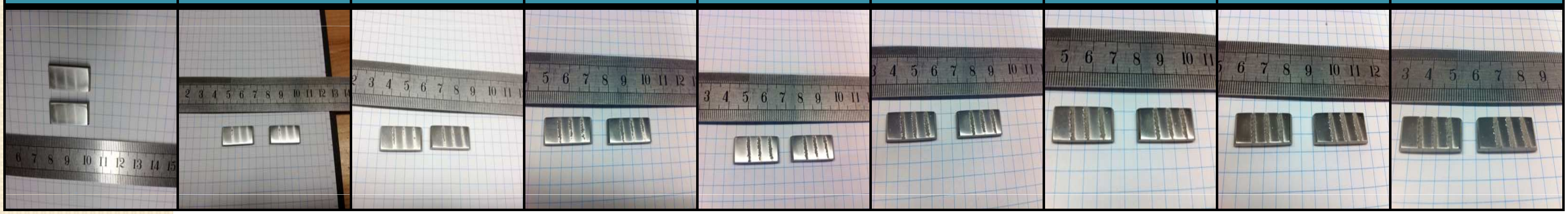
Progress:

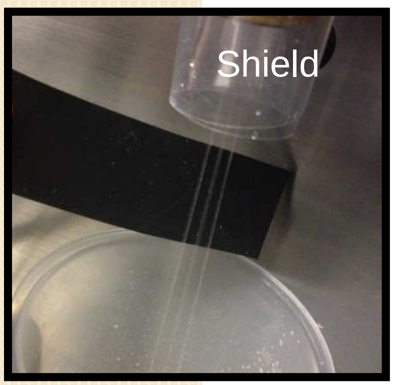
- Set up preliminary test with 400μm nozzle(3 orifices and 1 orifice).
- Investigated the effect of the rig parameters.
- Constructed the preliminary LIE stage curve of the substrate Ti64.
- LIE surface and erosion mechanism study.

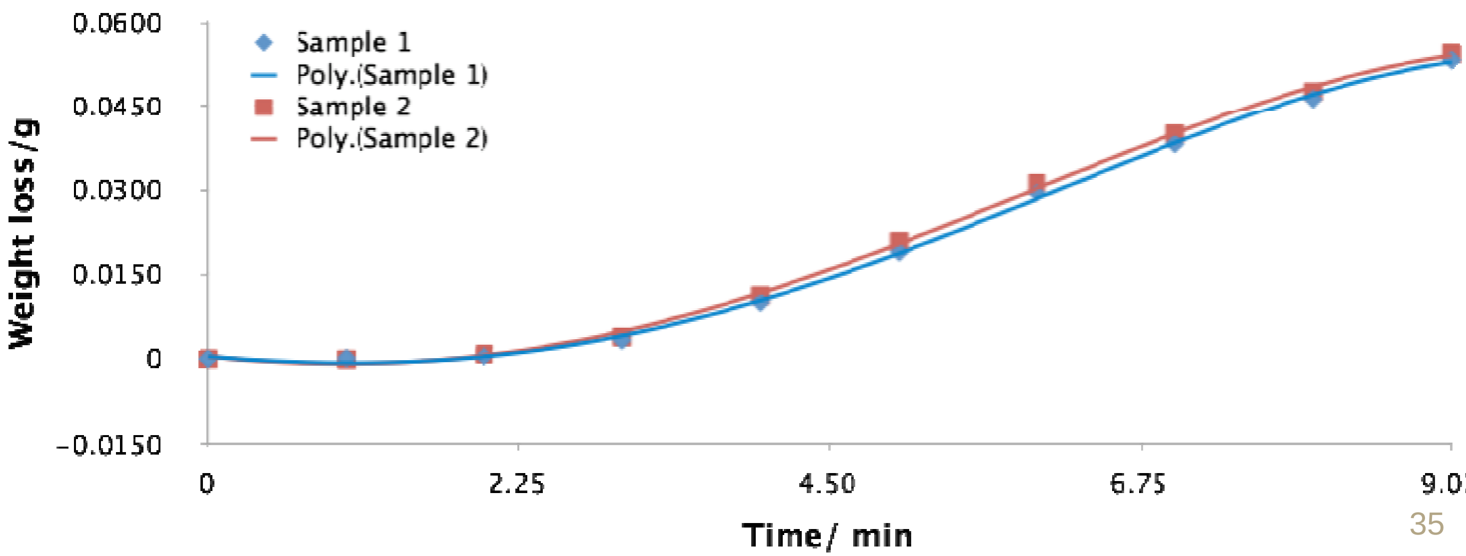
Water Erosion Rig Test(3 orifices)

Preliminary LIE stage curve of substrate Ti64(400μm nozzle)

1min	2mins	3mins	4mins	5mins	6mins	7mins	8mins	9mins

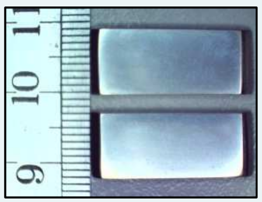
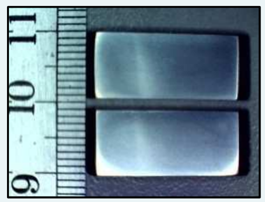
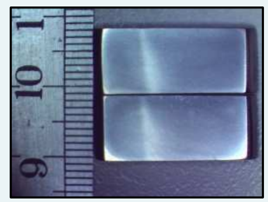
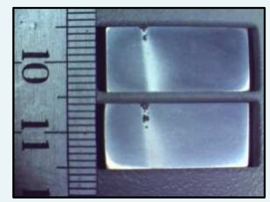
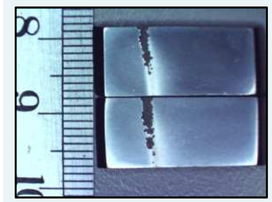
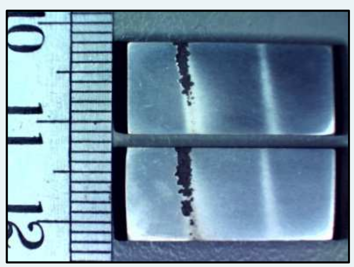
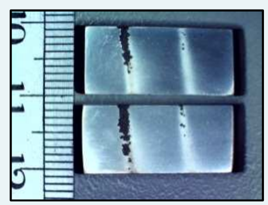






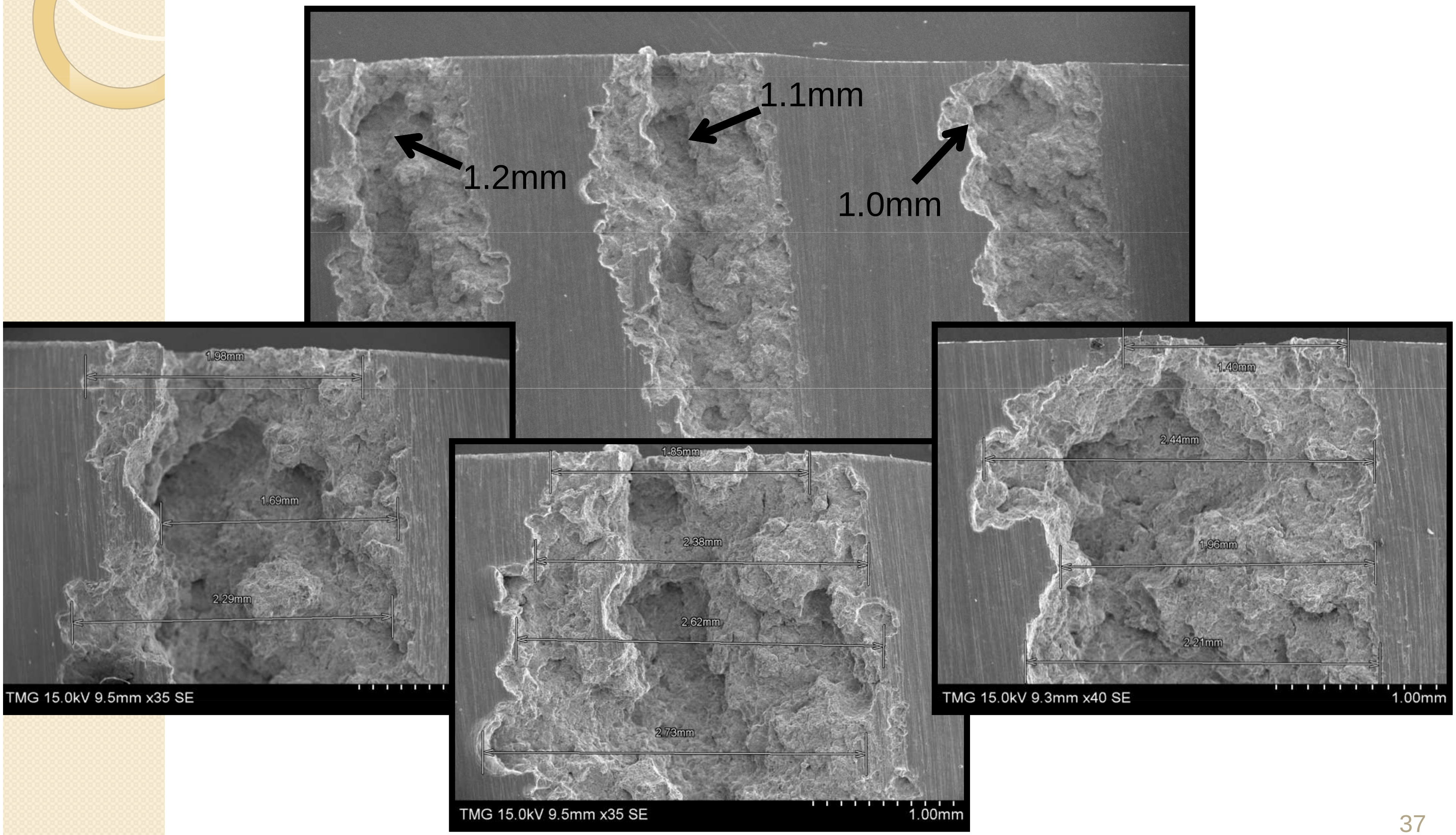
Water Erosion Rig Test (1 orifice)

Pressure: 20psi   Flow rate: 0.02~0.03L/min
Nozzle size: 400μm Droplet size: 497μm
Distance between the nozzle and the sample: 50mm

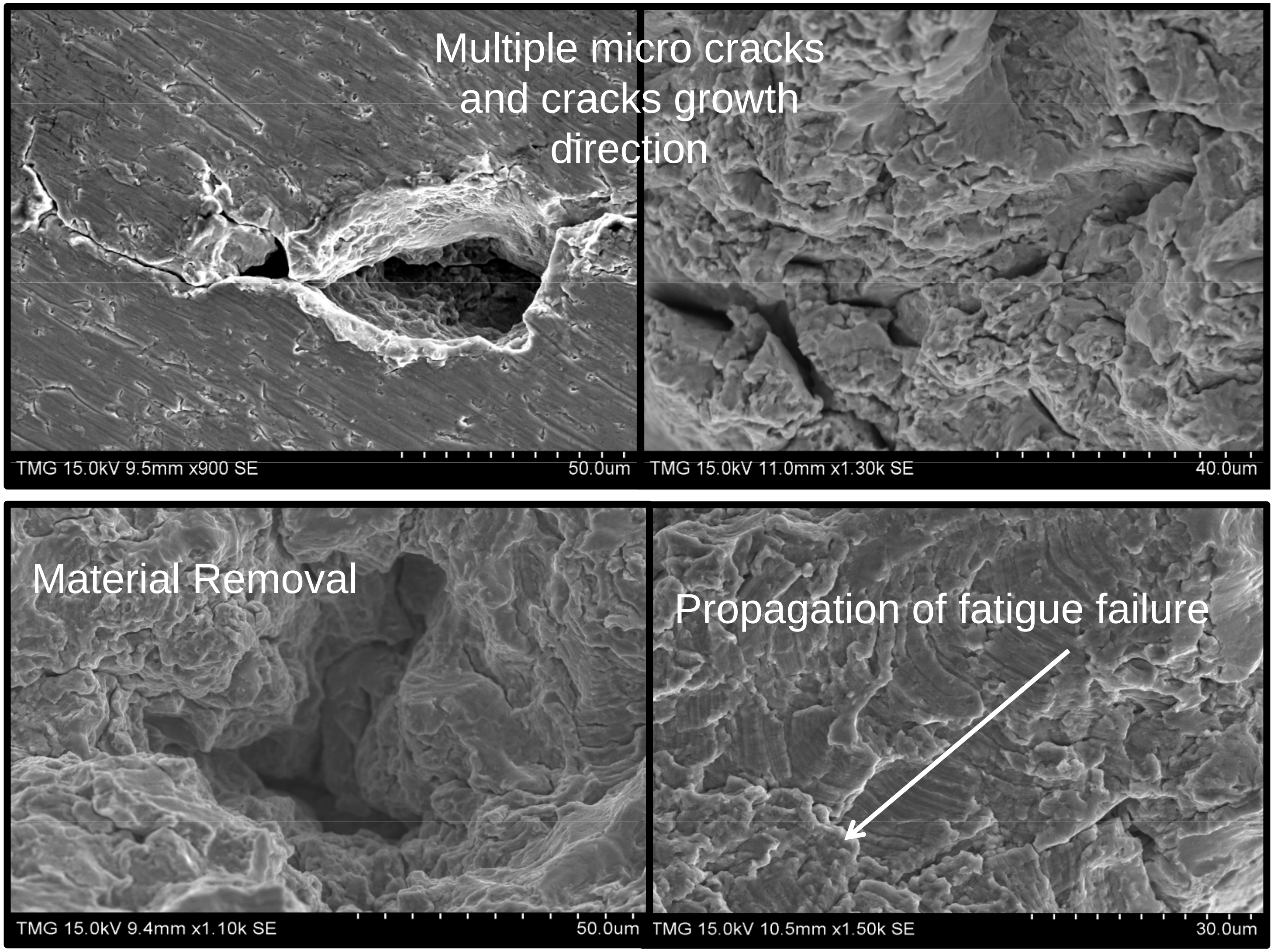
Time	30s	90s	150s	270s	390s
Before rotation					
After rotation					

The purpose of this test: To investigate the effect of different placement of the nozzle(by rotating the nozzle with one side orifice open 180 degree) to the erosion pattern.

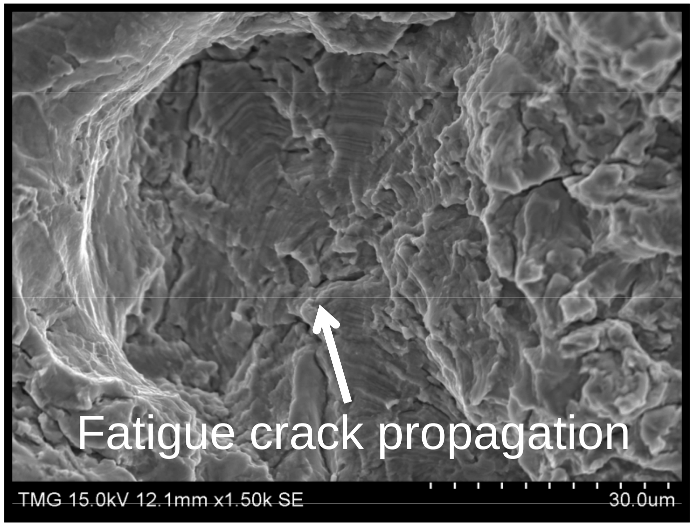
LIE Surface SEM Study

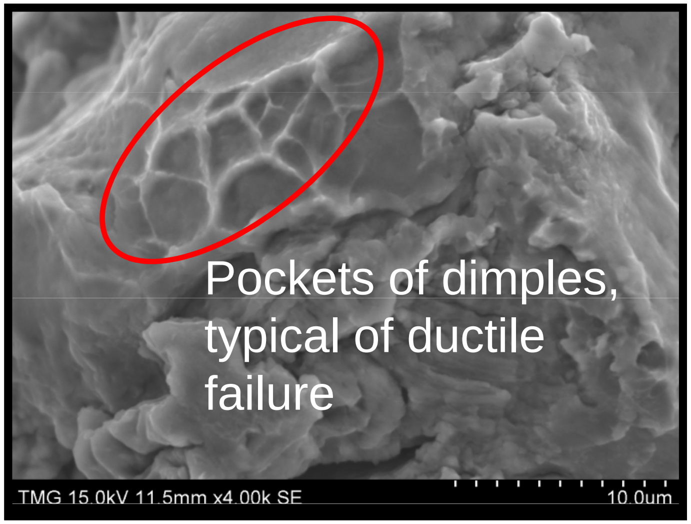


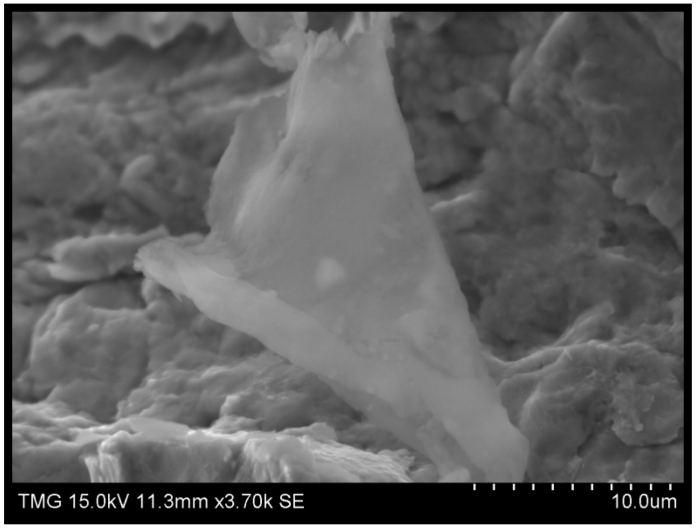
LIE Mechanism

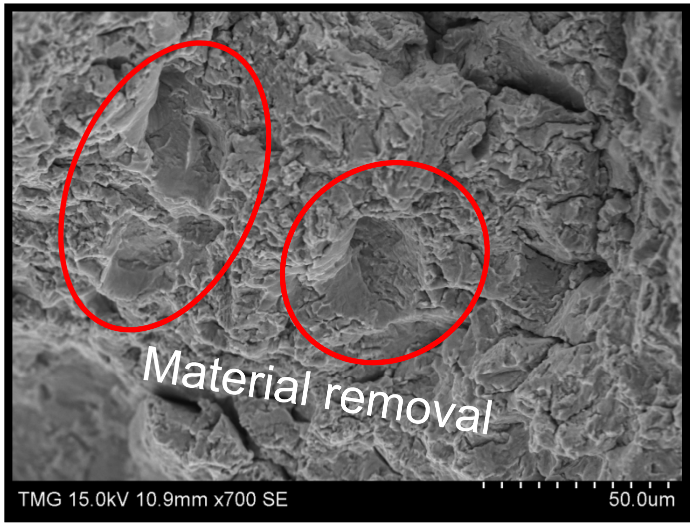


LIE Mechanism









Future Work…

- Cutting the LPB disks into T-shaped samples(water jet cutting).
- Residual stress measurements for LPB samples.
- Based on the analysis done by DOE(Minitab), get the optimized parameters.
- Confirm the results done by DOE with experimental work.

THANKS