The Effects of Top of Rail Materials and Rail Grinding on Head Hardened Rail

Presented by

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Background

- Previous research
  - Hardwick/Sheffield
  - Previous research indicated that using some products may have adverse effects on the rail, revenue service experience with these TOR materials did not typically manifest the previous results
- One more layer of real world approach
  - Class I railroads grind rail.
    - Would this mitigate crack propagation due to hydro-pressurization build up?

Test Outline

Part 1: → 1500 MPa
400 RPM
-1% Slip → 4000 Cycles Dry → 21000 Cycles Lubricated

Part 2: → Simulated Grind Cycle → 1500 MPa
400 RPM
-1% Slip → 210,000 Cycles Lubricated (No “dry” cycles)

TOR Friction Modifier Materials		
Water	Water Based TOR	Synthetic TOR
(1) - 1 Drop/second (0.53 ml/min)	0.05 ml/min	0.05 ml/min
(~0.497 g/min)	~0.046 g/min	0.038 g/min
(2) - Low Flow Rate (0.05 ml/min)	~0.055 g/ 500 cycles	~0.048 g/ 500 cycles
(~0.044 g/min)		

RCF Initialization

- Rolling Contact Fatigue
  - Reproduce the conditions of Hardwick at University of Sheffield
  - Sample geometry and twin disc machine parameters are modified to allow increased contact pressures and rotational speed
  - Close control of slip ratio (creepage) and applied loads (contact pressure)
  - Lubrication is applied after a dry cycle break in period

- 1500 MPa contact pressure where:

$$P_{max} = \frac{2F}{\pi a L}$$

- F is the Force set point
- a is contact patch dimension
- L is the contact length

- -1% slip ratio (i.e. $V_{Wheel} > V_{Rail}$) where:

$$\frac{Slip\ Ratio}{100\%} = \frac{2 \times (V_{Rail} - V_{Wheel})}{V_{Rail} + V_{Wheel}}$$

- V_{Rail} is the rail surface velocity
- V_{Wheel} is the wheel surface velocity

Test Materials

Rail Sample

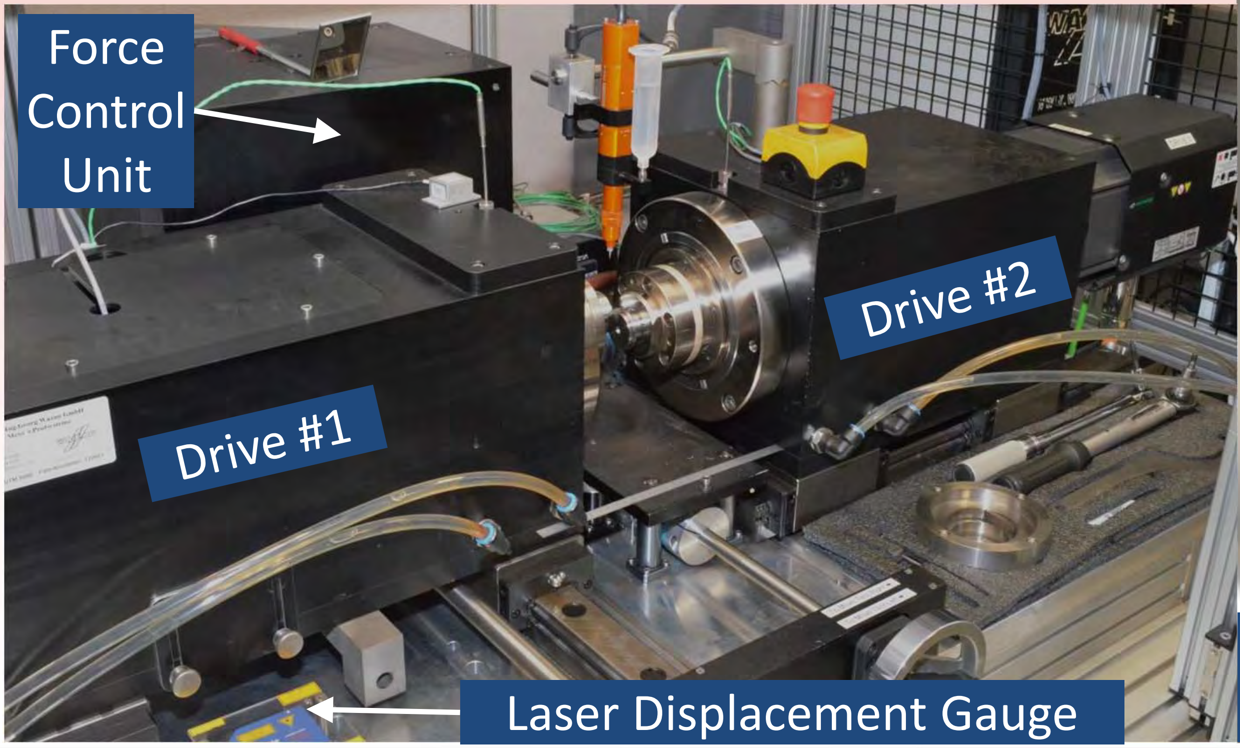
Head Hardened
Rail: ~400 HB
∅ = 45 mm
3.5 mm length

Wheel Surrogate

Head Hardened IH
Rail ~360 HB
∅ = 46.2 mm
20 mm length

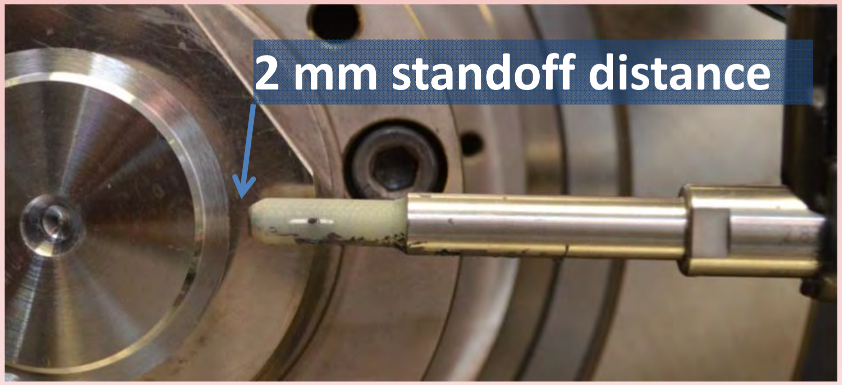
Wazau UTM 5000

- 5000 N Force Capacity
- 50 N-m Torque Capacity
- 3000 RPM, independent drive spindles
- *in-situ* eddy current
- Lubrication “drip” system - flow rate control

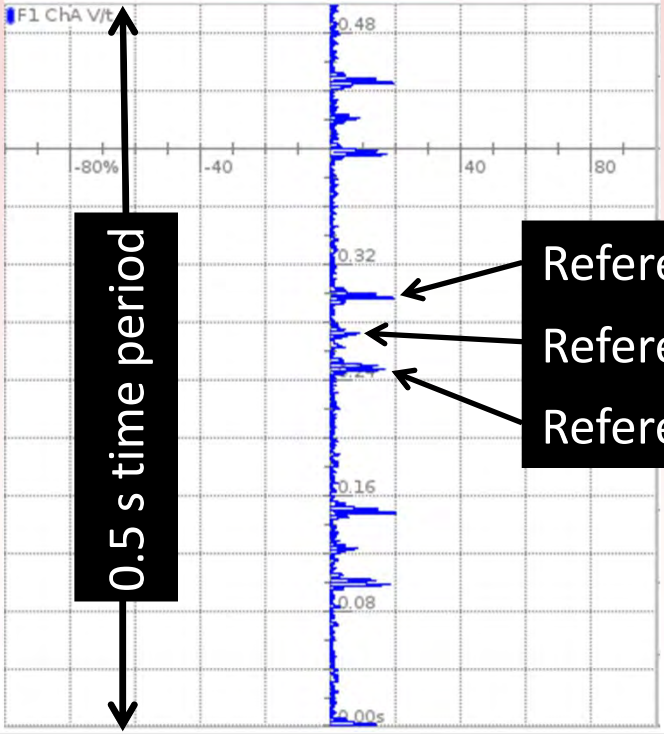


Eddy Current

- Constant Position for duration of test
- Calibrated against reference sample
  - 3 EDM reference flaws
  - 0.5 mm, perpendicular



2 mm standoff distance



0.5 s time period

Reference Flaw #1

Reference Flaw #2

Reference Flaw #3

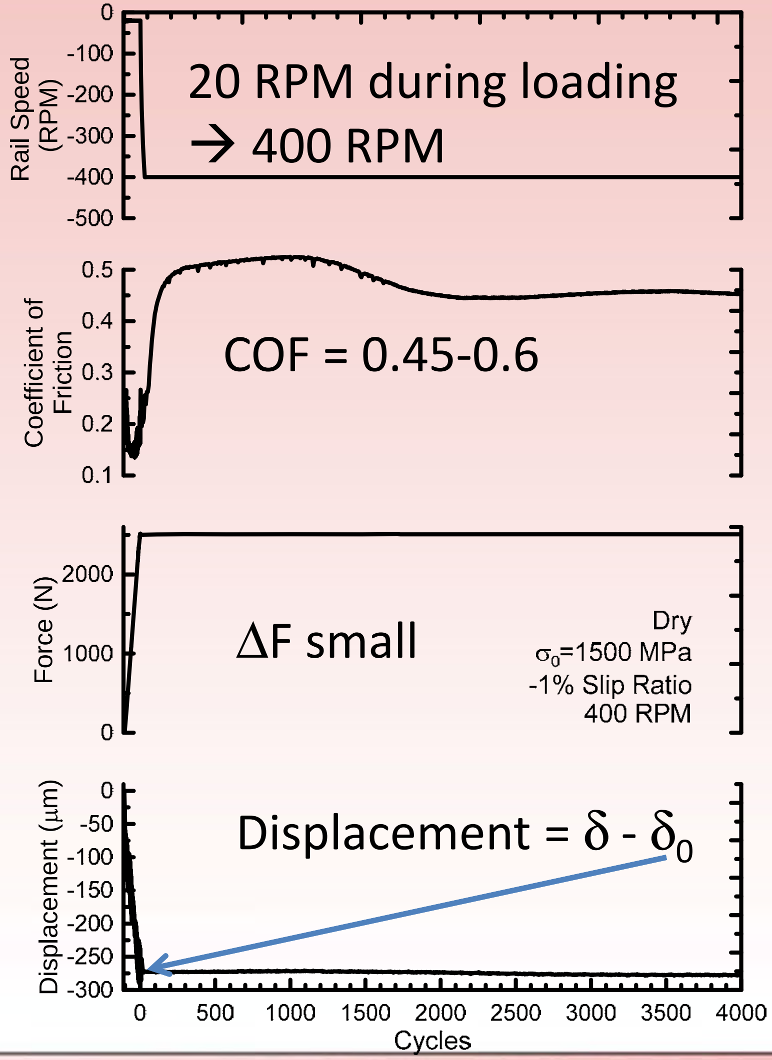
Typical 3-4 repeated signals in 0.5 s

- Measure the largest peaks in:
  - Top/Middle/Bottom 3rds
- Used same feature if identifiable

$$Max\ Crack\ Length = Ref.Length\ x\ \frac{Ave.of\ 3\ measurements}{Ave.of\ Calibration\ measurements}$$

4000 Cycle, Unlubricated “Dry” Portion

- Rolling Contact Fatigue - Dry
  - Unlubricated portion to
    - Break-in the sample surface
    - Produce surface damage
  - High Coefficient of Friction (0.45-0.6)
  - Low speed during force ramping to limit “uncounted” dry cycles
  - Cycle count and displacement based upon achieving steady state force level



20 RPM during loading → 400 RPM

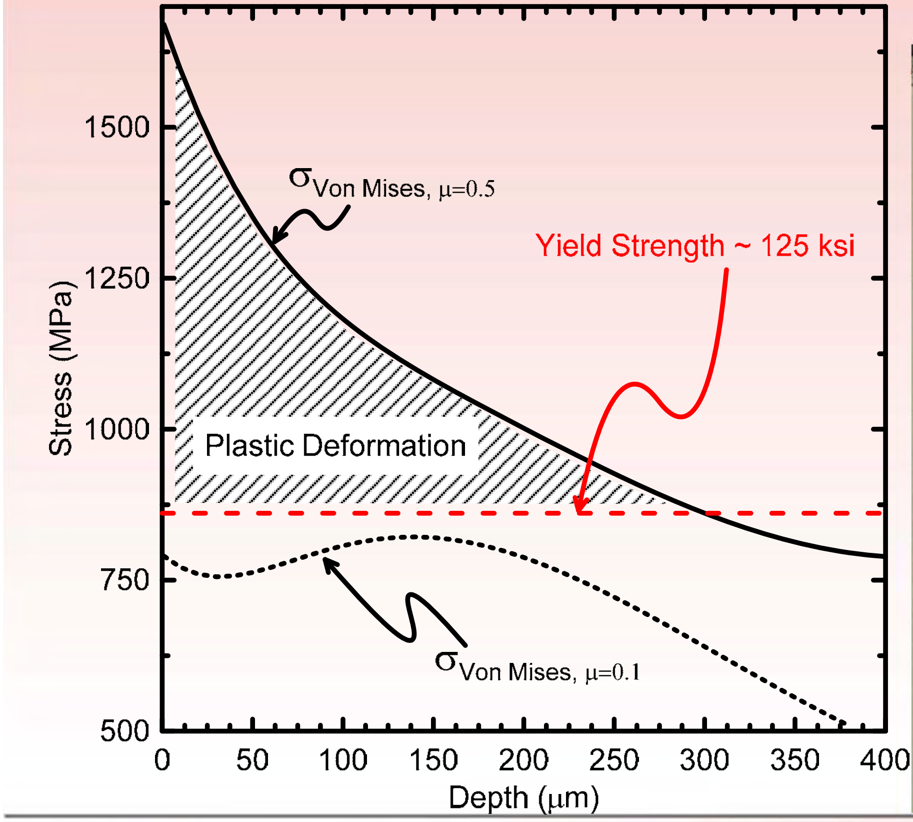
COF = 0.45-0.6

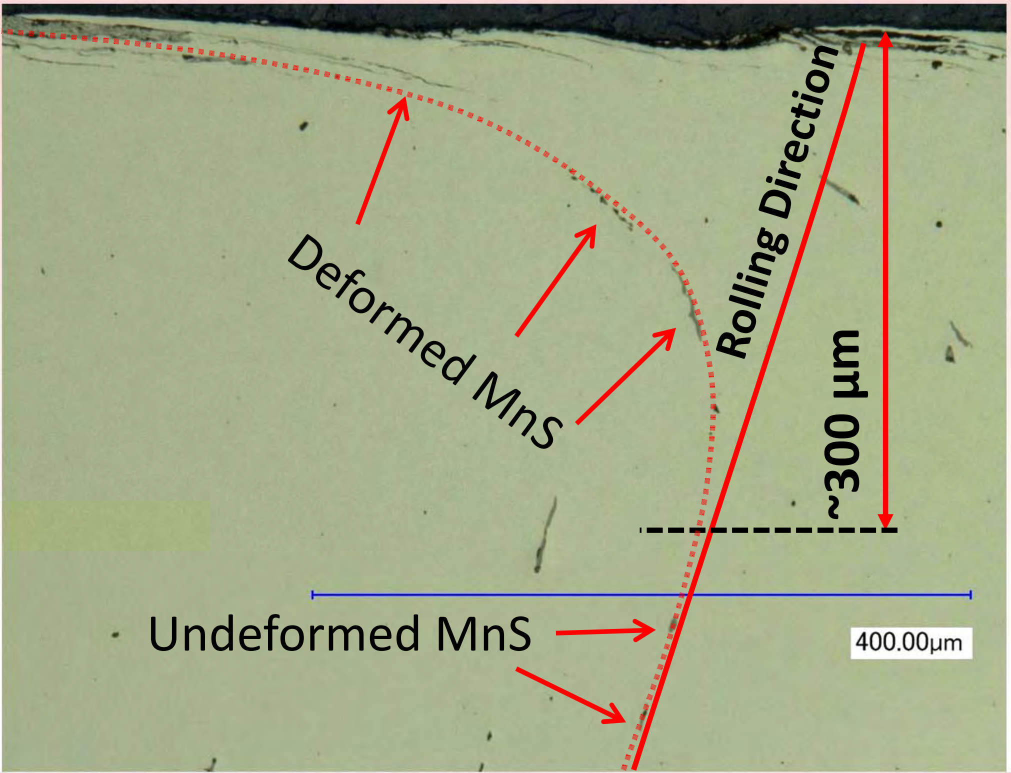
ΔF small

Displacement = $\delta - \delta_0$

Contact Stress

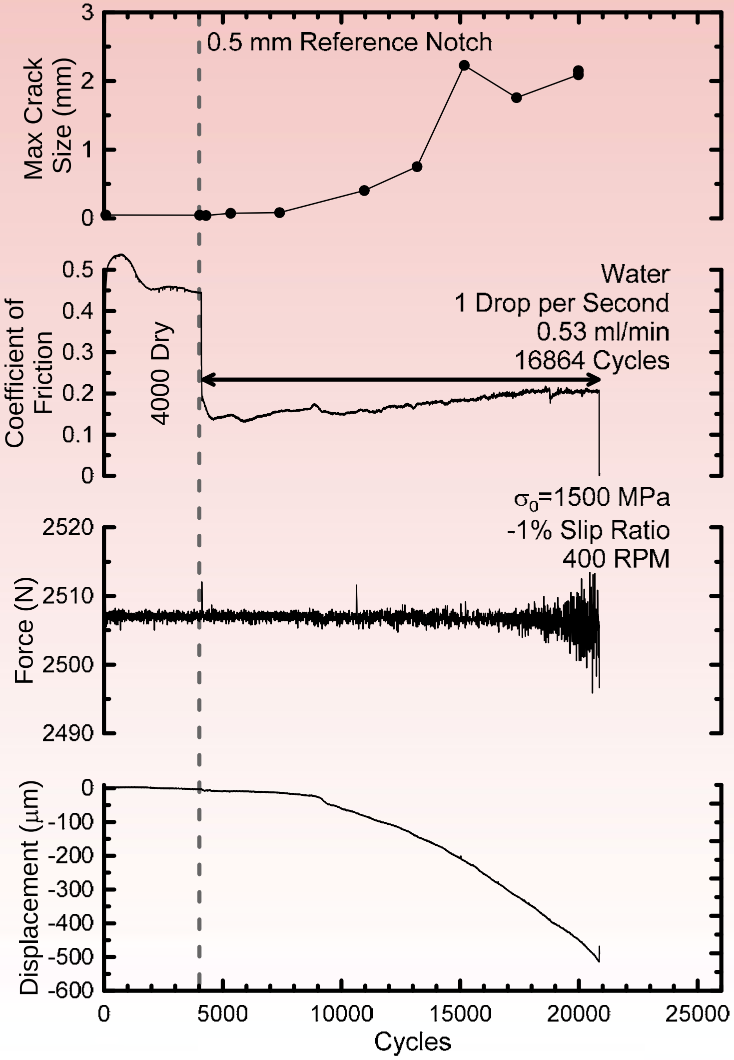
- Friction introduces surface traction
- Shear component that greatly modifies the $\sigma_{\text{Von Mises}}$
- Dry cycles COF~0.45-0.6, Lubricated COF ~0.1
- Dry cycles cause severe surface damage / deformation



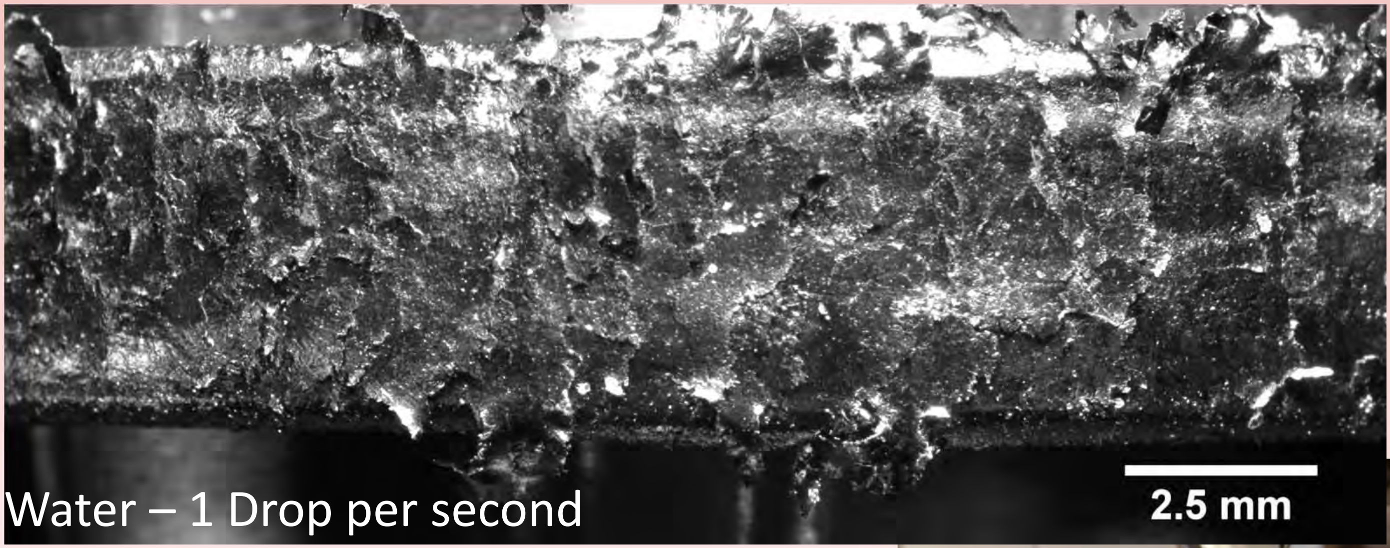


Water Part 1 – 1 Drop per second

- RCF Data
  - Max Crack Size based upon Eddy Current Signal
  - Coefficient of Friction
  - Dry (0.45-0.6) → Lubricated (0.1)
  - Force is constant
  - Displacement → estimate of material loss



Water - 1 Drop per second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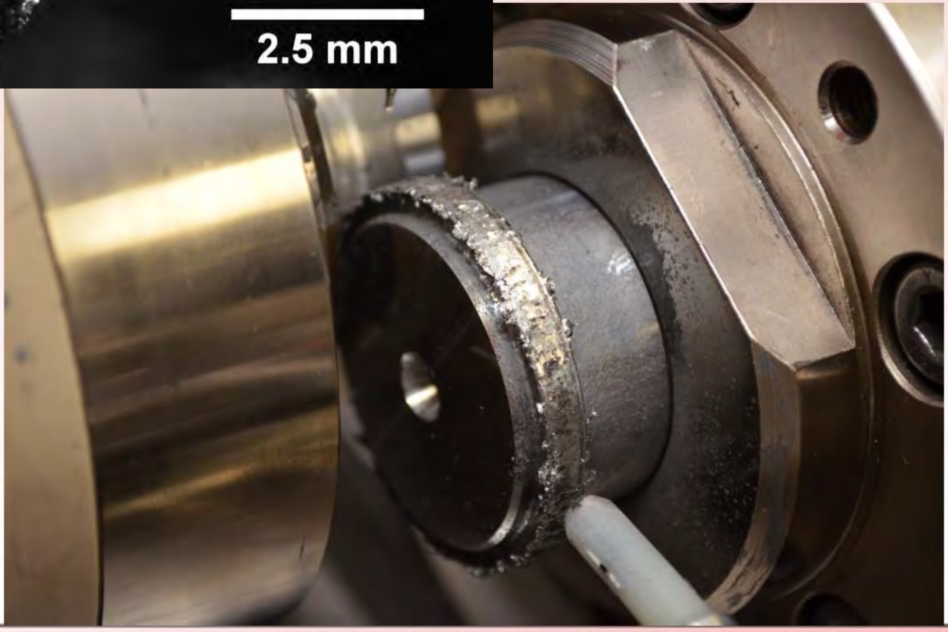
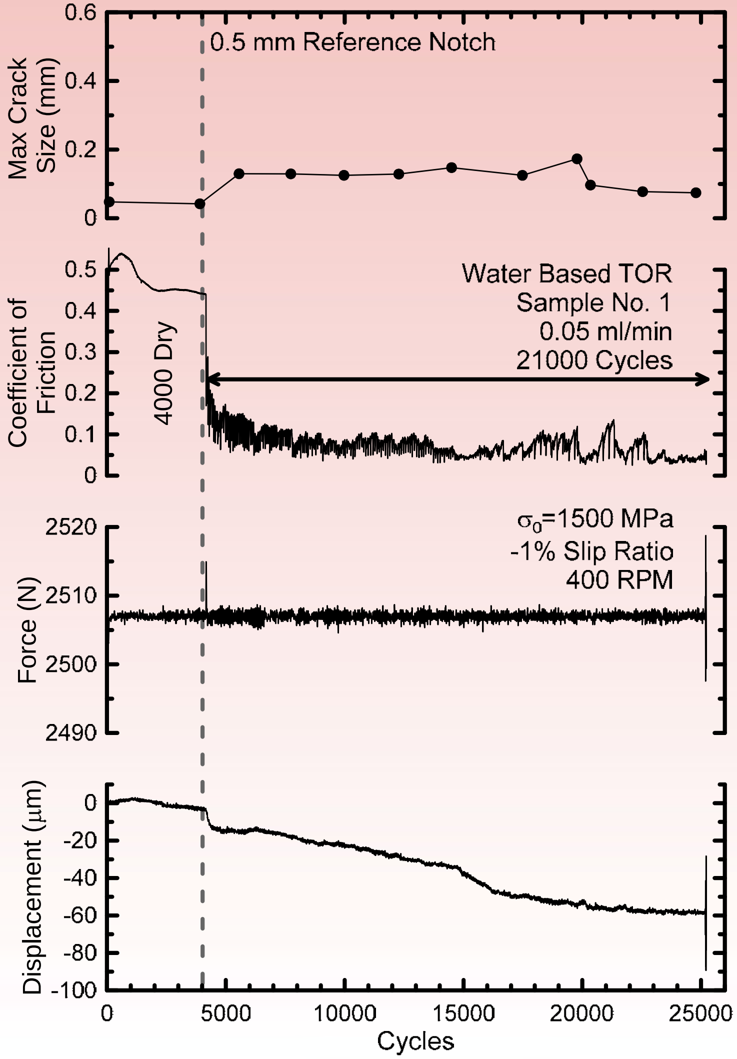
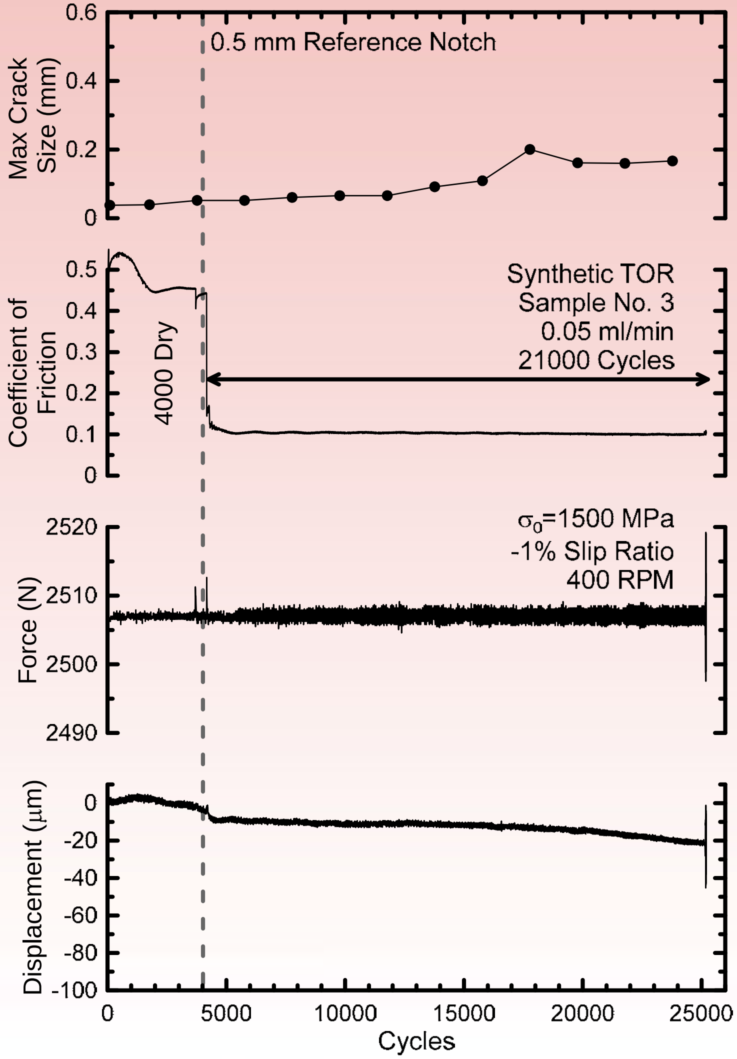


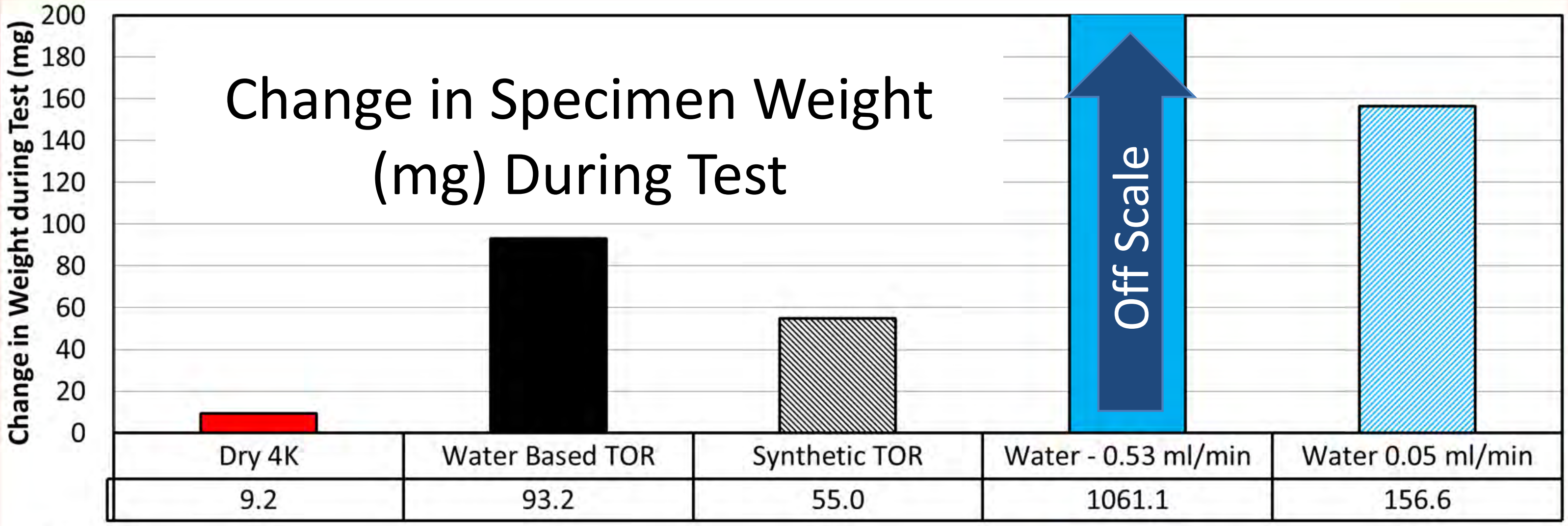
Water Based TOR



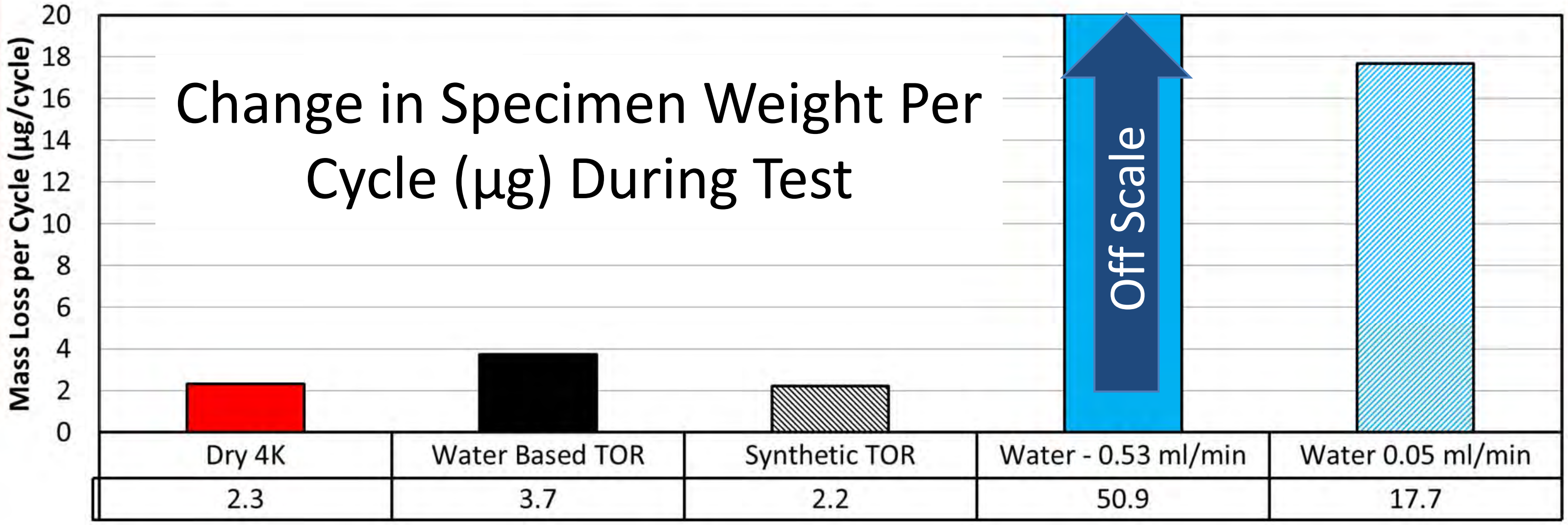
Synthetic TOR



Material Loss – Part 1

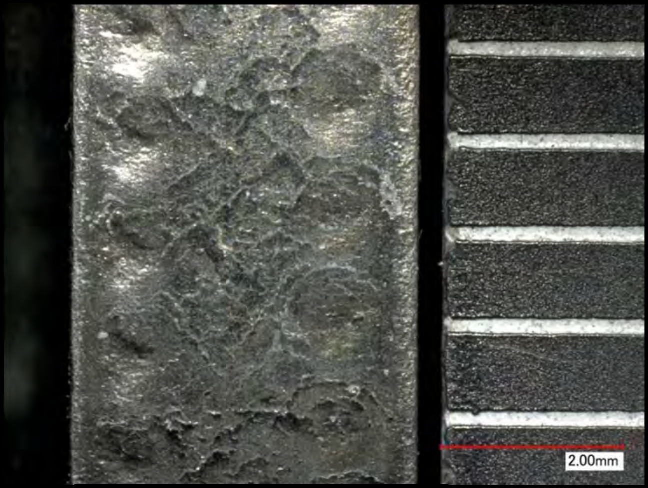


Dry 4K	Water Based TOR	Synthetic TOR	Water - 0.53 ml/min	Water 0.05 ml/min
9.2	93.2	55.0	1061.1	156.6

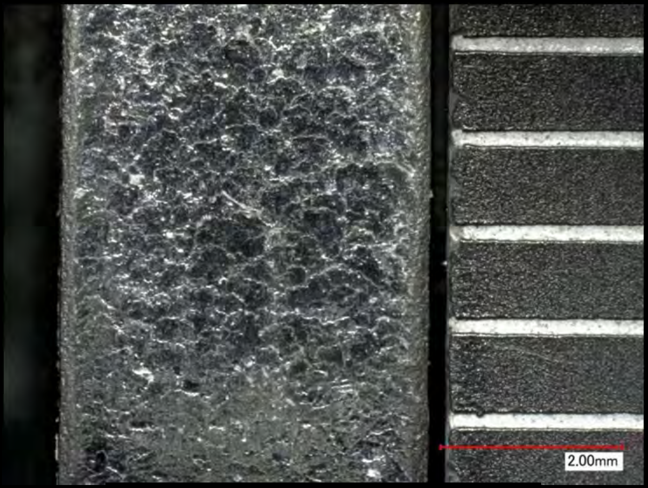


Dry 4K	Water Based TOR	Synthetic TOR	Water - 0.53 ml/min	Water 0.05 ml/min
2.3	3.7	2.2	50.9	17.7

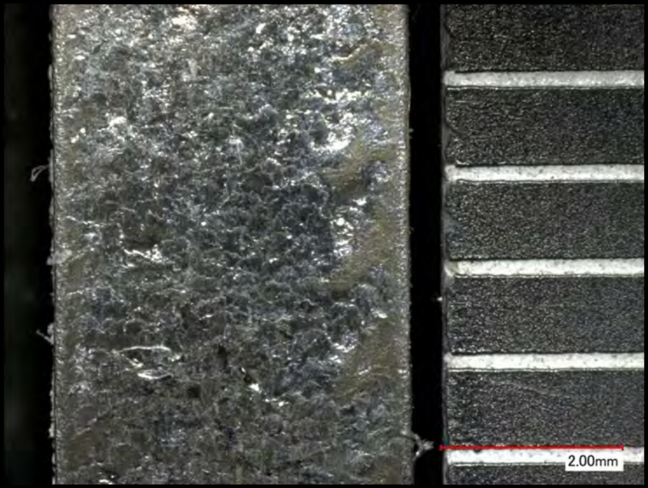
Part 1 – 4K Dry, 21K Lubricated



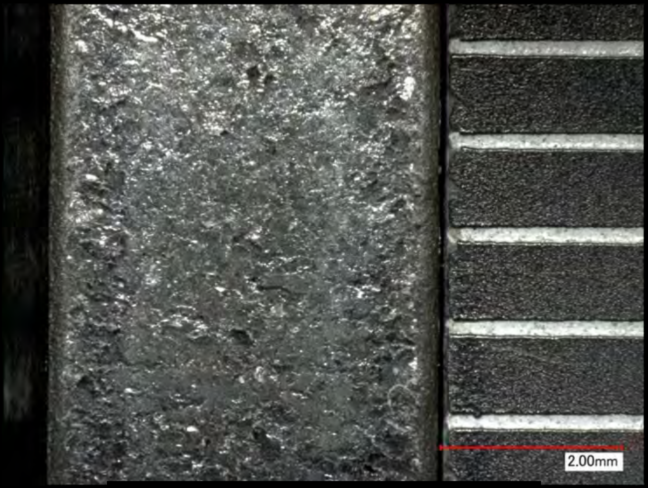
Dry – 4K cycles



Water Based TOR

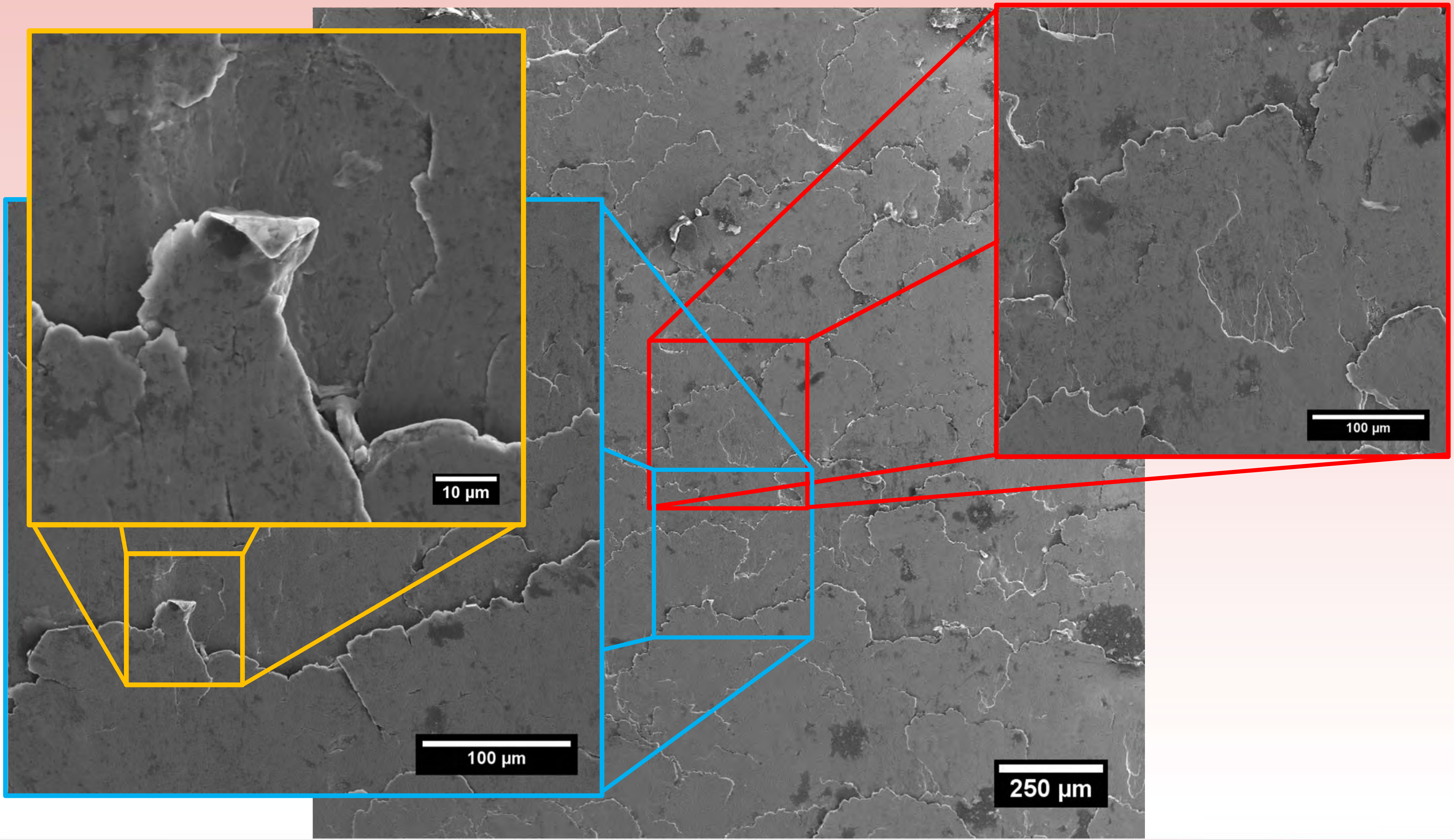


Synthetic TOR

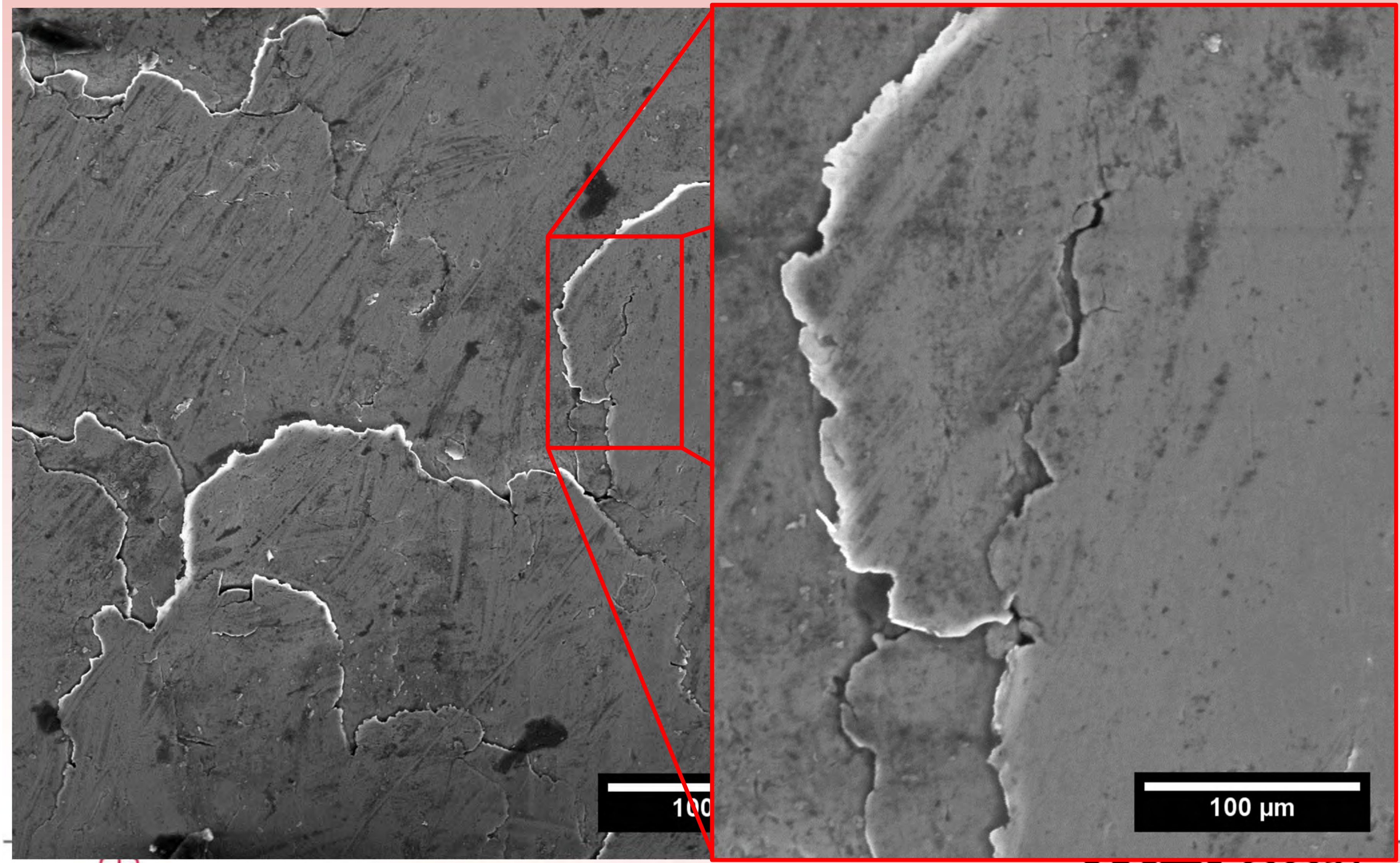


Water 0.05 ml/min

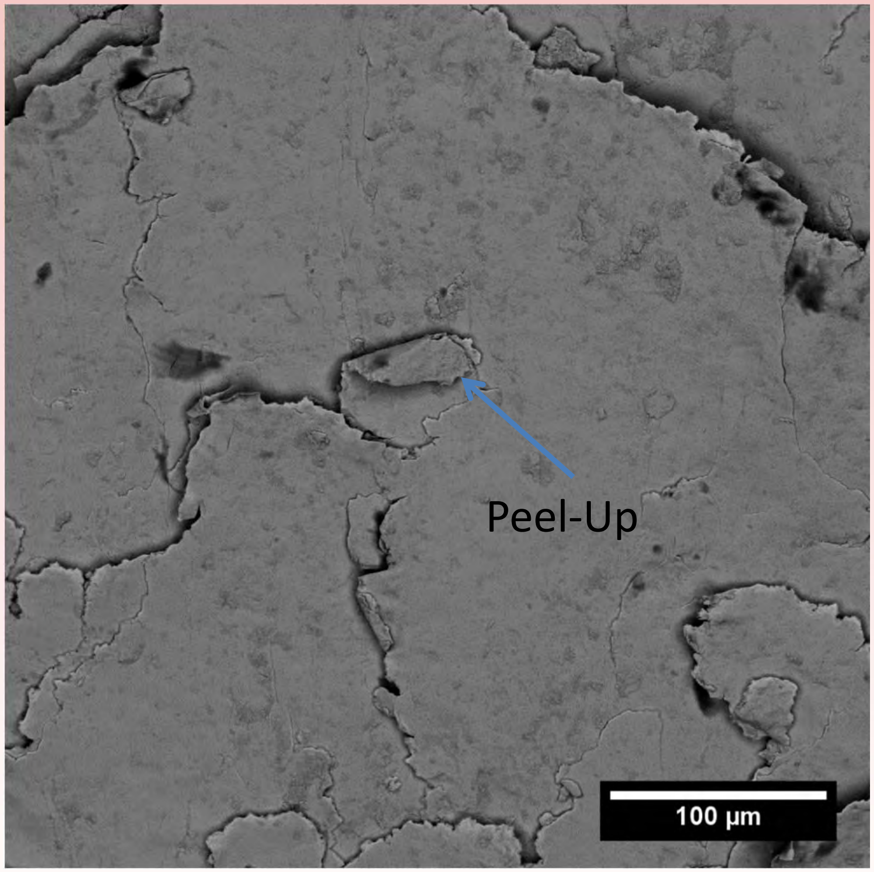
Water Based TOR



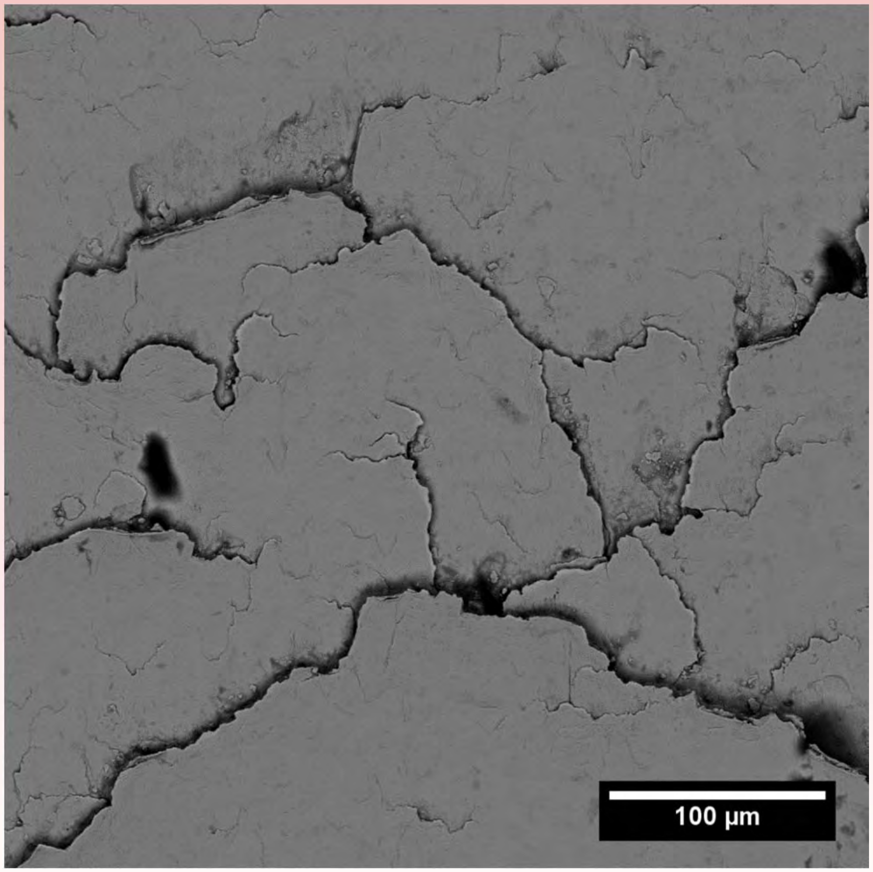
Synthetic TOR



Water and Dry 4k

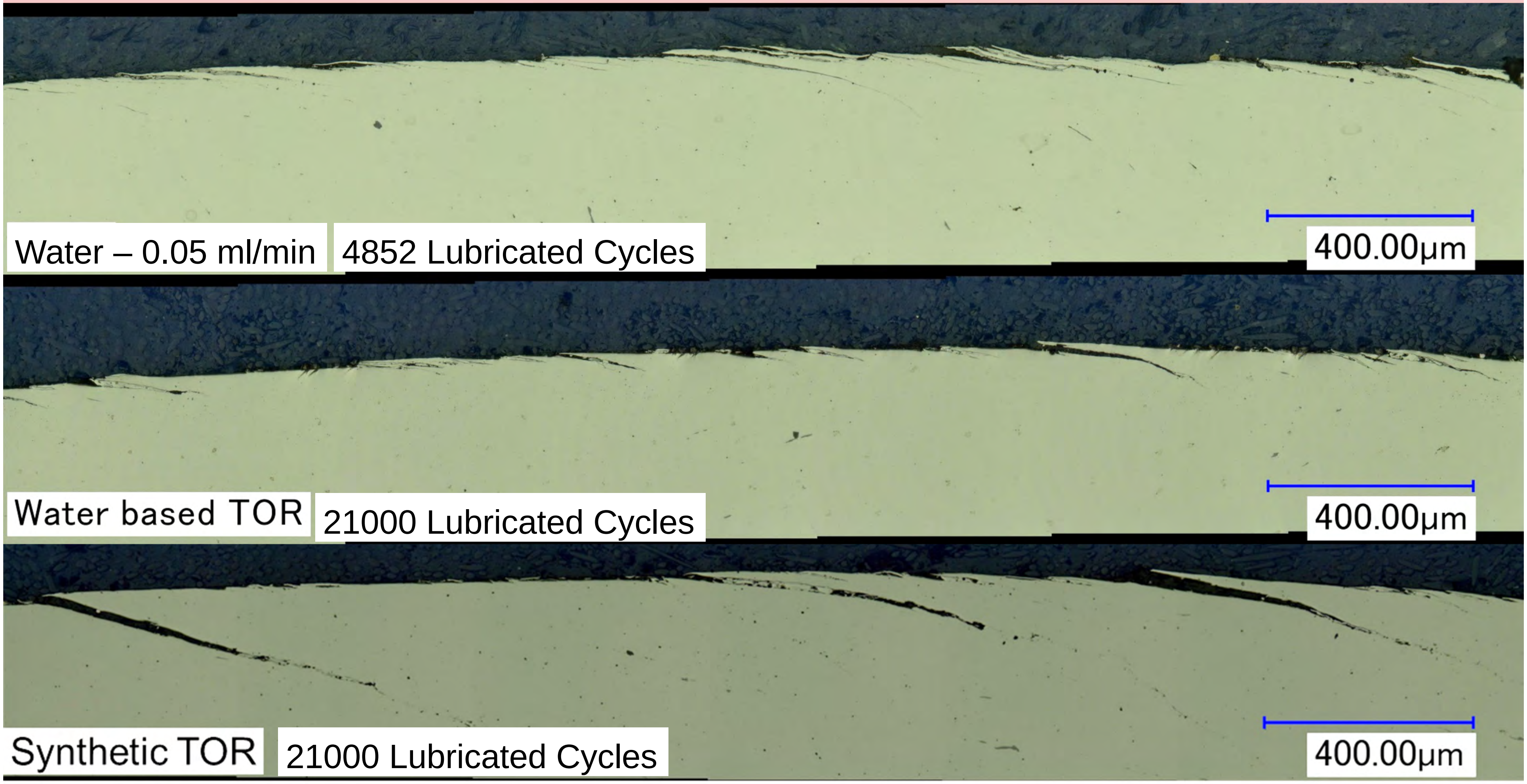


Water – 0.05 ml/min



Dry – 4K

Metallographic RCF Crack Comparison



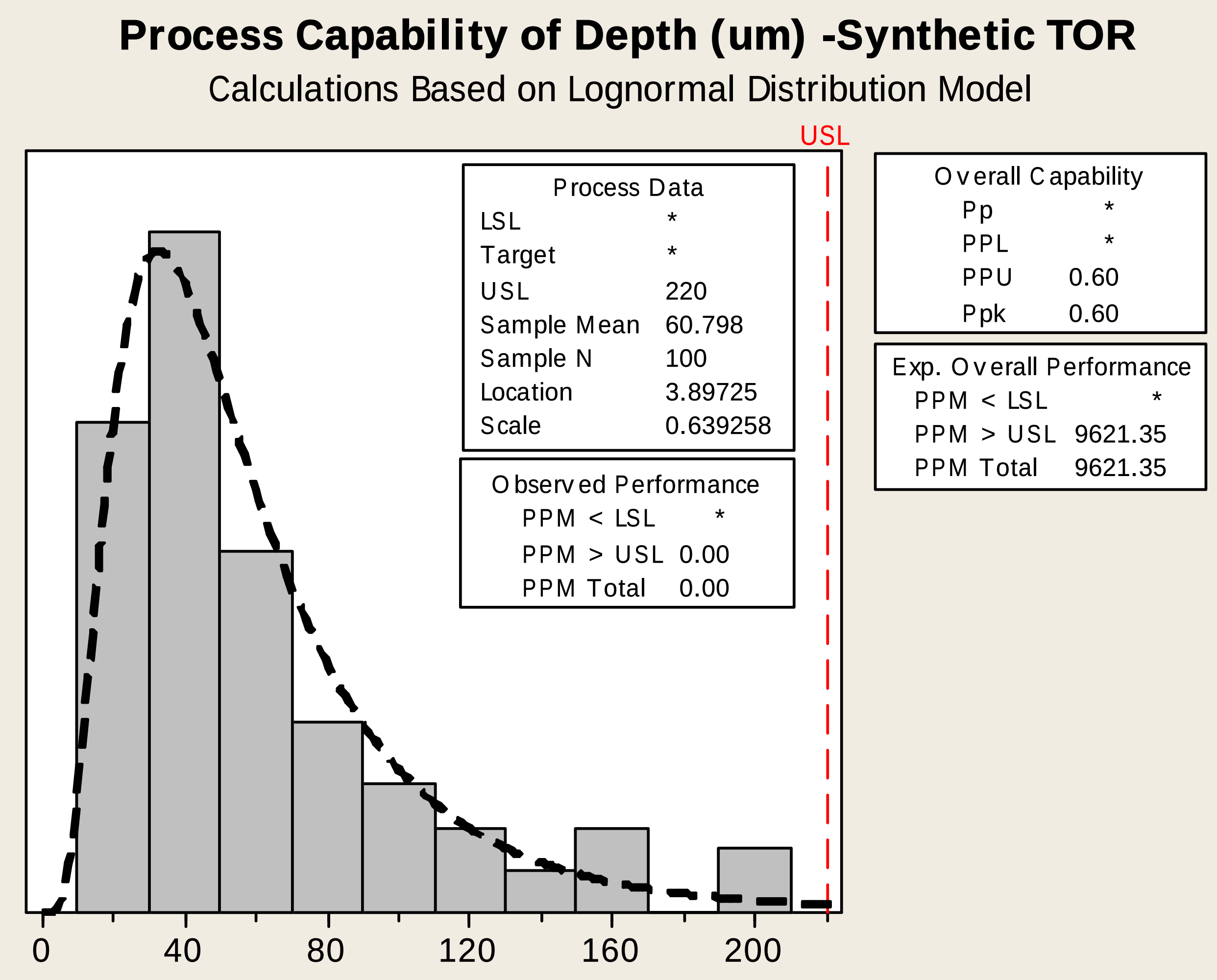
RCF Analysis for Grind Simulation

<u>Synthetic TOR</u>

N = 100

Mean = 61 µm

- 220 µm Grind Target
- Based upon <1% of cracks having remainder after grind simulation



Process Capability of Depth (um) -Synthetic TOR

Calculations Based on Lognormal Distribution Model

Process Data	
LSL	*
Target	*
USL	220
Sample Mean	60.798
Sample N	100
Location	3.89725
Scale	0.639258

Observed Performance	
PPM < LSL	*
PPM > USL	0.00
PPM Total	0.00

Overall Capability	
Pp	*
PPL	*
PPU	0.60
Ppk	0.60

Exp. Overall Performance	
PPM < LSL	*
PPM > USL	9621.35
PPM Total	9621.35

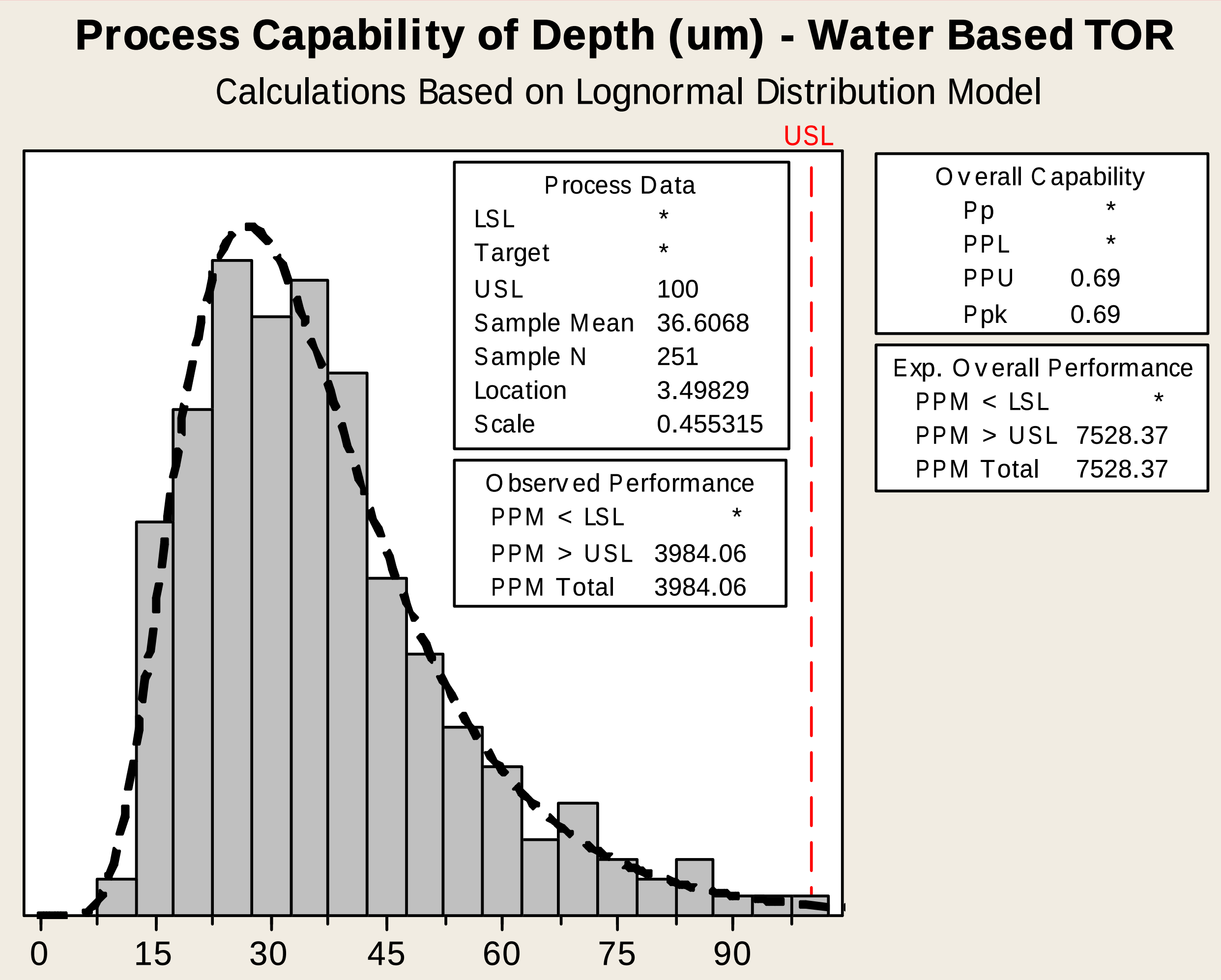
RCF Analysis for Grind Simulation

Water Based TOR

N = 251

Mean = 37 µm

- 100 µm Grind Target
- Based upon <1% of cracks having remainder after grind simulation



Process Capability of Depth (um) - Water Based TOR

Calculations Based on Lognormal Distribution Model

Process Data	
LSL	*
Target	*
USL	100
Sample Mean	36.6068
Sample N	251
Location	3.49829
Scale	0.455315

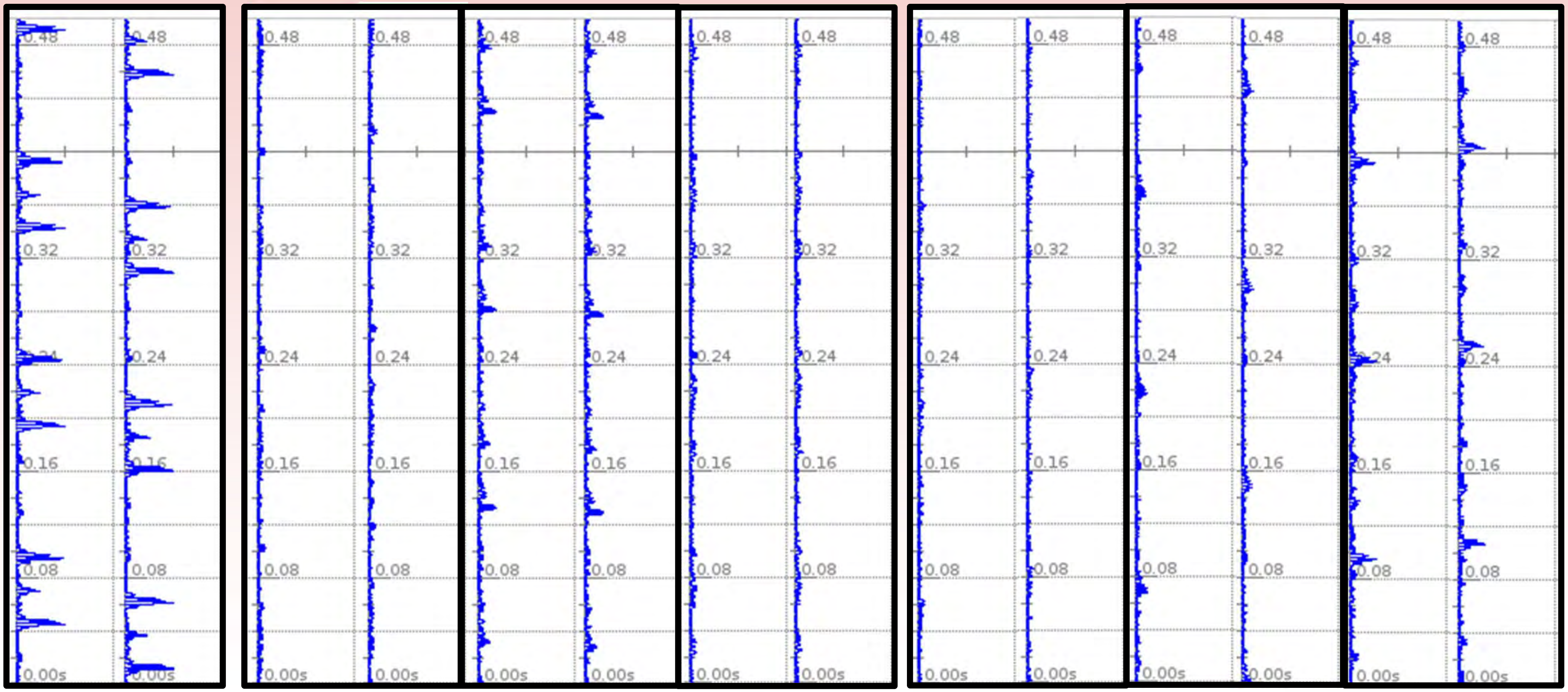
Observed Performance	
PPM < LSL	*
PPM > USL	3984.06
PPM Total	3984.06

Overall Capability	
Pp	*
PPL	*
PPU	0.69
Ppk	0.69

Exp. Overall Performance	
PPM < LSL	*
PPM > USL	7528.37
PPM Total	7528.37

Phase 2: Testing After Grinding

Calibration	Synthetic Based TOR			Water Based TOR		
	#2	#3	#4	#2	#3	#5
0.5 mm	0.1 mm	0.21 mm	< 0.1 mm	< 0.1 mm	0.13 mm	0.28 mm



Phase 2: Testing After Grinding

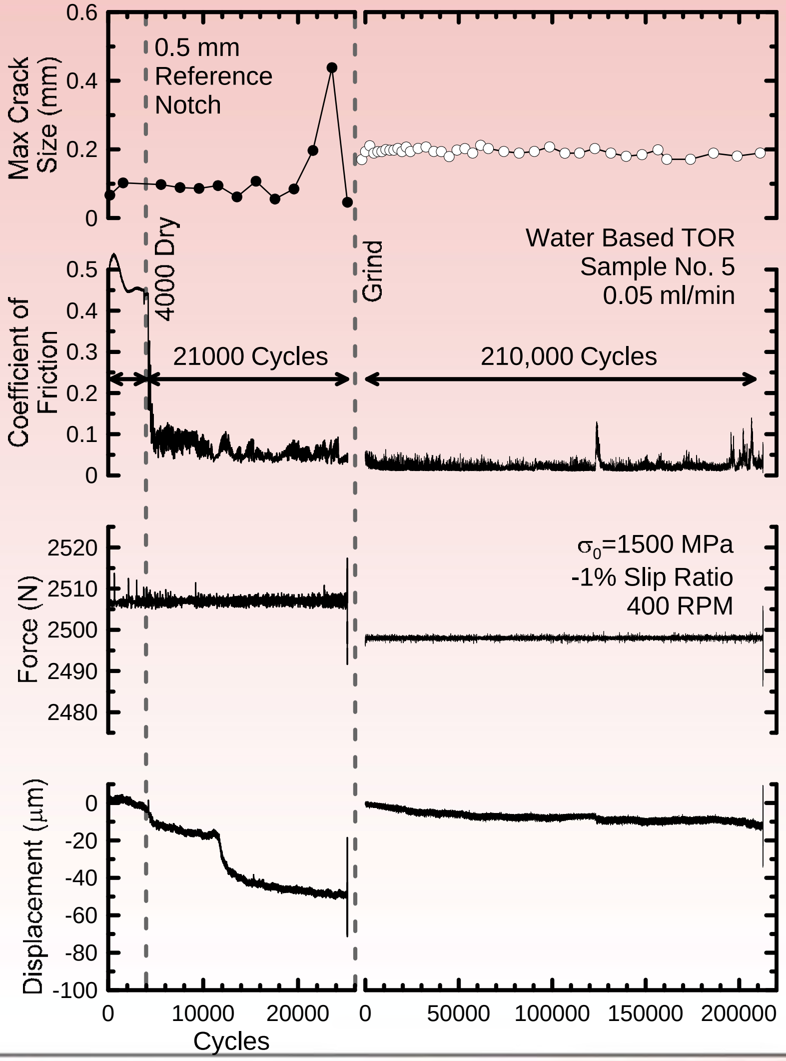
Based upon eddy current analysis of the 6 grind-simulation samples

For each TOR material, a sample set representing 3 residual crack conditions were obtained after grind simulation

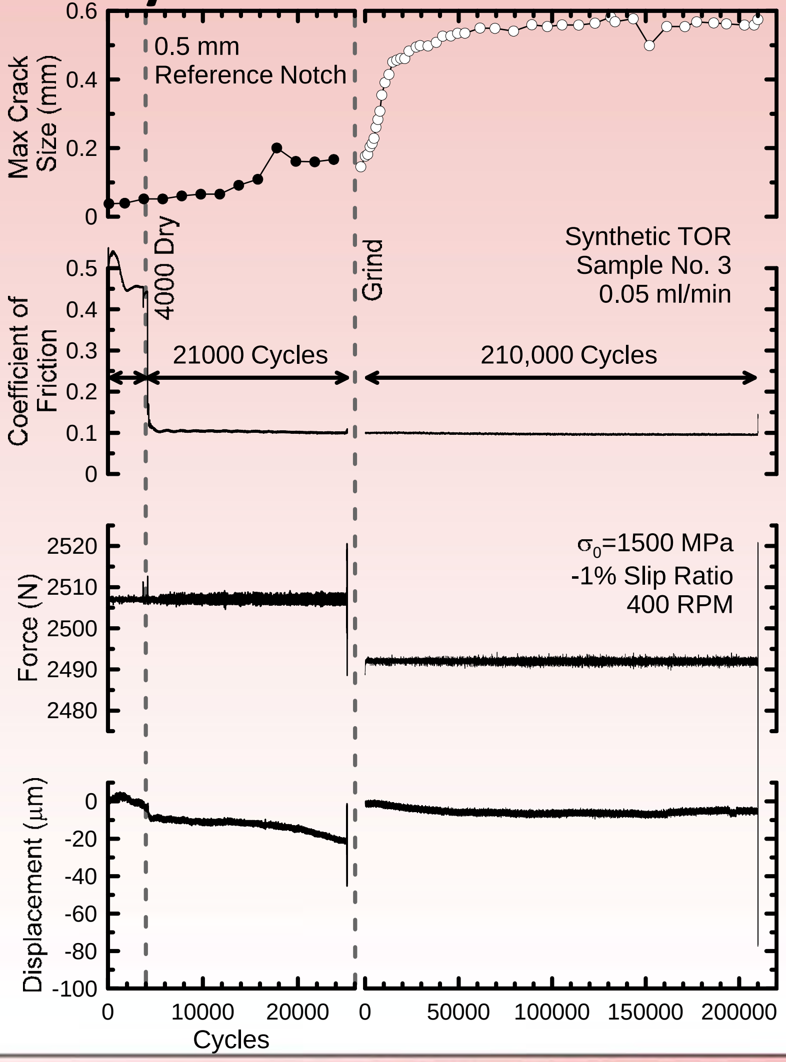
1. 1 disk with no measureable cracks (< 0.1 mm)
2. 1 disk with trace amounts of cracks (~ 0.1 mm)
3. 1 disk of very detectable cracks (> 0.2 mm)

TOR Comparison

Water Based TOR – 0.28 mm



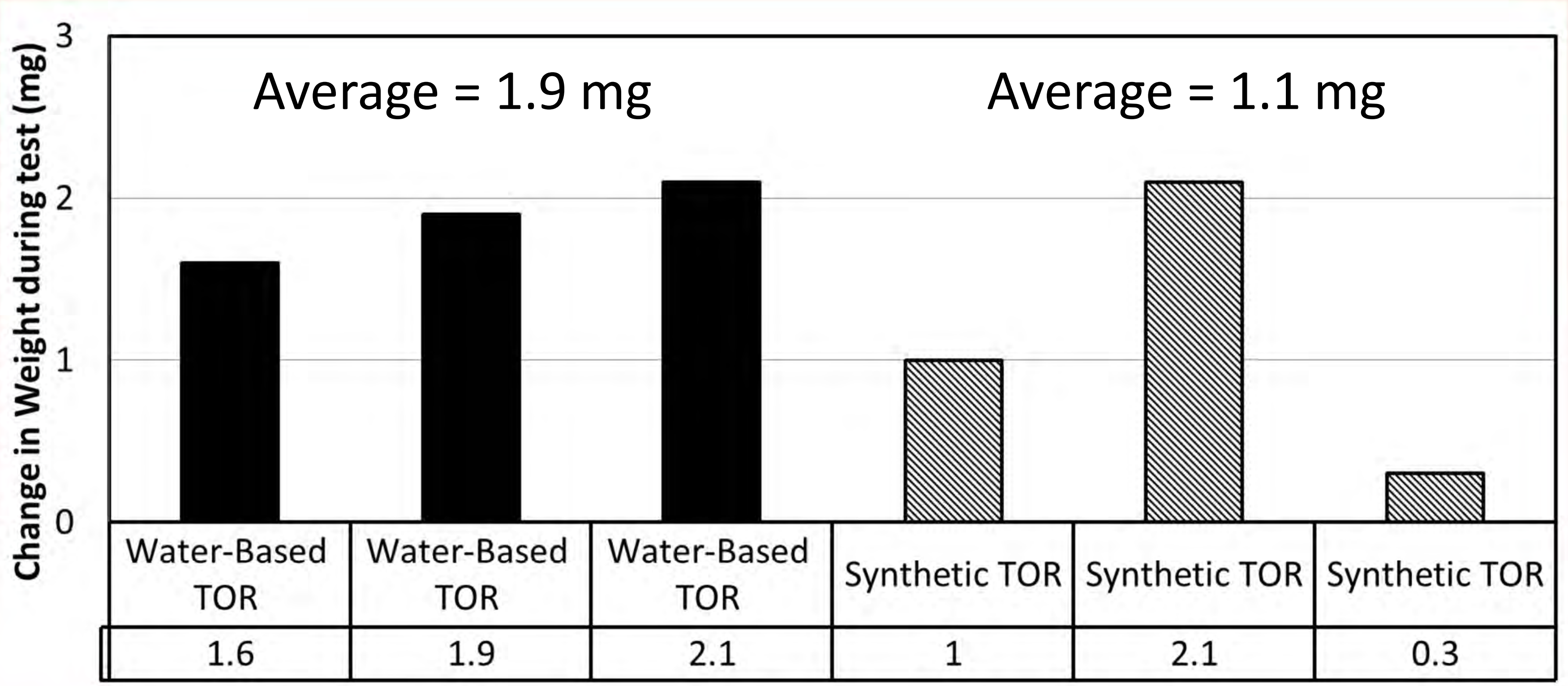
Synthetic TOR – 0.21 mm



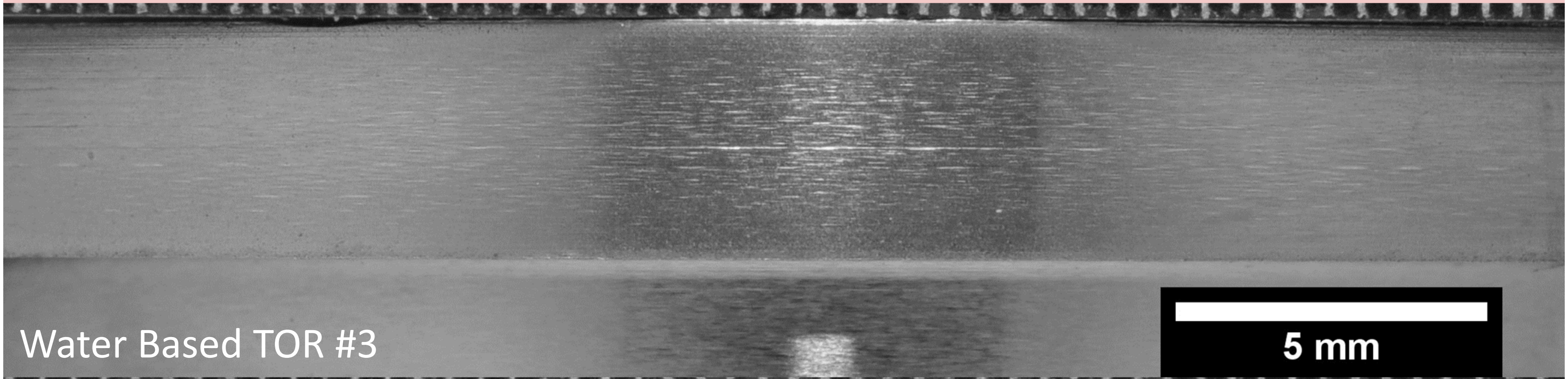
TOR Comparison

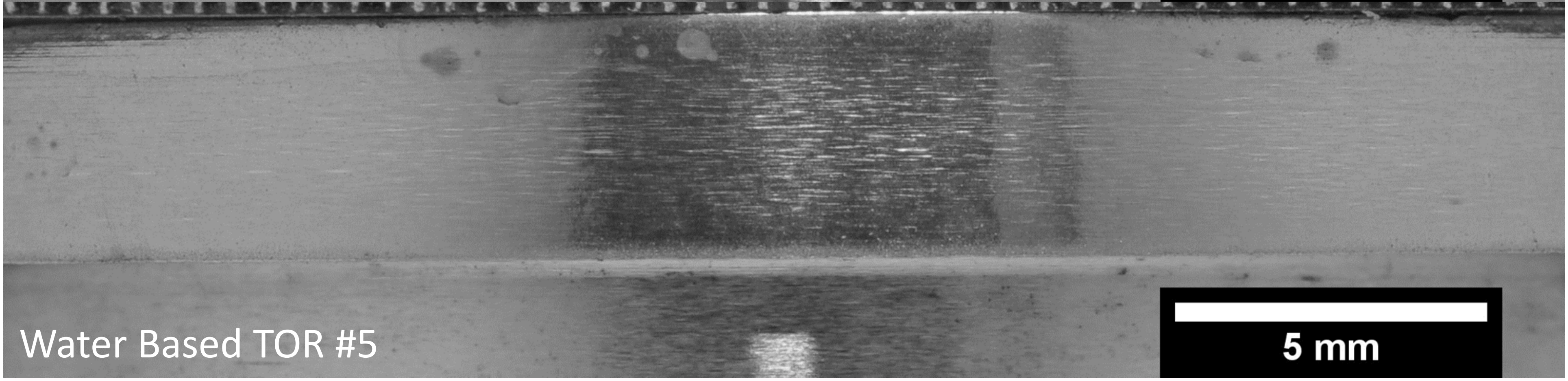
Water Based TOR
Part 1 – Average
93.2 mg / 25000 cycles

Synthetic TOR
Part 1 – Average
55 mg / 25000 cycles

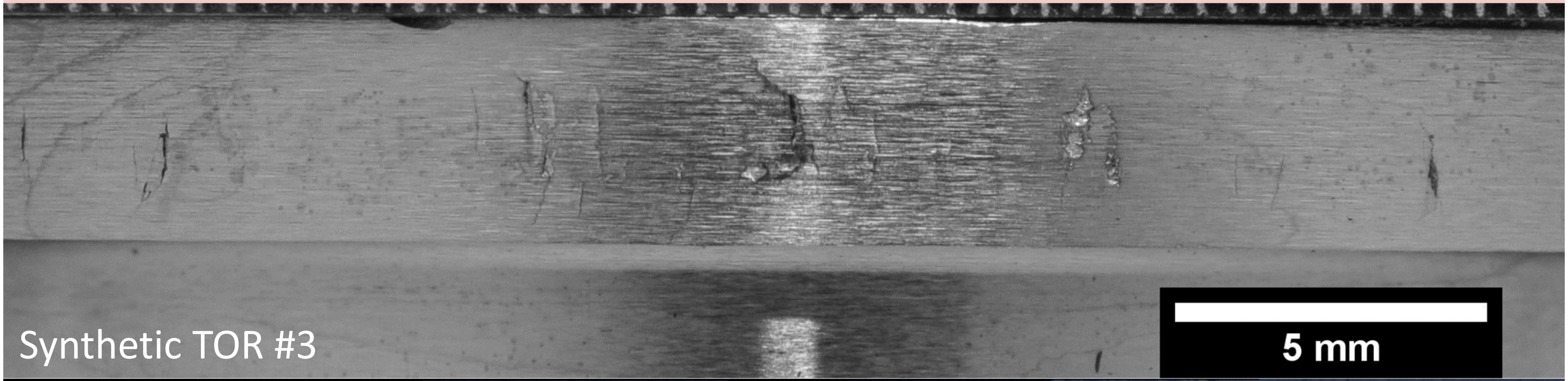


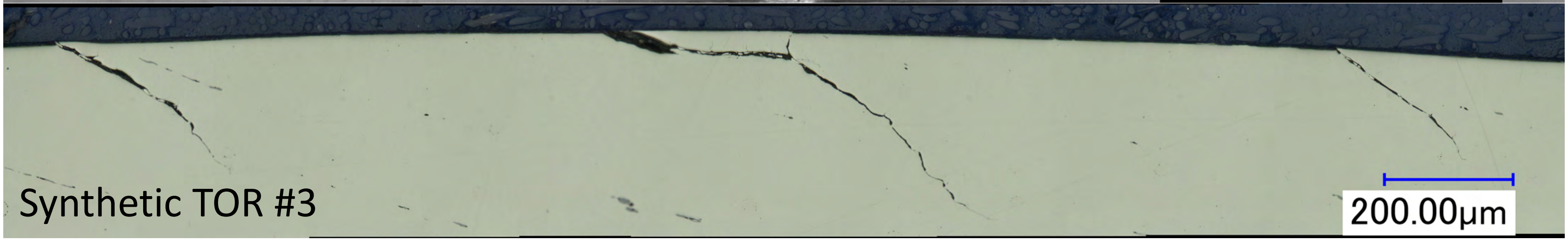
210K Lubricated


Water Based TOR #3


Water Based TOR #5

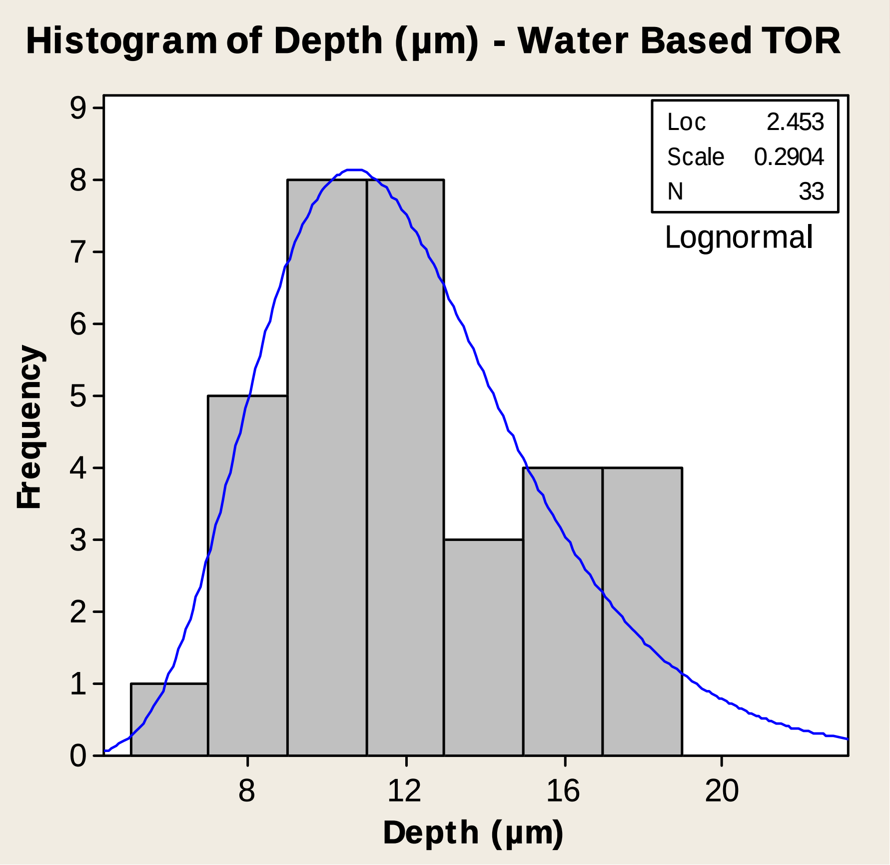
210K Lubricated

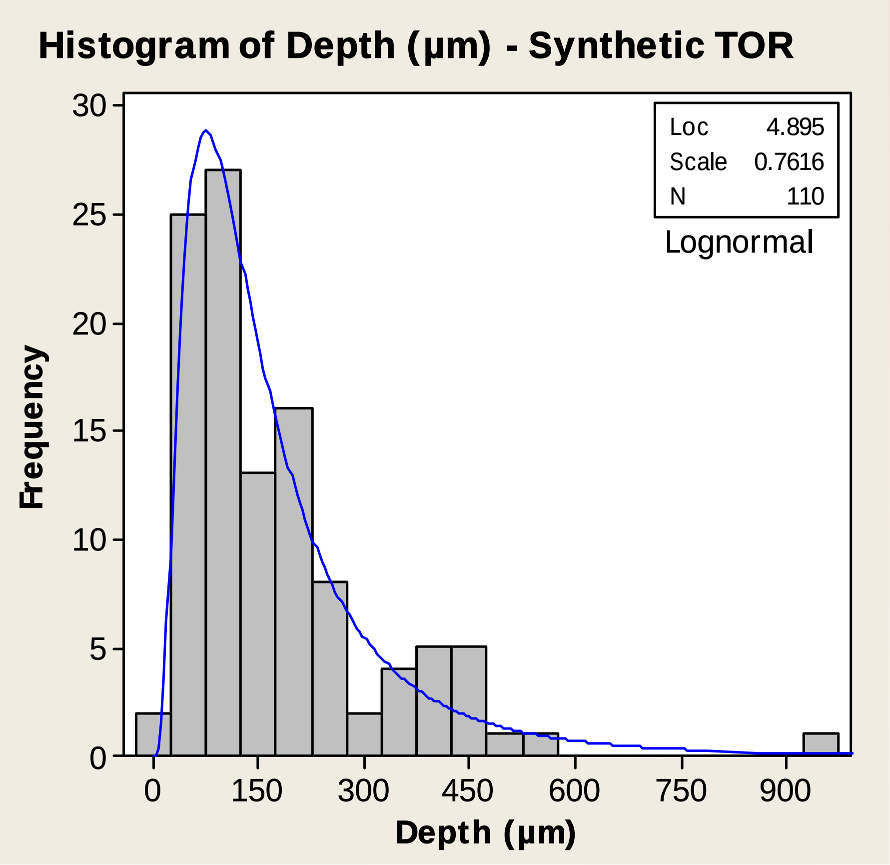

Synthetic TOR #3


Synthetic TOR #3

Crack Propagation

Crack population (combined, 3 samples each) show that the Synthetic TOR exhibits higher crack counts and larger depth values





Considerations

Sub-sized Testing vs. Revenue Service Conditions

1. Stress field/microstructure scale differences (1:30th scale)
2. Friction coefficient not representative of revenue service
   - COF - Water Based TOR - **0.07** Pt. 1**, 0.03** Pt. 2
   - COF - Synthetic TOR - **0.11** Pt. 1, **0.10** Pt. 2
   - Lubrication rates likely in excess of what would represent revenue service conditions (modification for future study)
3. Severe surface layer damage during dry break-in results in wide-flat deformation cracks
   - Surface appearance is that the material is “rolled” out over adjacent material
   - Representative of “dry” service conditions

Comparisons to Revenue Service

Axle load ~ 36 tons = 1 wheel pass

Approximate, but conservative, estimate of MGT

- 4,000 dry cycles = 0.14 MGT (< 2 days on 36 MGT line)
- 25,000 cycles = 0.9 MGT (9 days on 36 MGT line)
- 210,000 cycles = 7.5 MGT (75 days on 36 MGT line)

Both TOR materials have been in use in revenue service

- Long term, continuous usage
- Synthetic TOR ~ 6 years in ~50 MGT line
- Water Based TOR ~ 7 years in ~70 MGT line
- No manifestation of damage as shown in the disc-on-disc testing
  - Grinding practice was in place

Conclusions

The Effects of Grinding

1. The grind simulation samples do have significantly less crack propagation than the original study at 10X cycles.
2. If there is residual RCF after grinding, that could be the area of growth depending on the Friction Modifier used.
3. When using an HH material there seems to be a max depth of crack propagation.
4. The HH rail did not have the severe RCF propagation as that exhibited by the rails used in the previous study (WRI 2014)
5. If FM equipment in the field is OOS, it is important to have systems return to service in a timely manner to minimize crack initialization.

Jim Thompson **Greg Garcia** **Nick Dryer** **Greg Lehnhoff** **Mark Richards**


Photo taken by Joe Kristan

EVRAZ

BNSF RAILWAY

Wazau UTM 5000

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- 50 N-m Torque Capacity
- 3000 RPM, independent drive spindles
- *in-situ* eddy current
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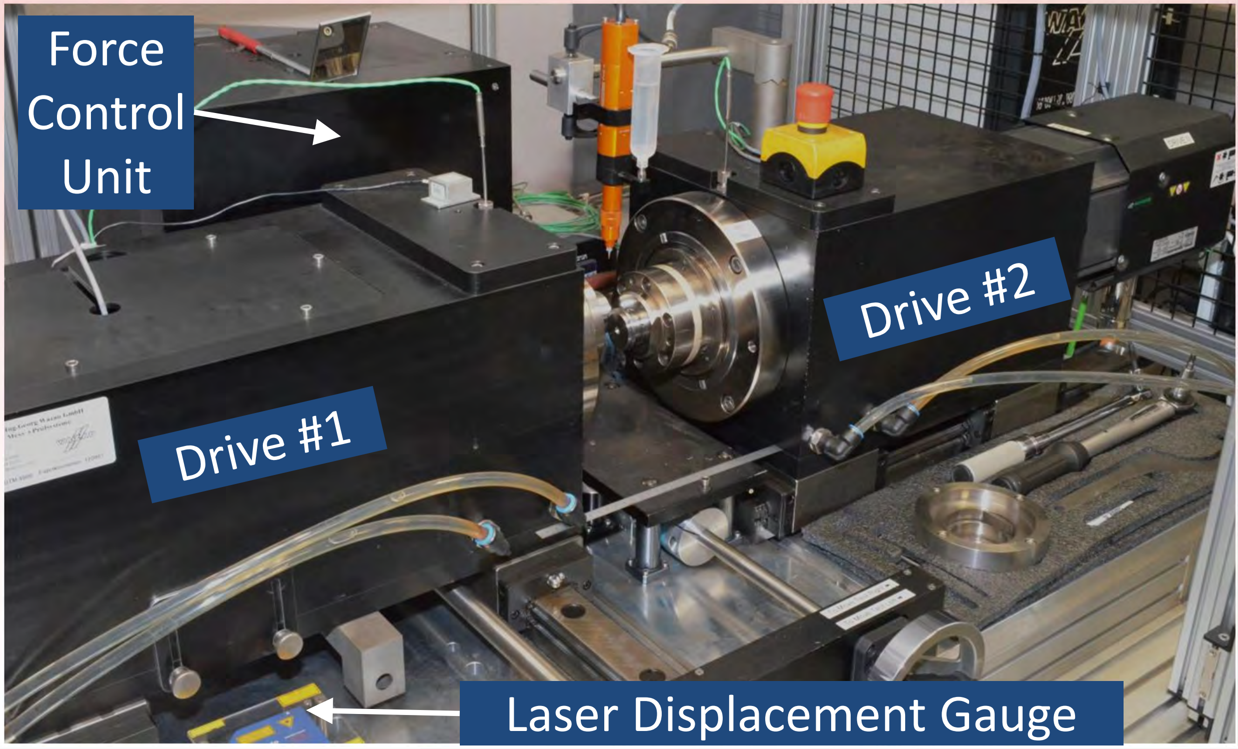

Force Control Unit

Drive #2

Drive #1

Laser Displacement Gauge

Drip System

Drive #1 “Wheel”

Drive #2 “Rail”

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  - Reproduce the conditions of Hardwick at University of Sheffield
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  - Lubrication is applied after a dry cycle break in period

- 1500 MPa contact pressure where:

$$P_{max} = \frac{2F}{\pi a L}$$

- F is the Force set point
- a is contact patch dimension
- L is the contact length

- -1% slip ratio (i.e. $V_{Wheel} > V_{Rail}$) where:

$$\frac{Slip\ Ratio}{} = \frac{2 \times (V_{Rail} - V_{Wheel})}{il + V_{Wheel}}$$

$$\frac{Slip\ Ratio}{100\%} = \frac{2 \times (V_{Rail} - V_{Wheel})}{V_{Rail} + V_{Wheel}}$$

- V_{Rail} is the rail surface velocity
- V_{Wheel} is the wheel surface velocity

Following Pages (36-40 point)

Subhead (28 point)

1. This is a sample of 24 point text in black.
2. This is a sample of 24 point text in black.
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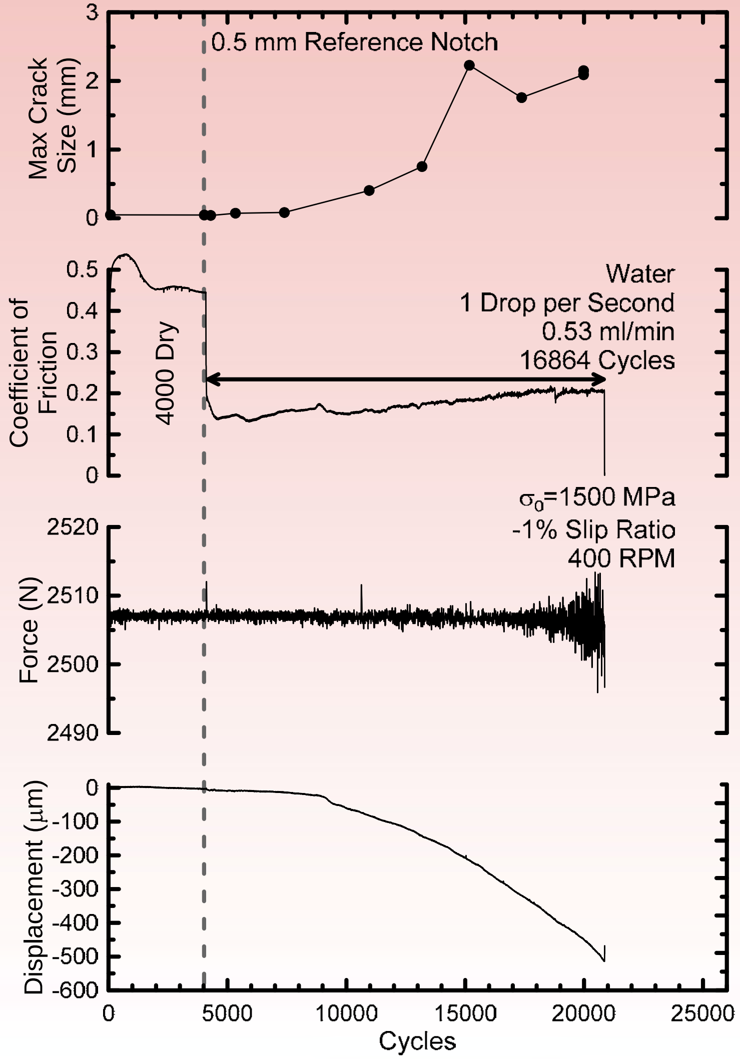
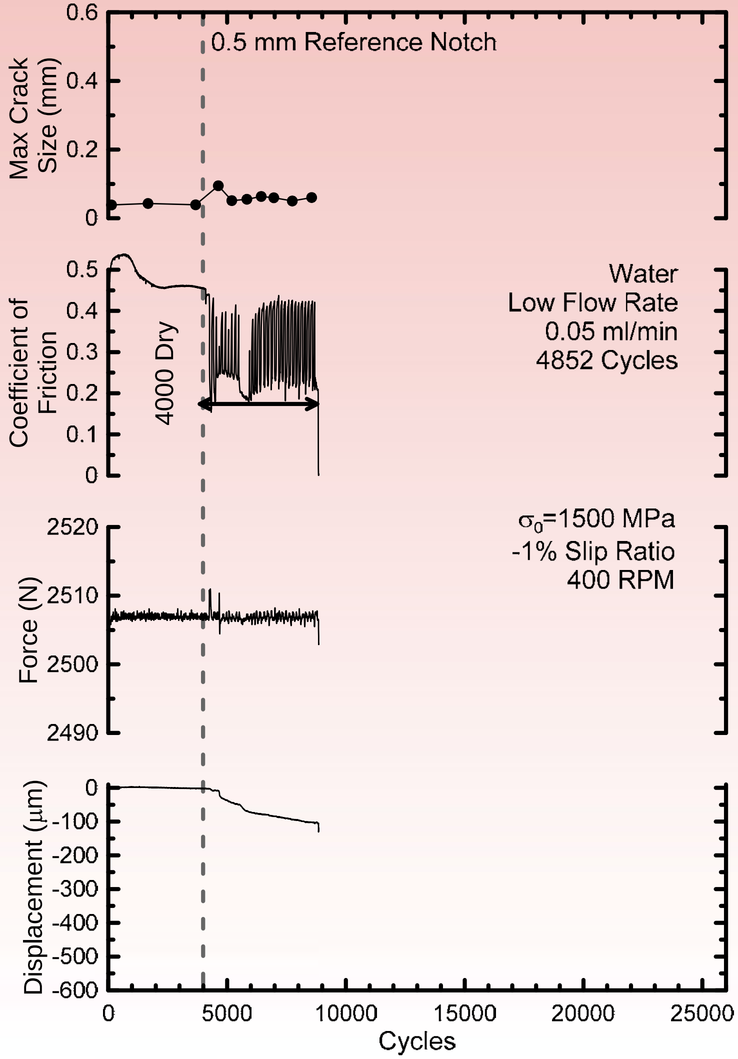
(20 point) for readability

Water Part 1

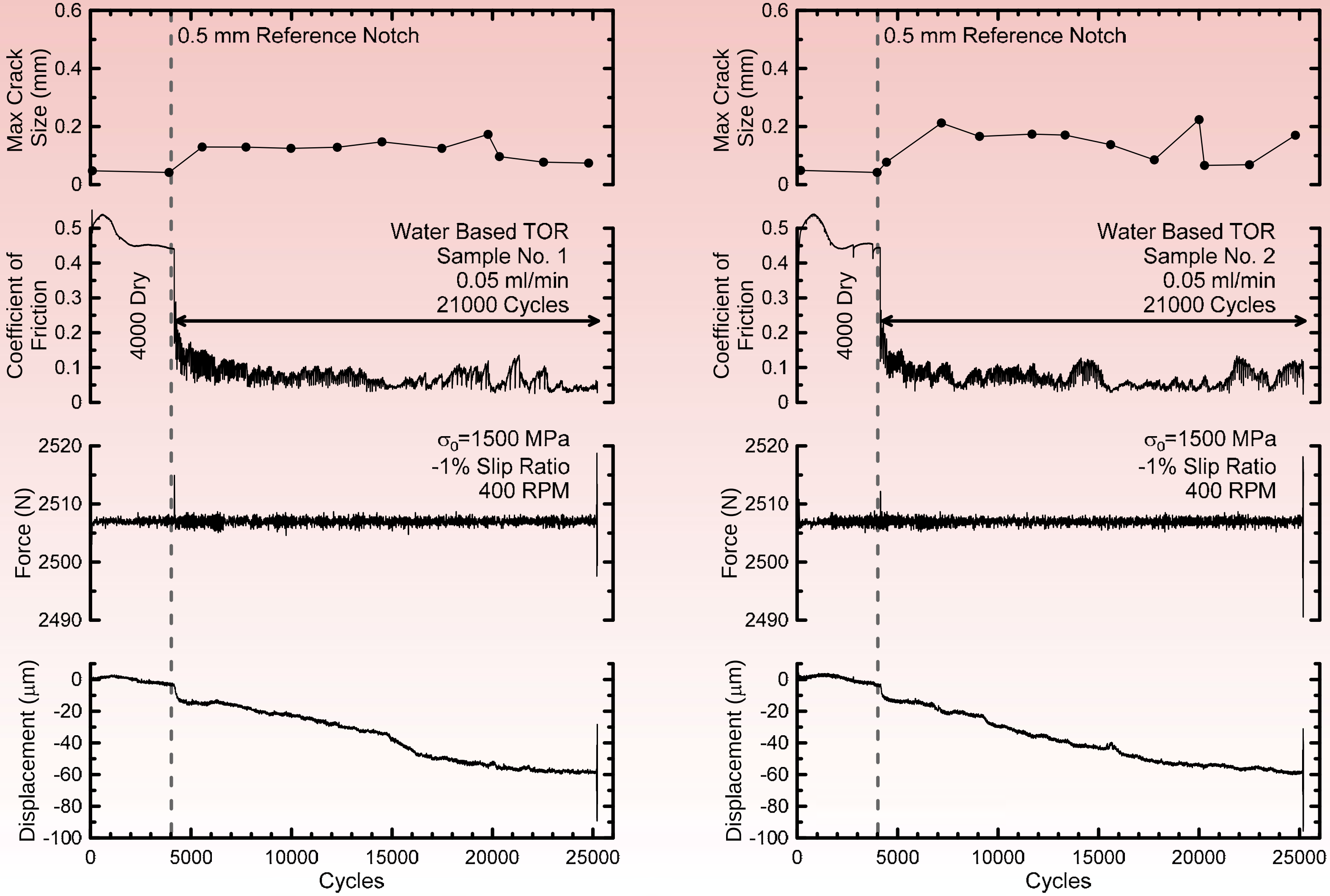


0.5 mm Reference Notch
Max Crack Size (mm)
3
2
1
0
Coefficient of Friction
0.5
0.4
0.3
0.2
0.1
0
4000 Dry
Water
1 Drop per Second
0.53 ml/min
16864 Cycles
σ_0=1500 MPa
-1% Slip Ratio
400 RPM
Force (N)
2520
2510
2500
2490
Displacement (μm)
0
-100
-200
-300
-400
-500
-600
0
5000
10000
15000
20000
25000
Cycles

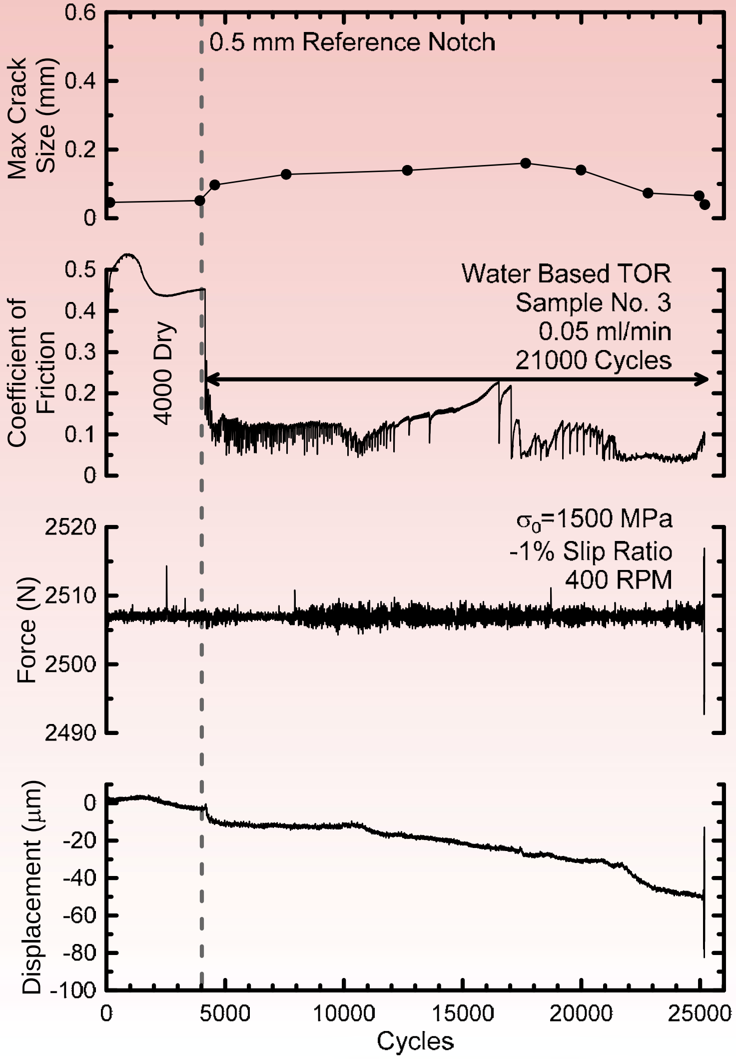


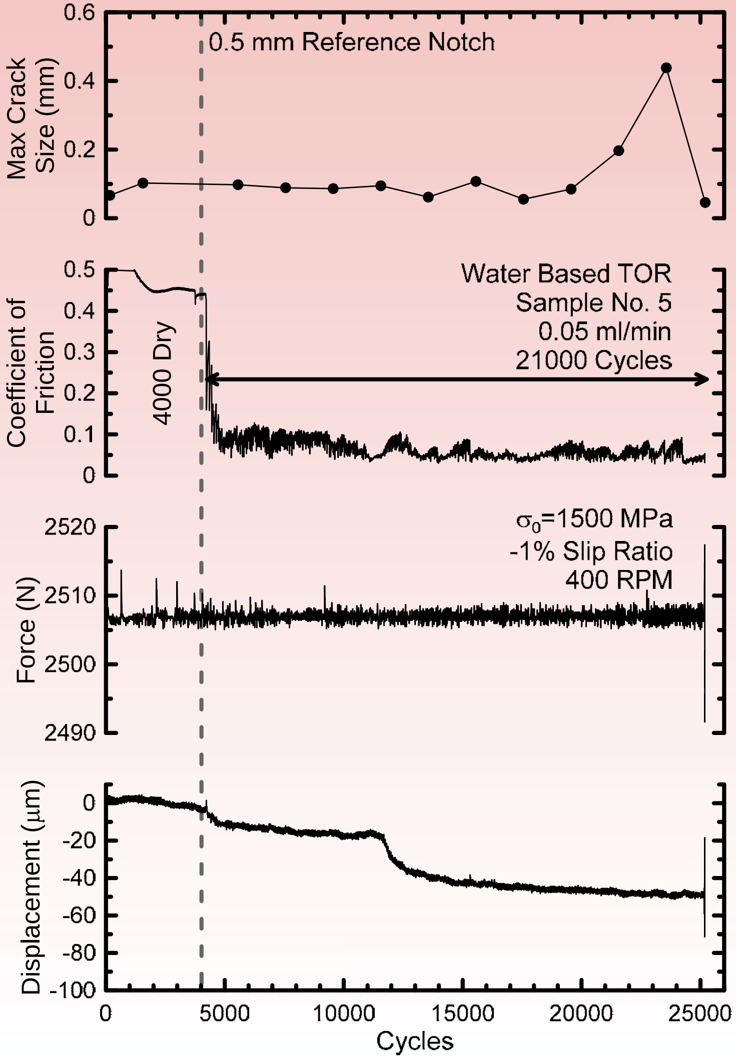
0.5 mm Reference Notch
Max Crack Size (mm)
0.6
0.4
0.2
0
Coefficient of Friction
0.5
0.4
0.3
0.2
0.1
0
4000 Dry
Water
Low Flow Rate
0.05 ml/min
4852 Cycles
σ_0=1500 MPa
-1% Slip Ratio
400 RPM
Force (N)
2520
2510
2500
2490
Displacement (μm)
0
-100
-200
-300
-400
-500
-600
0
5000
10000
15000
20000
25000
Cycles

Water Based TOR Part 1

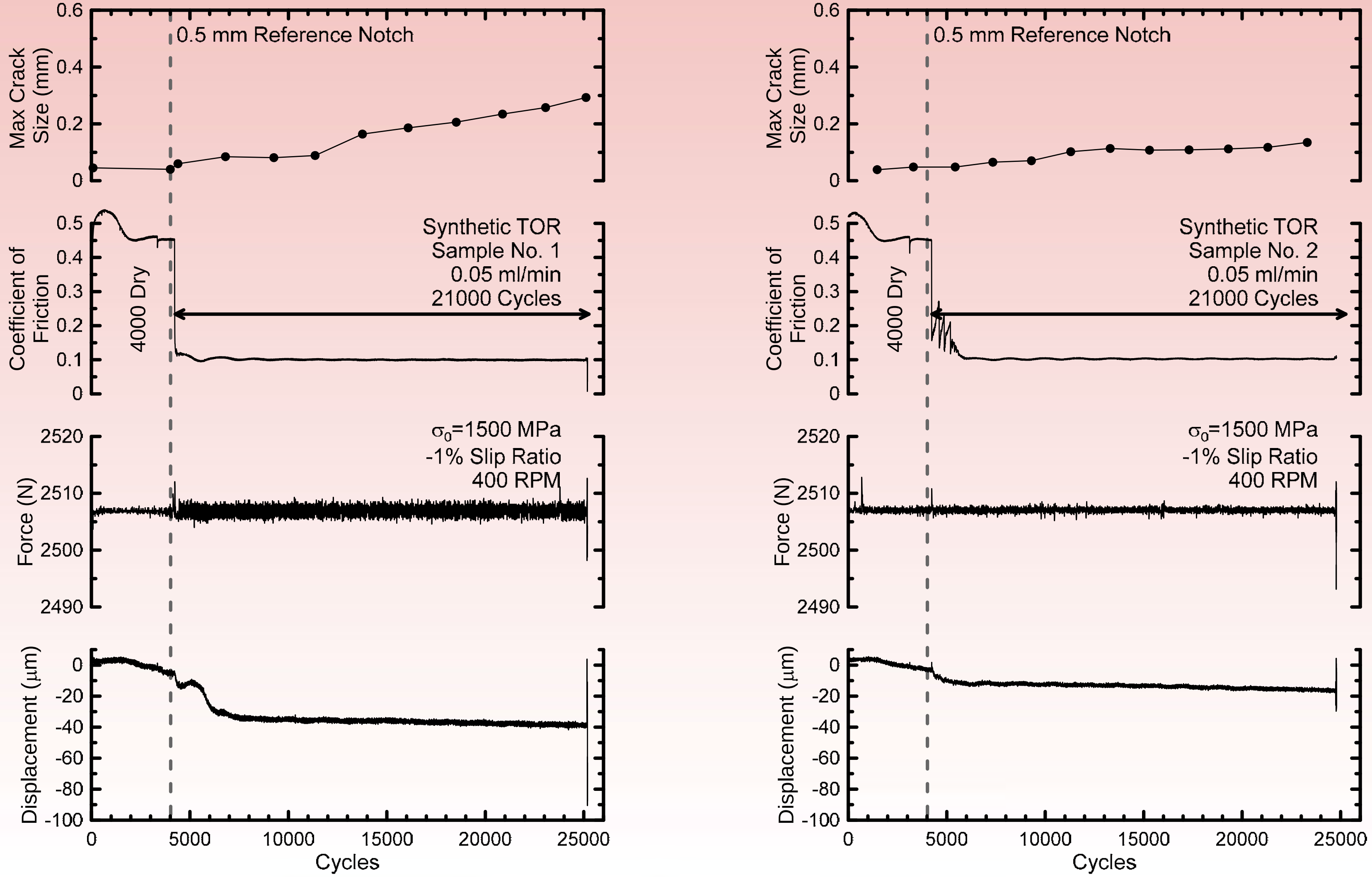


Water Based TOR Part 1

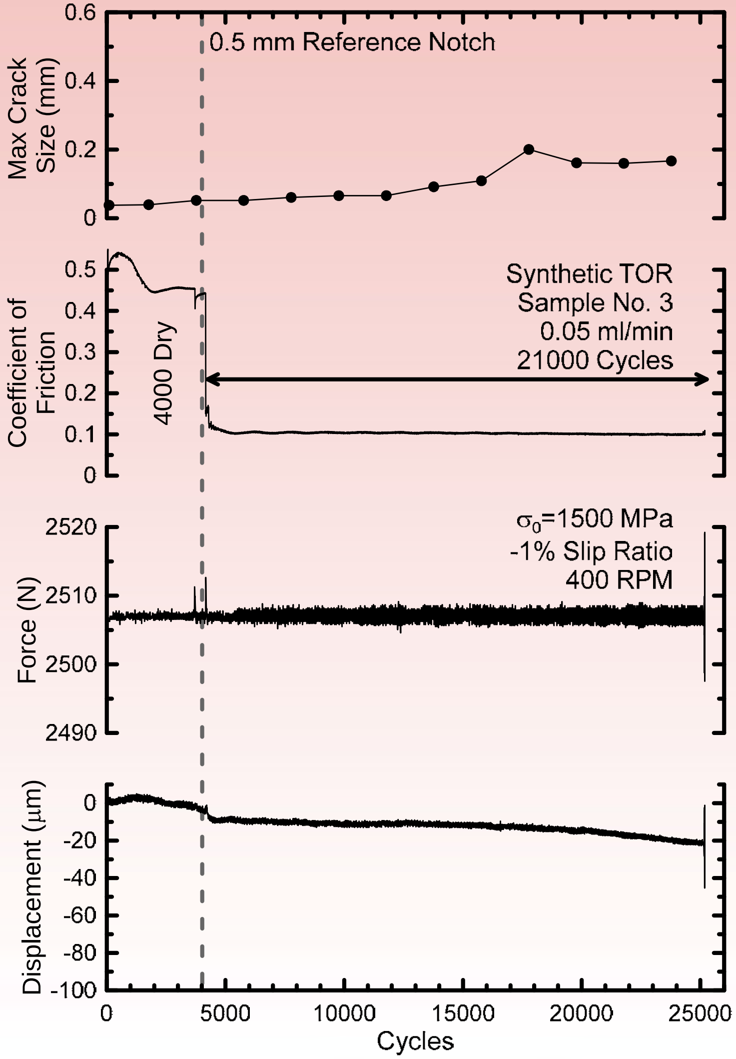


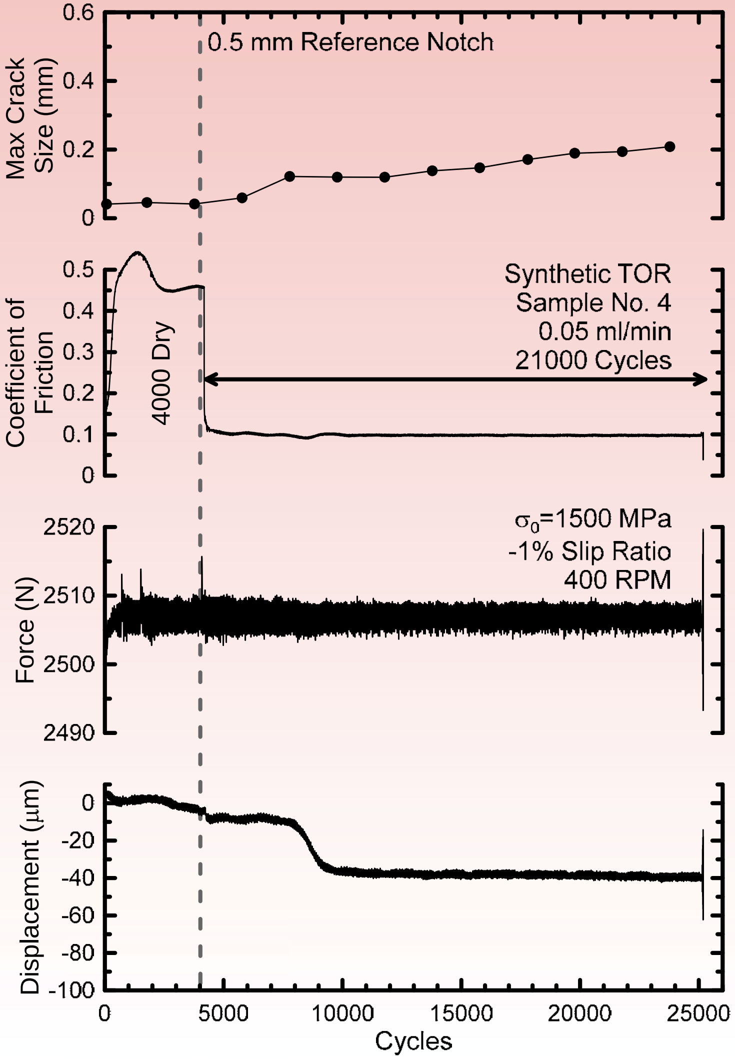


Synthetic TOR Part 1

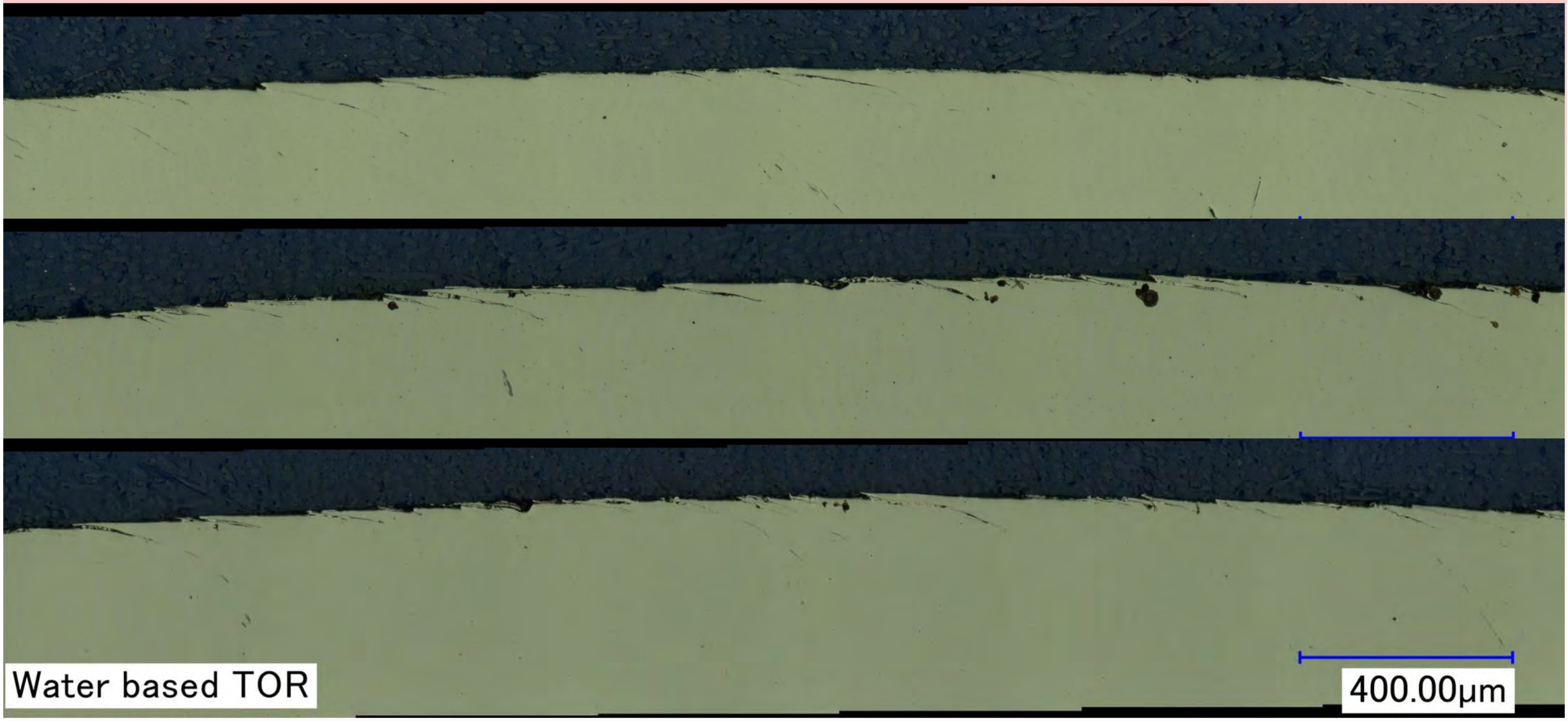


Synthetic TOR Part 1

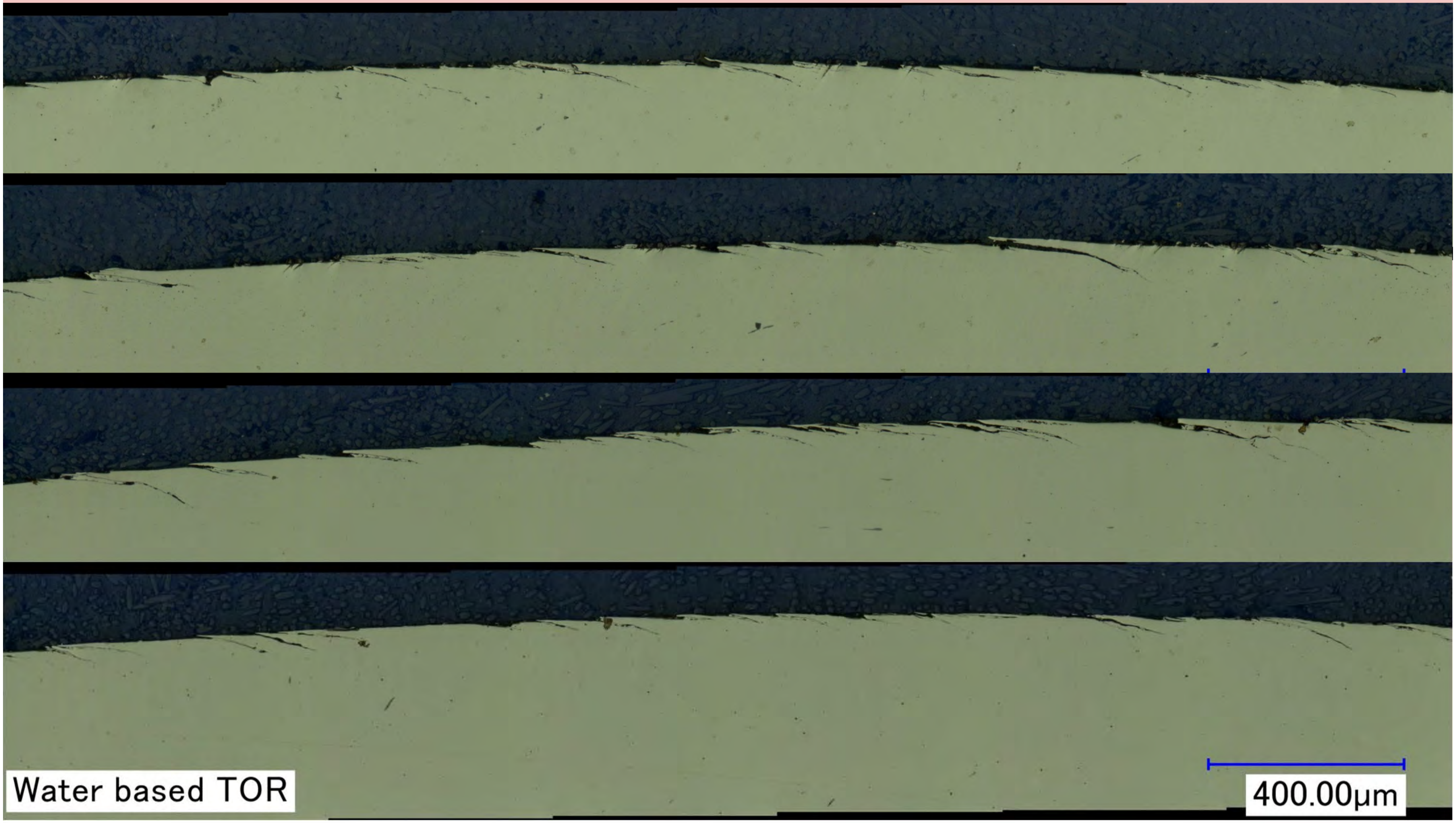




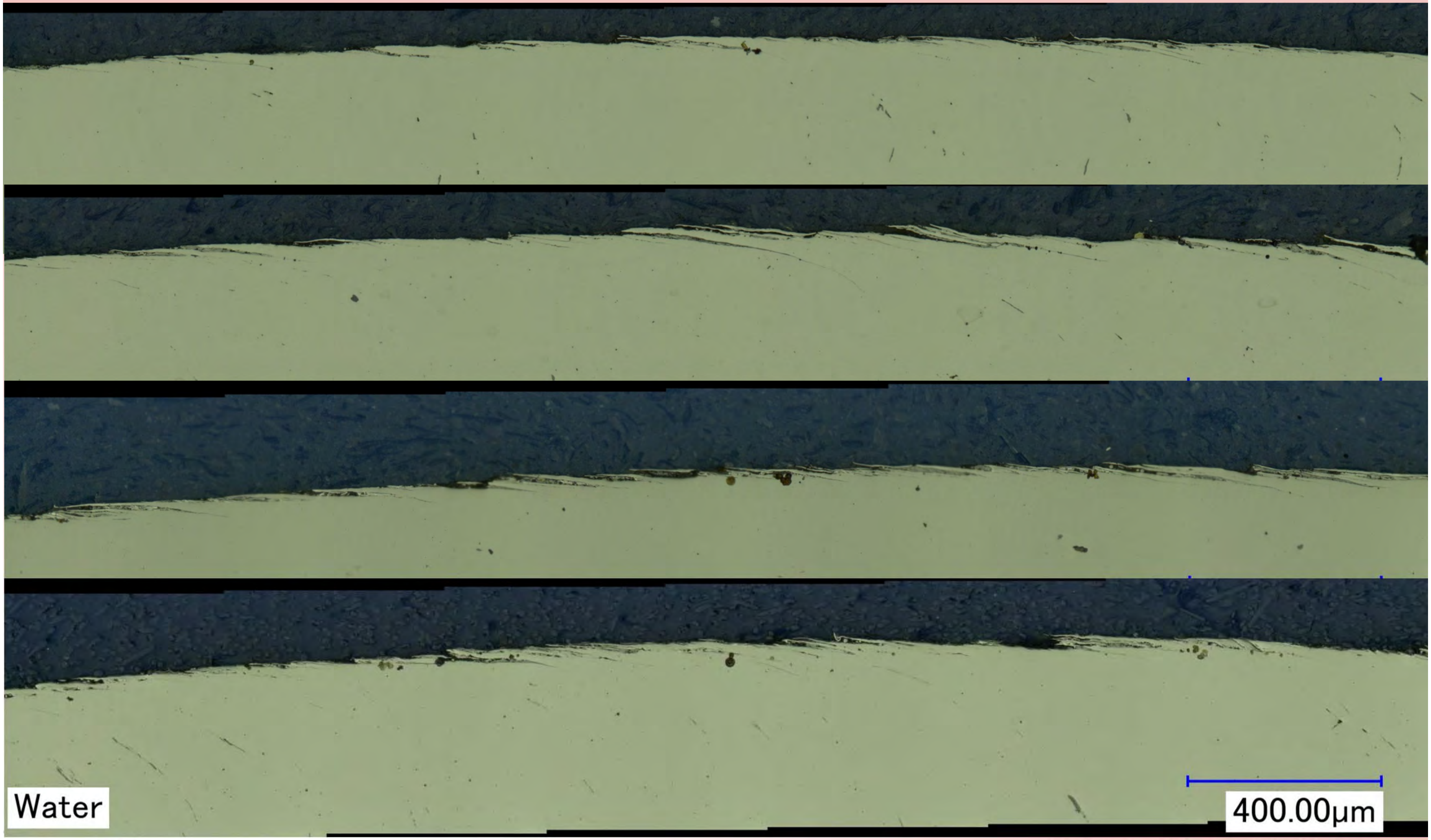
Water Based TOR Part 1



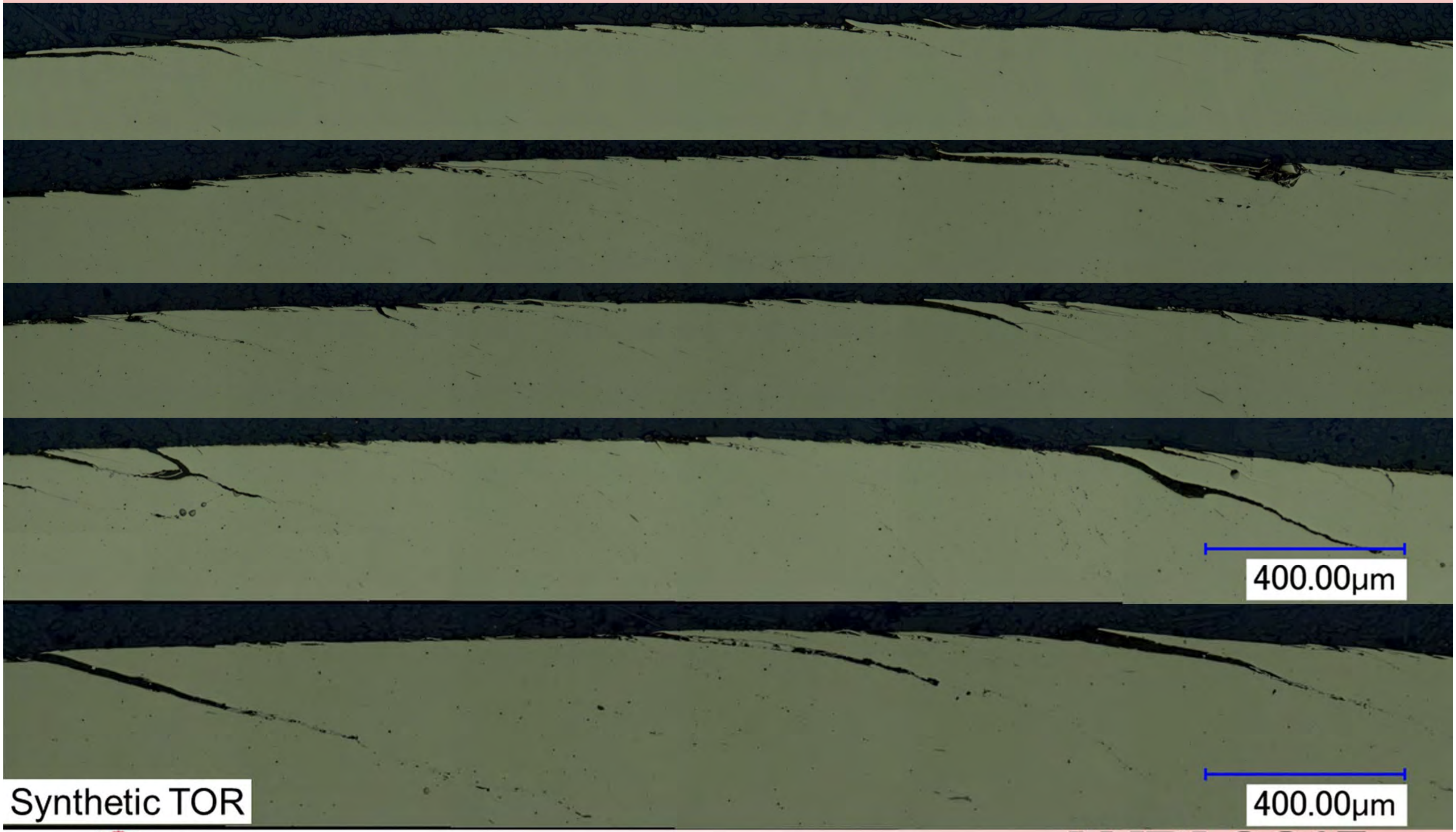
Water Based TOR



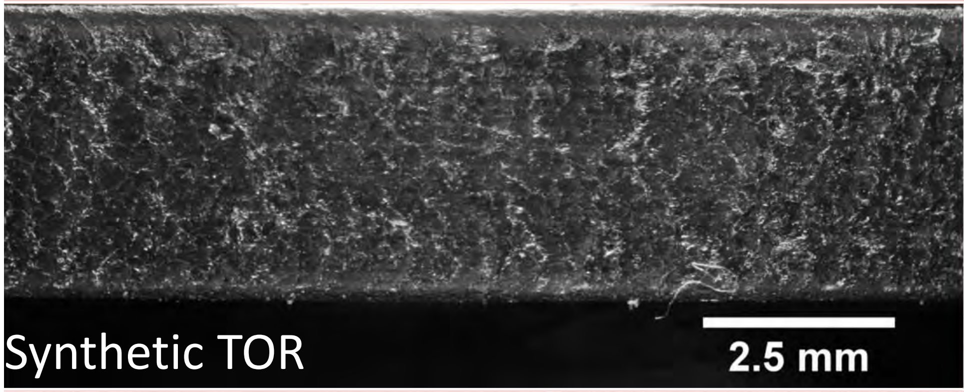
Water – 0.05 ml/min



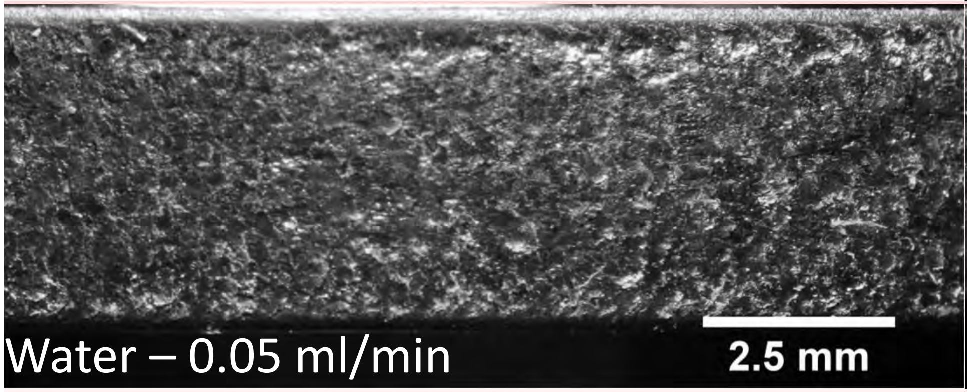
Synthetic TOR

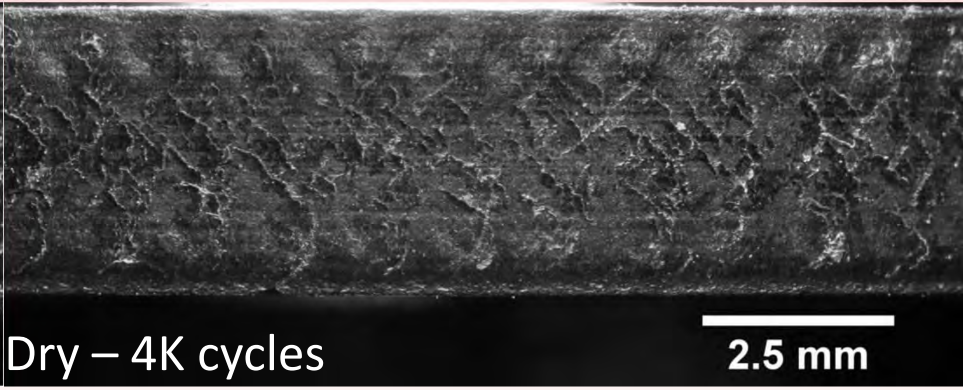


Dry, 21k Lubricated

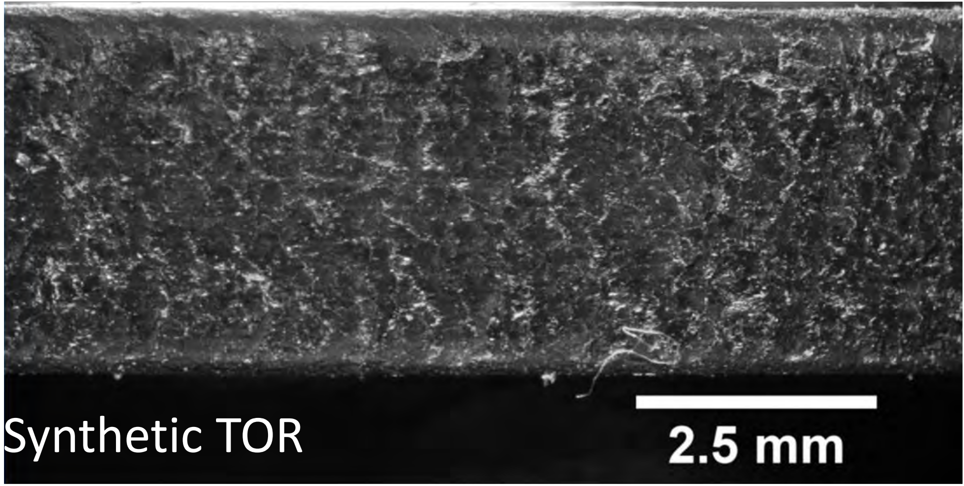

Synthetic TOR


Water Based TOR

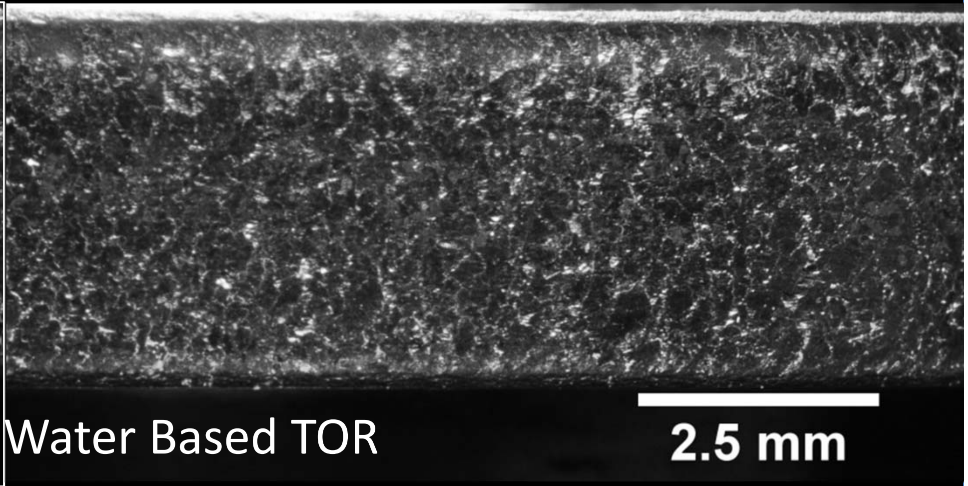

Water – 0.05 ml/min


Dry – 4K cycles

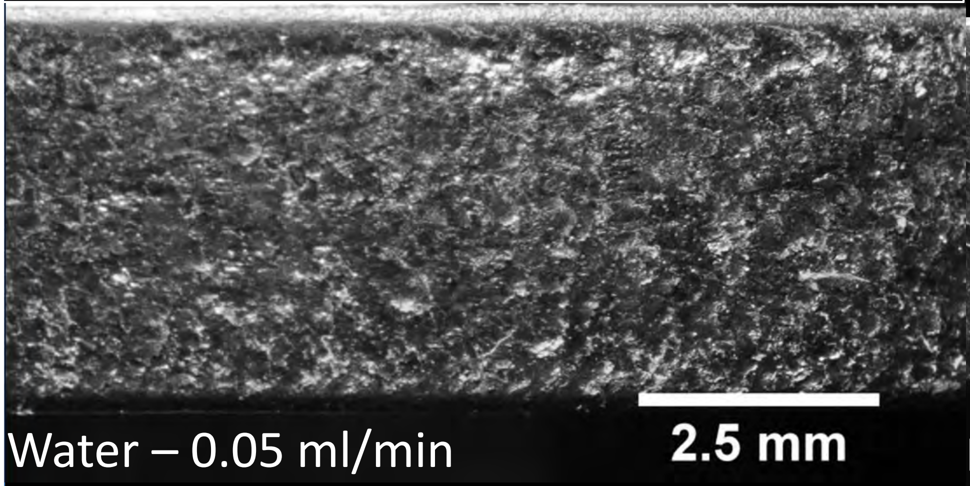
4k Dry – 21k Lubricated



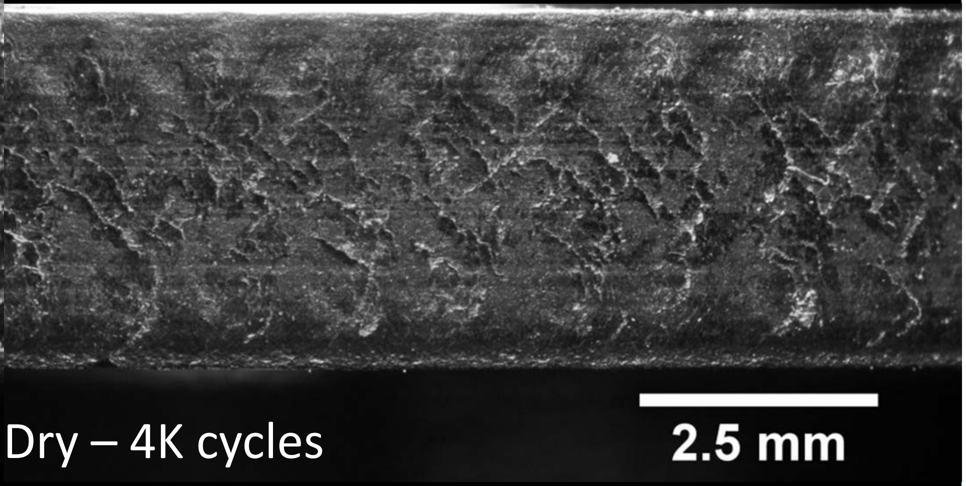
Synthetic TOR



Water Based TOR

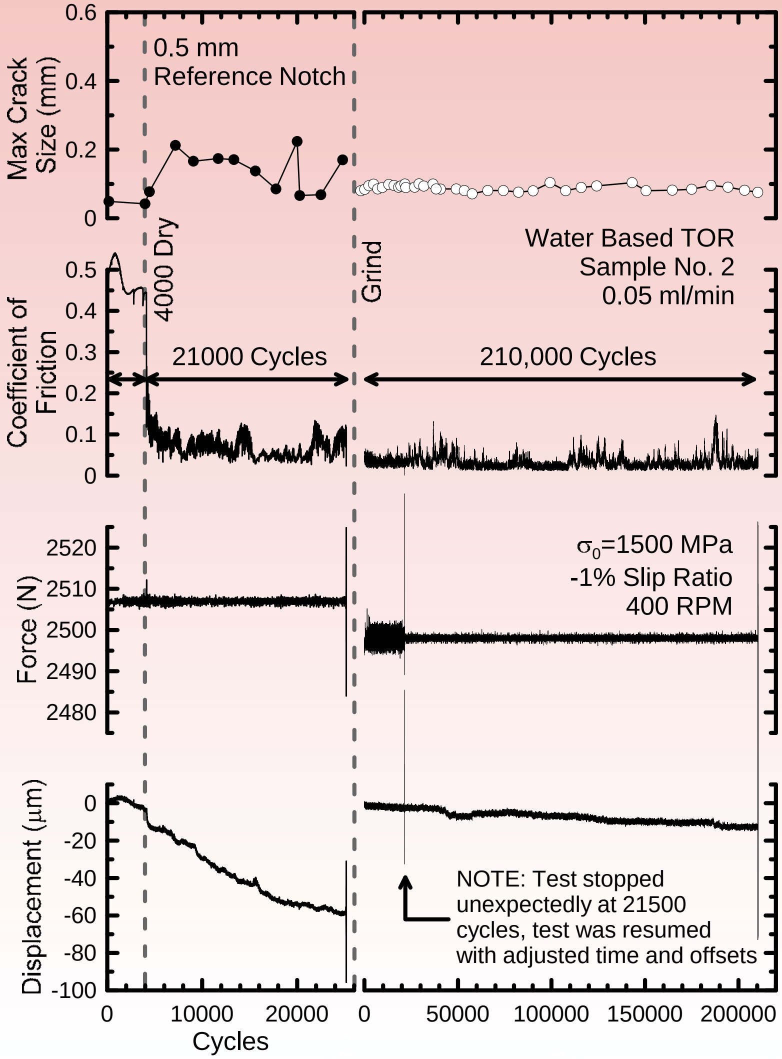


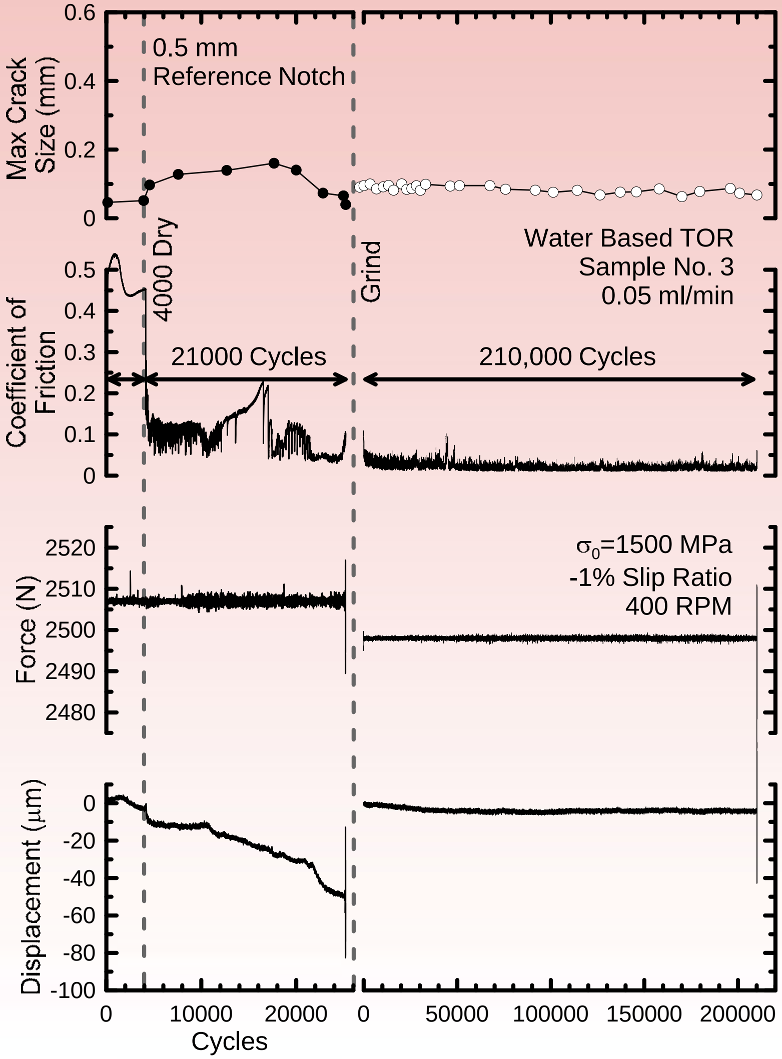
Water – 0.05 ml/min



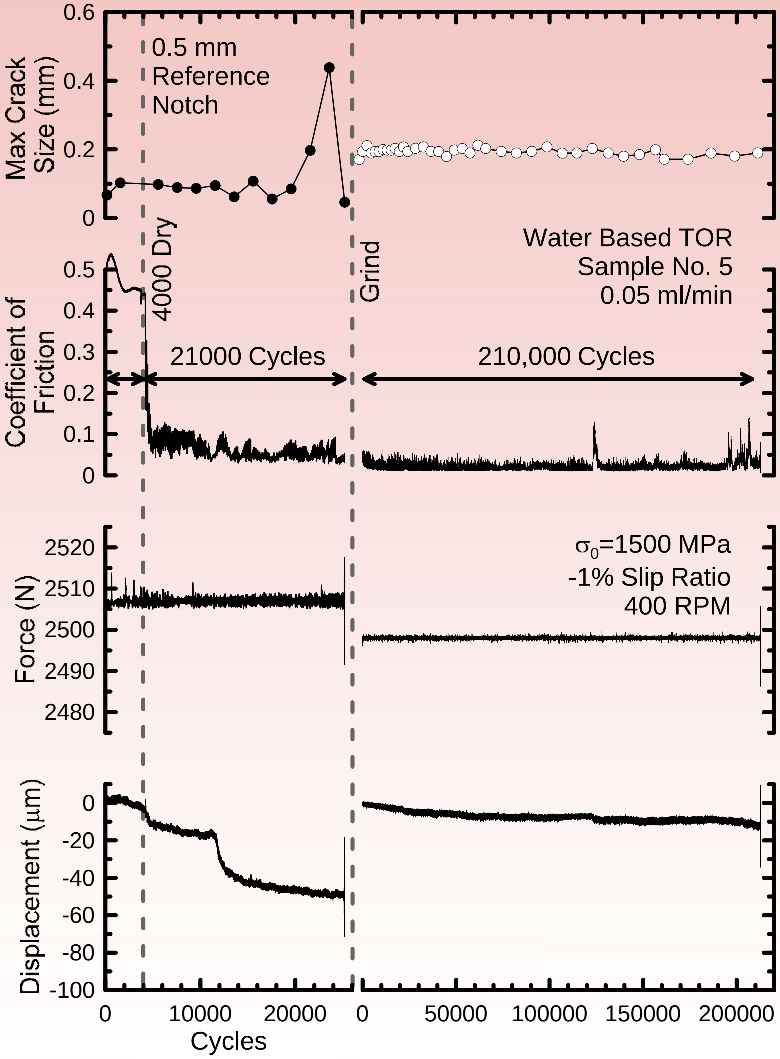
Dry – 4K cycles

Water Based TOR Part 2

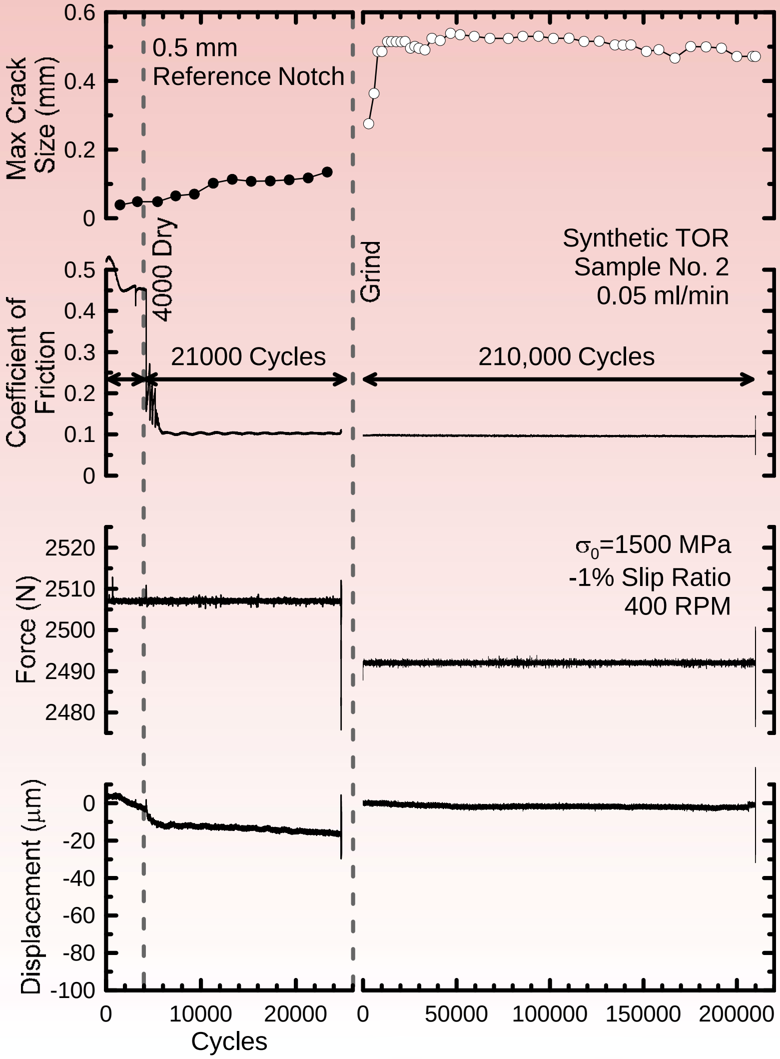


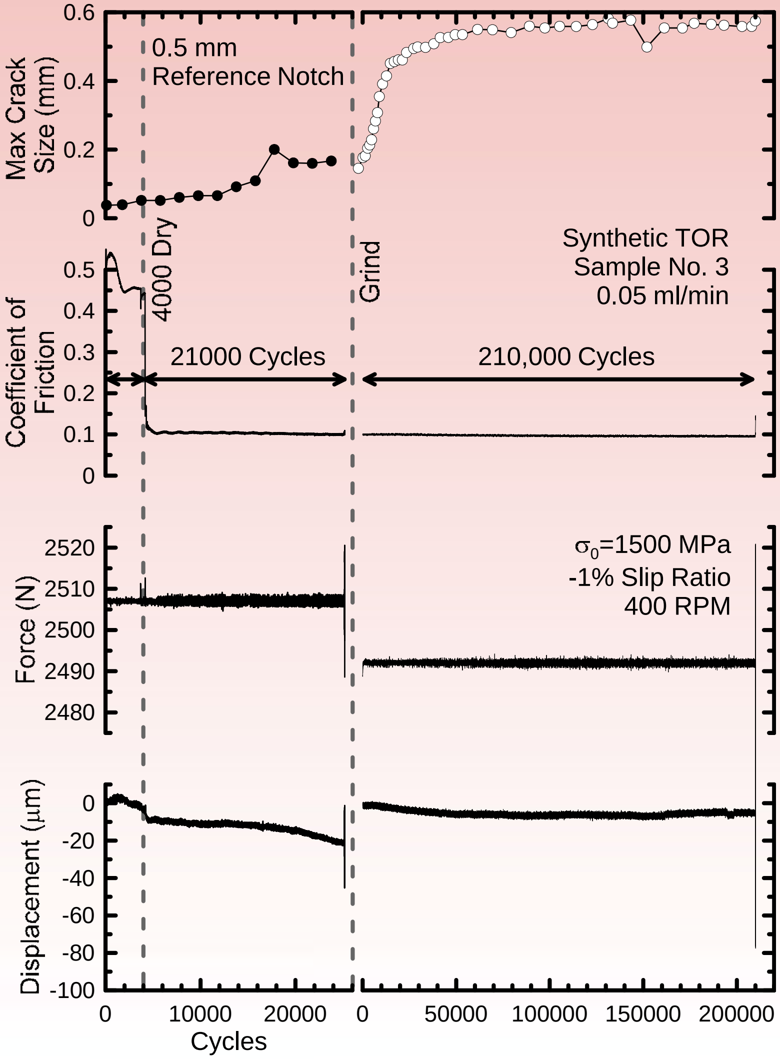


Water Based TOR Part 2

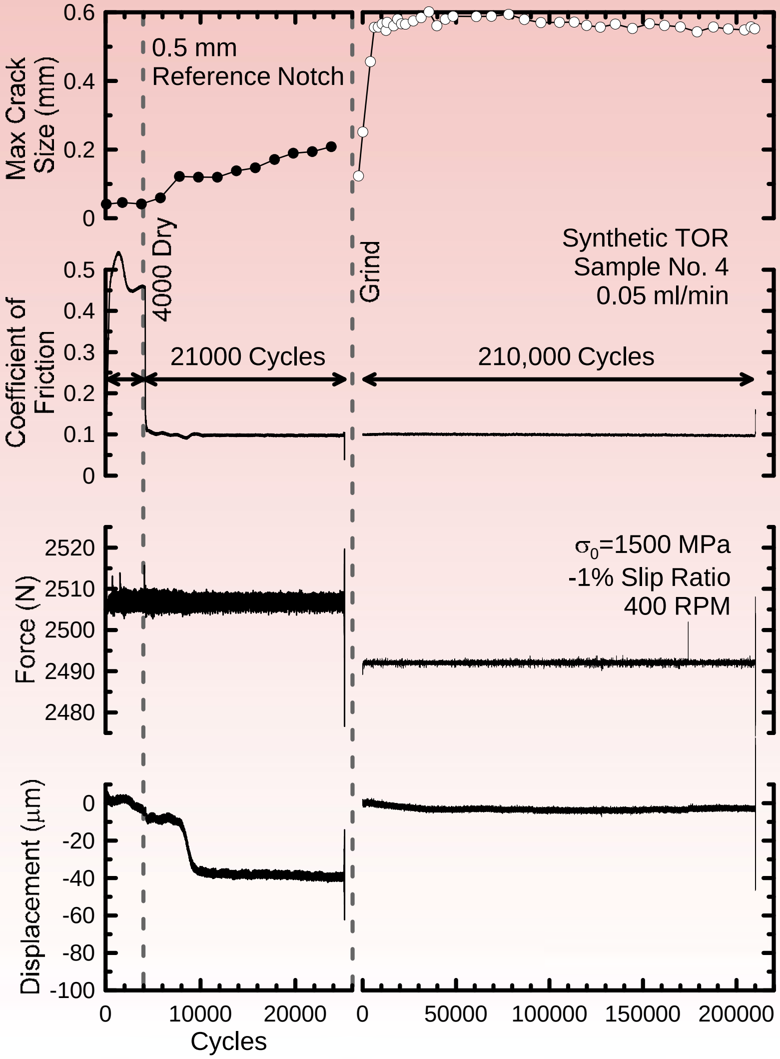


Synthetic TOR Part 2



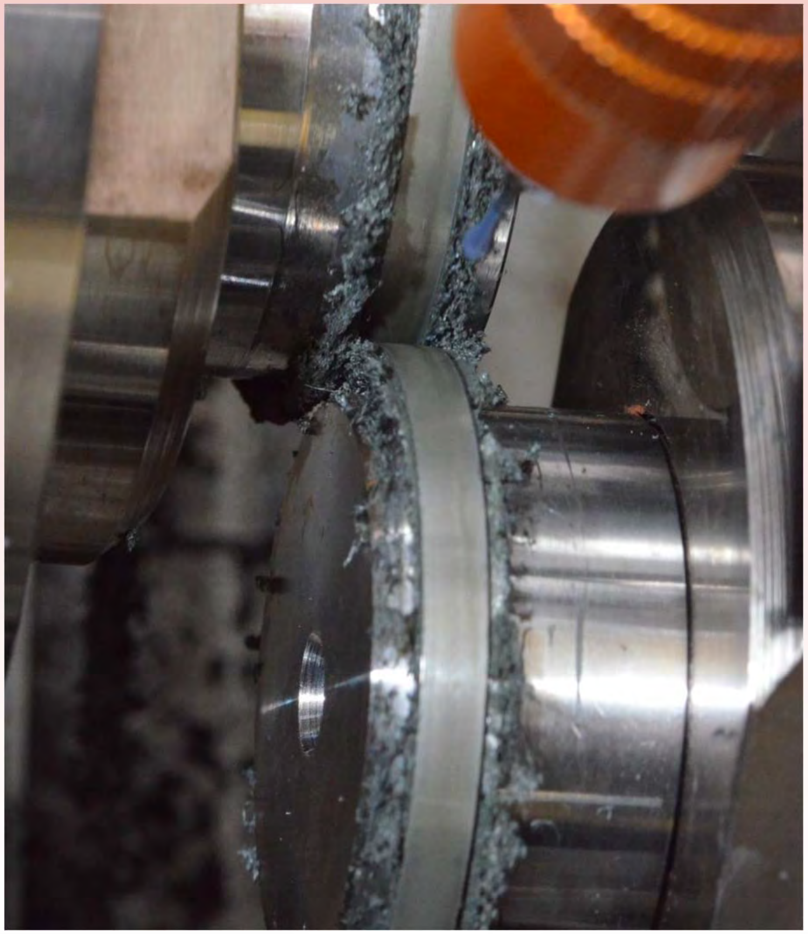


Synthetic TOR Part 2



210K Lubricated

Water Based TOR



Synthetic TOR