Daimler Surveillance Panel Meeting Minutes

May 14, 2018
11:00 AM – 1:00 PM CST

Call Participants:
Lubrizol - Patrick Joyce, Kevin O'Malley, John Loop and Greg Matheson
Southwest Research Institute – Jose Starling, Jim McCord
Intertek – Jim Moritz, Josh Ward, Juan Vega
Daimler - Suzanne Neal, Greg Braziunas
Infineum - Jim Gutzwiller, Elisa Santos, David Brass, Bob Salgueiro, Jun Cui
Chevron Oronite – Mark Cooper, Jo Martinez
TEI – Mark Sutherland
TMC – Sean Moyer
Afton – Bob Campbell, Christian Porter

Unfinished Business

Oil C Run Update

Lubrizol had reached the 2 kPa crankcase pressure point at 155 hours on their Oil C test (Batch C liners), but was still waiting on ICP data confirmation to calculate actual hours to scuff result. Intertek at the time of this call was at the 180 hour soak with no signs of scuffing.

Review Liner Analysis Presentation – Bob Salgueiro

Infineum performed additional analysis comparing PNB and Batch C liners using similar techniques as had previously been discussed (SEM, EDS, etc). The difference in the graphite flakes between PNB and Batch C liners were highlighted in this analysis as well which aligns with the analysis presented by Southwest in the previous meeting. The presentation with complete analysis done by Infineum is attached to these minutes. It was commented by Greg that the analysis is valuable but unfortunately doesn't address how these differences impact test severity. The differences in the liners including different supplier and casting process have been known so it was stated that some of these differences shown in the analysis are not un-expected. It was also mentioned that this is the batch of liners we have to work with on this test and any other options are extremely limited.

Review Reference Oil Statistical Analysis – Kevin O'Malley

Kevin presented his statistical analysis and showed various models for the purpose of discussion but mentioned that although various models can be fit to the data none of them are actually appropriate for this test given the collinearity. At the end of the presentation it was discussed that coupled interactions between the ring and liner batches should be considered closely in the statistical analysis. This includes impacts of Batch B rings and their interactions with PNB liners and Batch B rings and Batch C liners, etc. Kevin will take this as an action item. This presentation by Lubrizol with further description of the analysis is also attached to these minutes.

Batch C Liner Next Steps – SP

Discussion took place in the panel as to what should be done next. There were various options discussed including turning the test back on and continue monitoring as additional references where conducted. Also, the option was presented to try to separate the impact of each component via additional testing. It was suggested that before deciding what to do next we should look at the operational and chemical data from these Oil C runs being run at Intertek and Lubrizol to verify nothing odd can be observed. It was also mentioned that with this data it is difficult to proceed with the test as is due to the increased variability that these new Batch C liners seem to be showing. It was discussed that this Oil C being used for these runs was acquired by Detroit Diesel and shipped to TMC. This oil was labeled as 866 which is considered Oil C. It was mentioned that the original Matrix Oil C and Oil X formulations where not shipped to TMC but were directly shipped to the labs. After review of the additional data from the current Oil C runs and any additional statistical analysis presented, the next meeting will be focused on a path forward for the test.

Next Meeting:

Next meeting is scheduled for Thursday May 24th, 2018 from 9:30 AM to 11:30 AM CST.

DD13 Liner Analysis – Batch C vs PNB

Presented to the Daimler Surveillance Panel

May 14, 2018

Performance you can rely on.

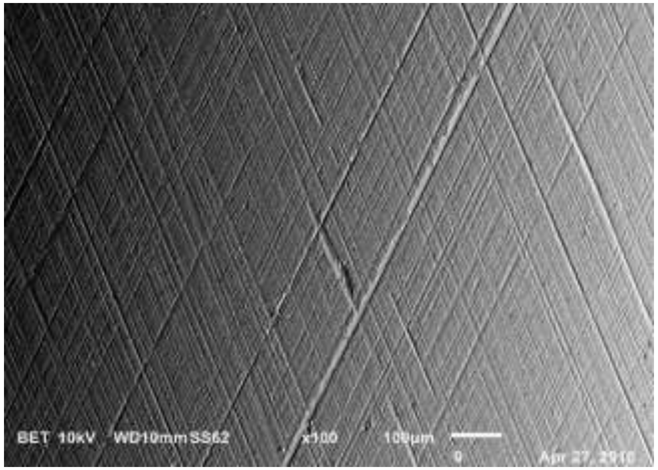
Overview

- Purpose – assess and compare the surface and metallurgy of Batch C liners in comparison to previous PNB liners

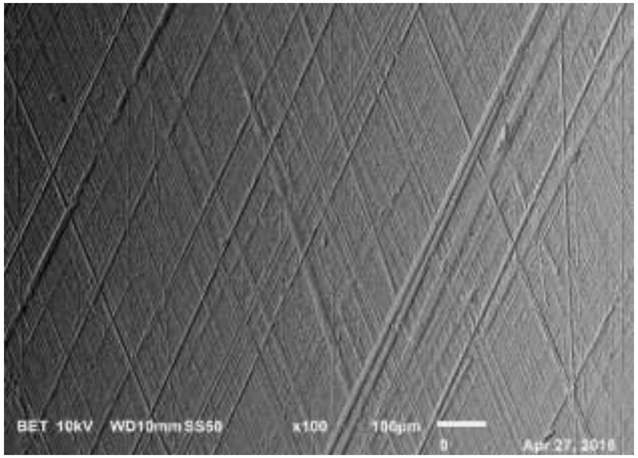
- Methodology –
  – Scanning Electron Microscope (SEM) - observe the topography of the liner surfaces
  – SEM cross-section – measure the microstructure of the liners
  – Energy Dispersive X-Ray Spectroscopy (EDS) - measure the element composition
  – White Light Interferometry (WIL) – measure surface roughness
  – Vickers Hardness Test – measure surface hardness

SEM - BET Mode TDC

PNB

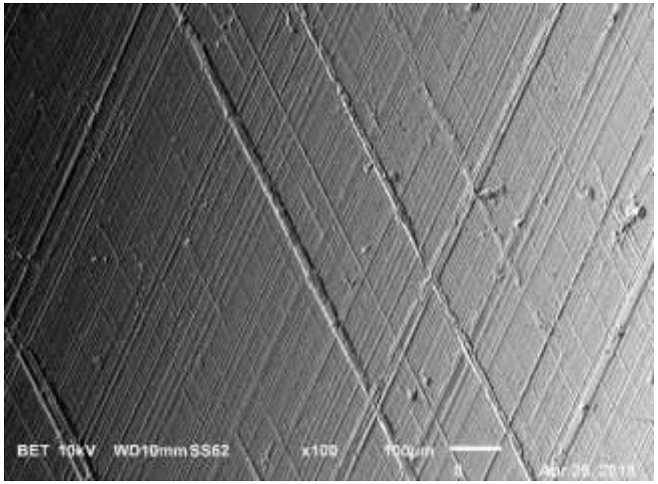


Front

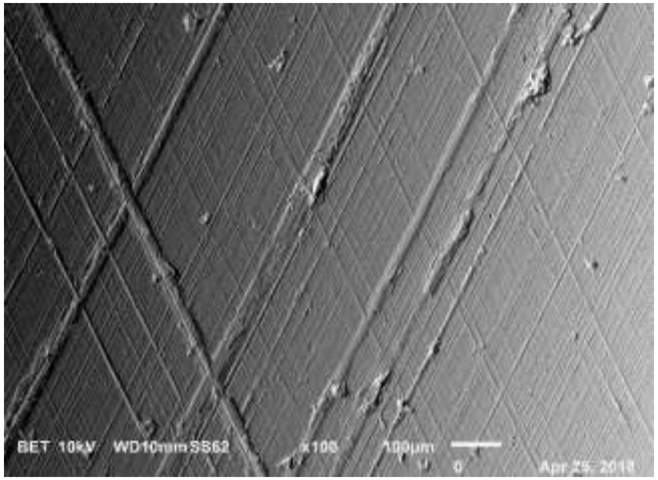


Thrust

Batch C



Front



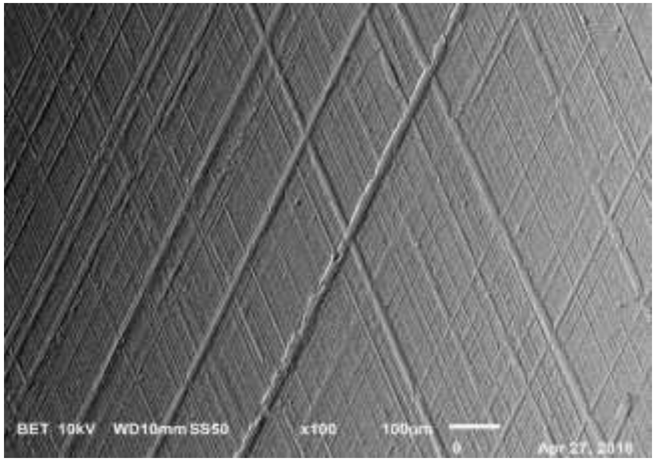
Thrust

Infineum information shared with the Daimler Surveillance Panel

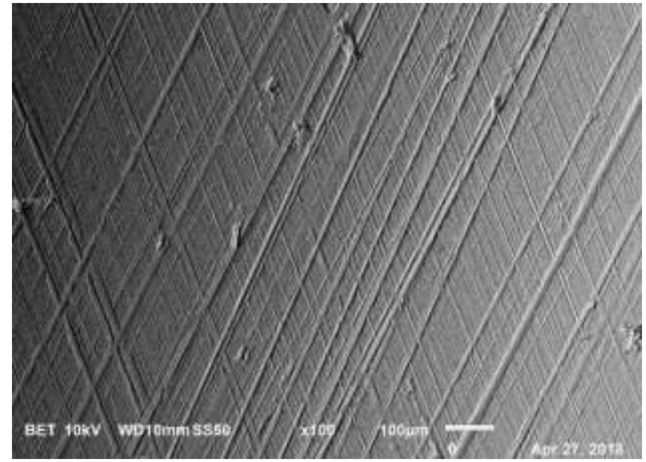
SEM - BET Mode Mid-Stroke

Infineum

PNB

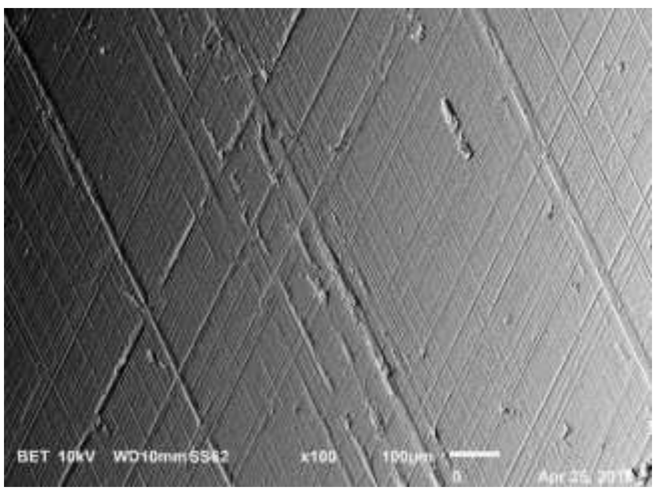


Front

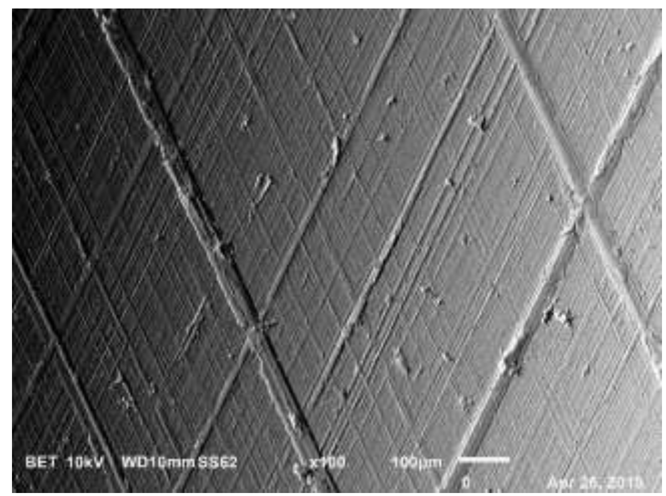


Thrust

Batch C



Rear

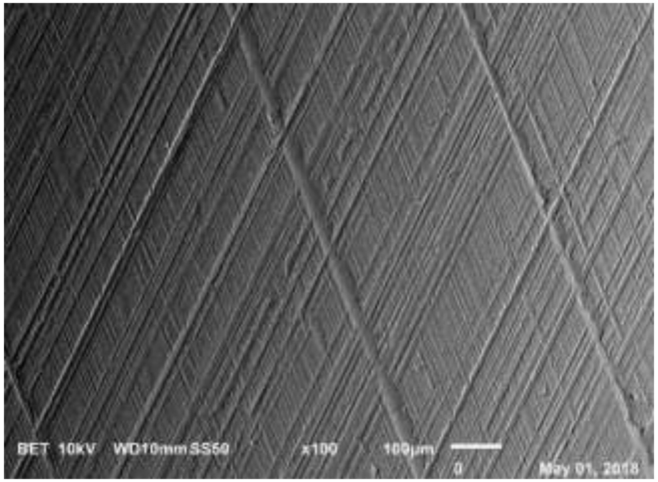


Anti-Thrust

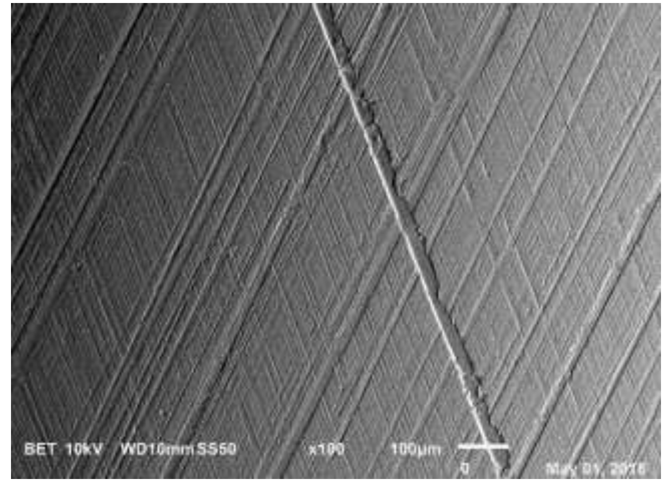
Infineum information shared with the Daimler Surveillance Panel

SEM - BET Mode BDC

PNB

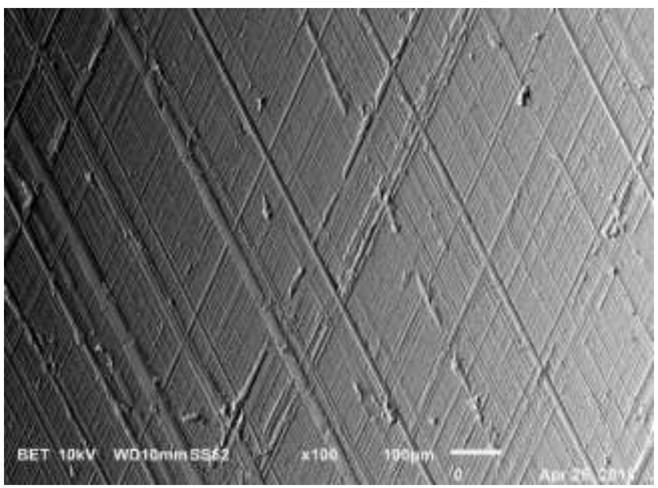


Thrust

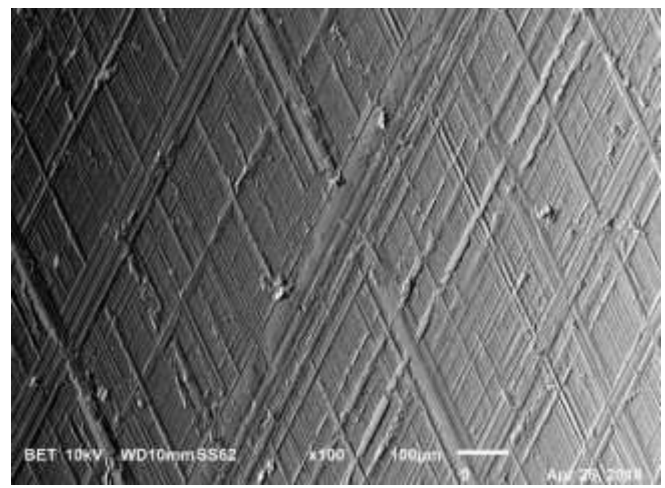


Front

Batch C

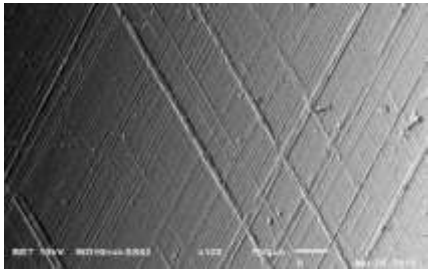


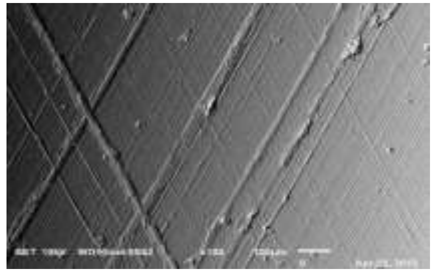
Anti-Thrust

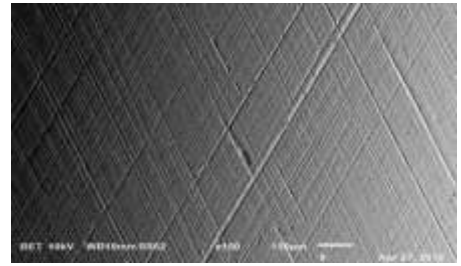


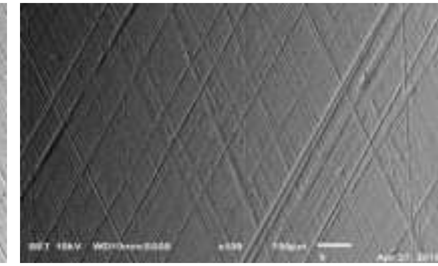
Rear

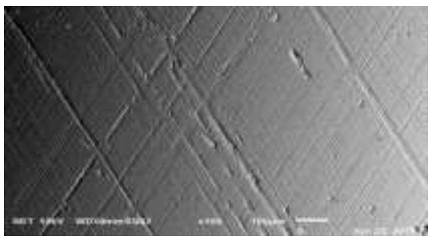
Honing Variance From TDC to BDC Using BET

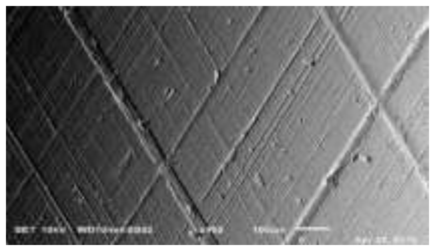

Front TDC Batch C

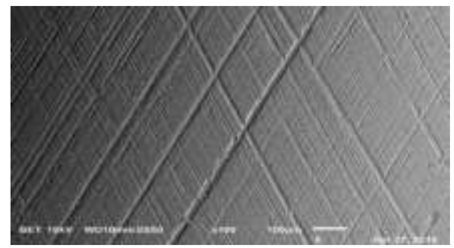

Thrust TDC Batch C

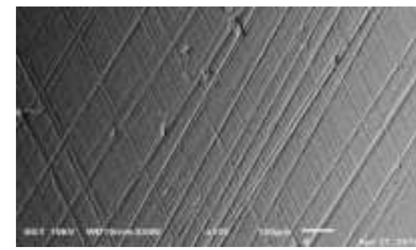

TDC Front PNB

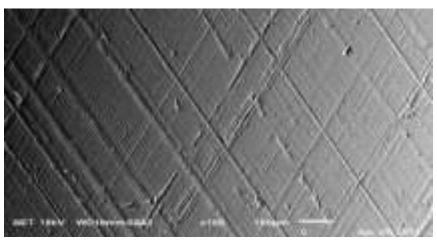

TDC Thrust PNB

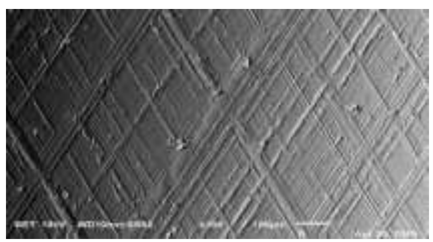

Rear Mid Stroke Batch

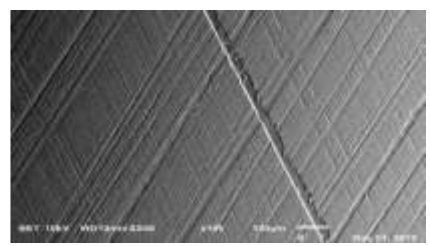

AT Mid Stroke Batch C

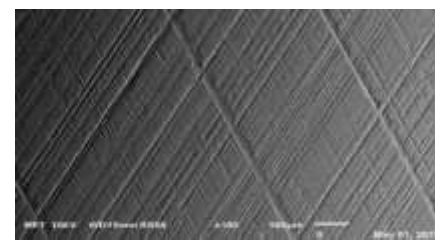

Front Mid Stroke PNB


Thrust Mid Stroke PNB


BDC AT Batch C

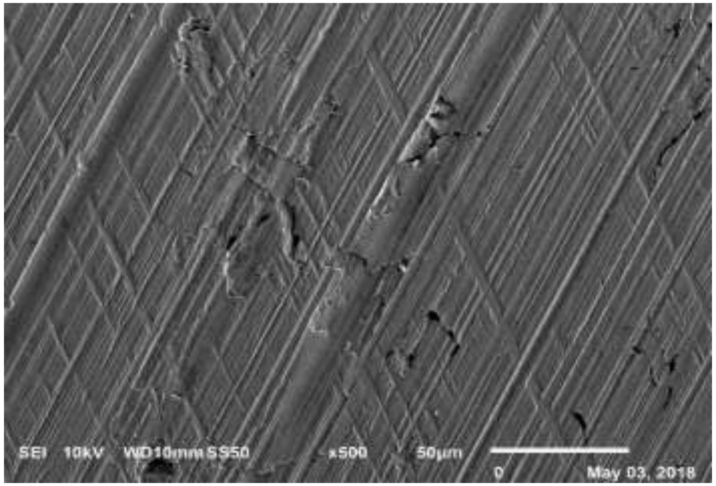

BDC Rear Batch C

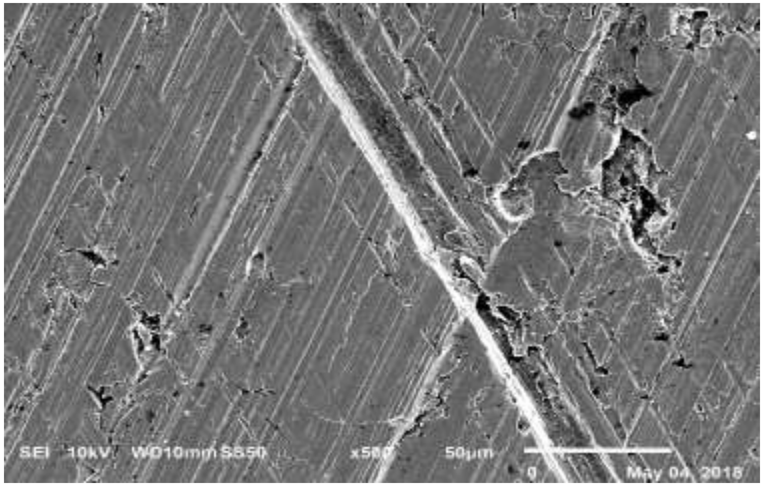

BDC Front PNB

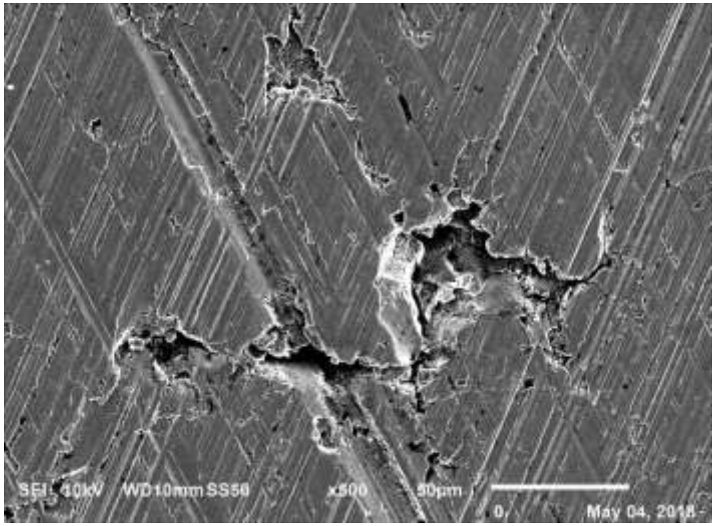

BDC Thrust PNB

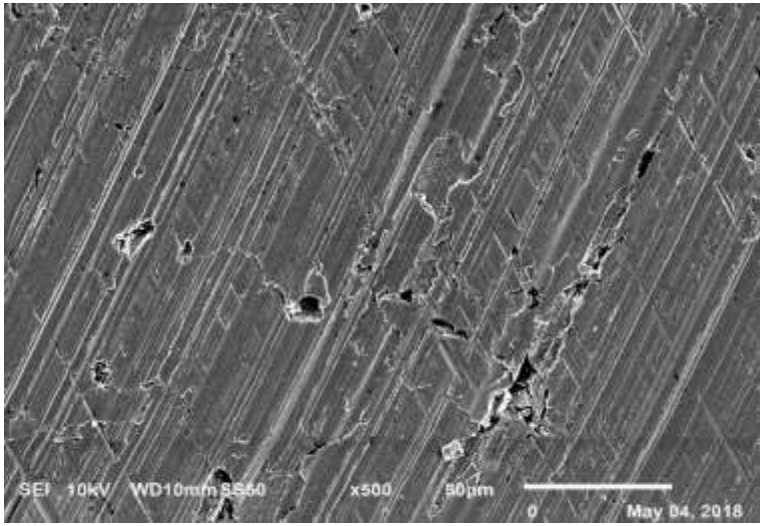
- PNB Liners show a more consistent hone distribution from TDC to BDC
- Both Liners have a higher hone density as approaching BDC
- Batch C shows more defects in the face of the liner

Batch C Surface Irregularities







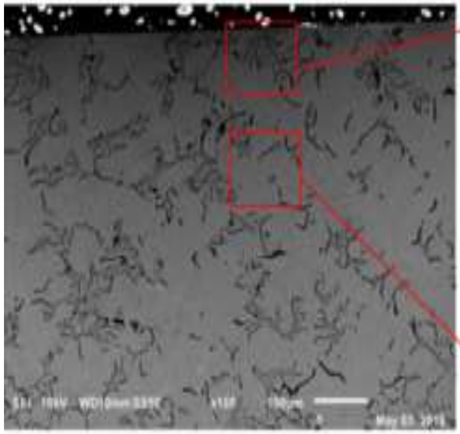


- Potential Cracking identified in multiple locations on Batch C Liners

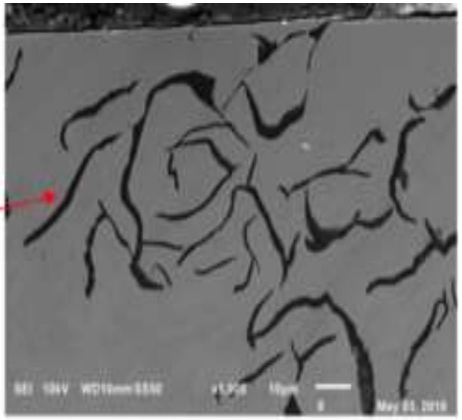
Infineum information shared with the Daimler Surveillance Panel

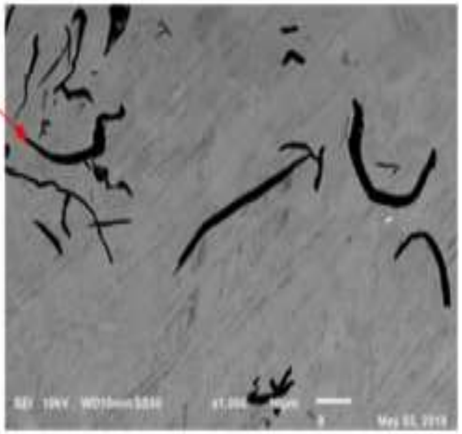
Cross Section Comparisons at Liner ID

Batch C



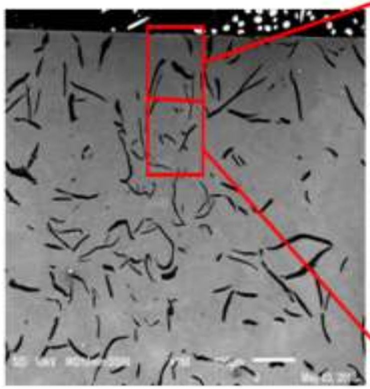
Near ID Surface, SEI
x150



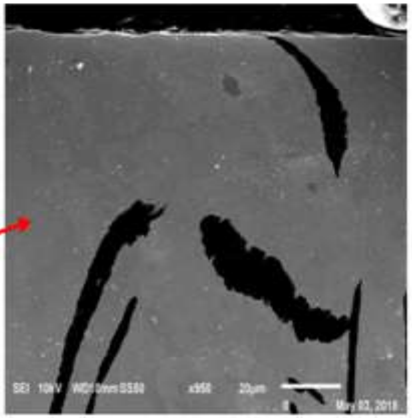


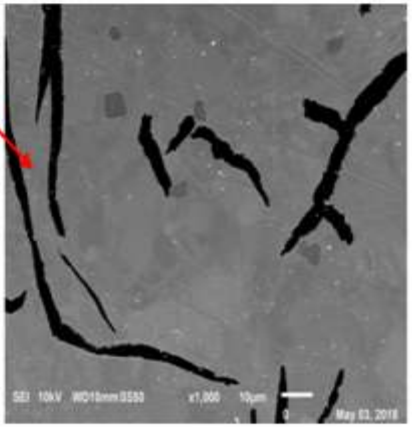
SEI x1000

PNB



Near ID Surface, SEI
x150

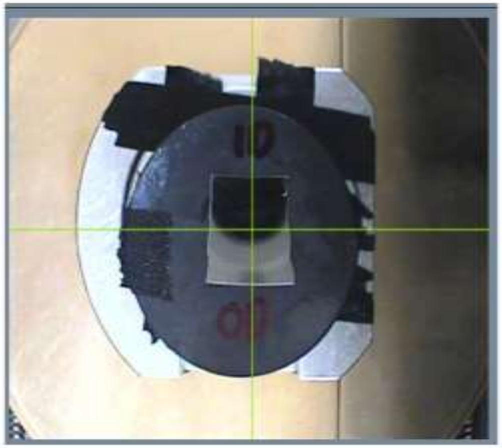




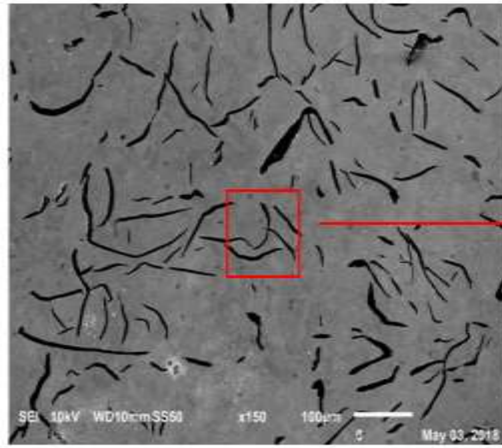
SEI x1000

Cross Section Comparison Mid Liner

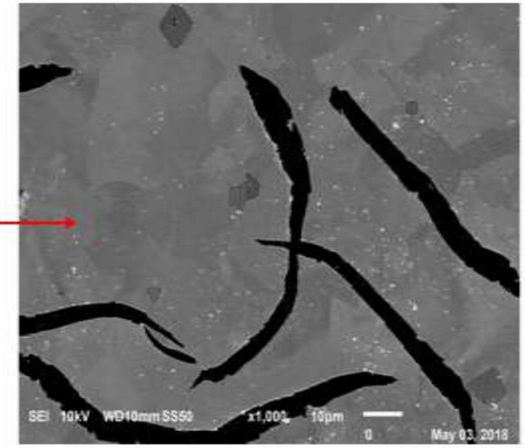
PNB



Location on Liner

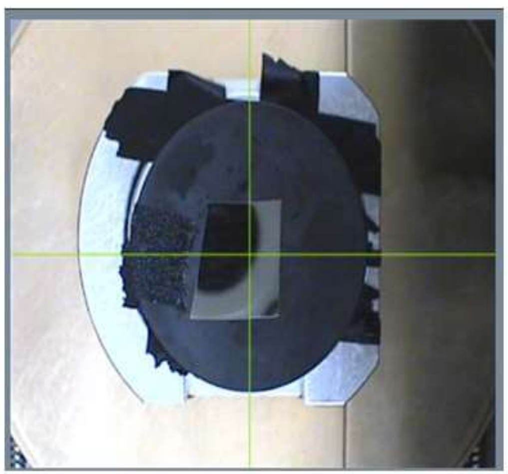


Mid-section , SEI x150

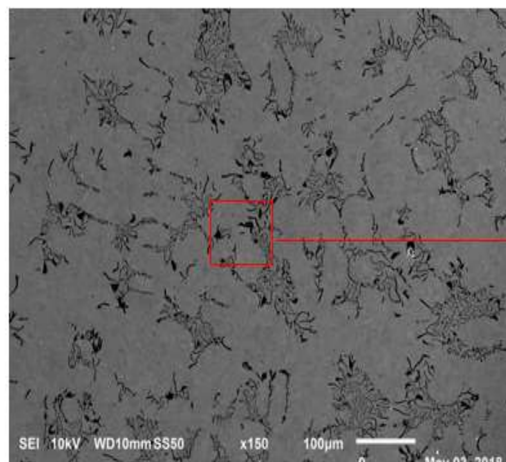


SEI x1000

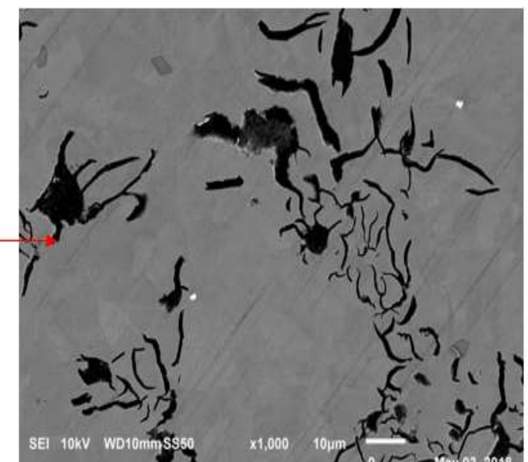
Batch C



Location on Liner



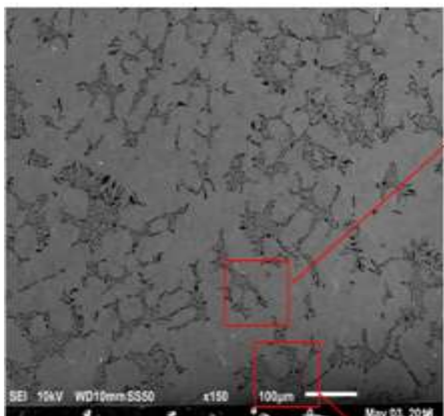
Mid-section , SEI x150



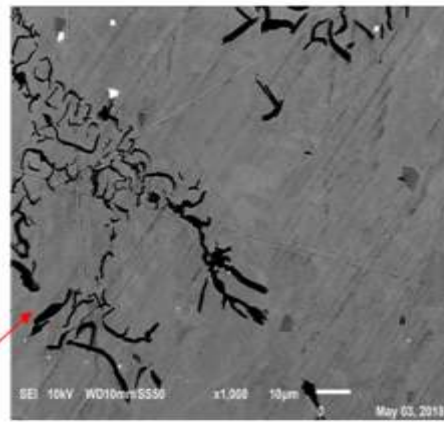
SEI x1000

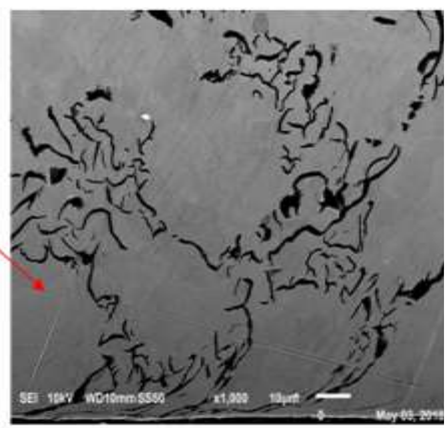
Cross Section Comparisons at Liner OD

Batch C



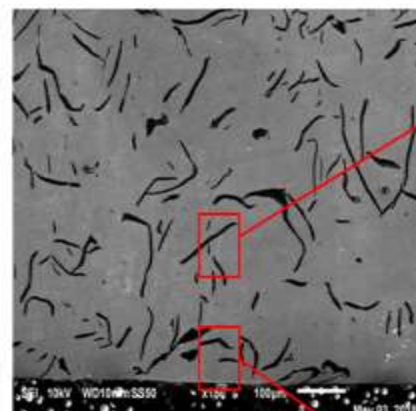
Near OD Surface , SEI
x150



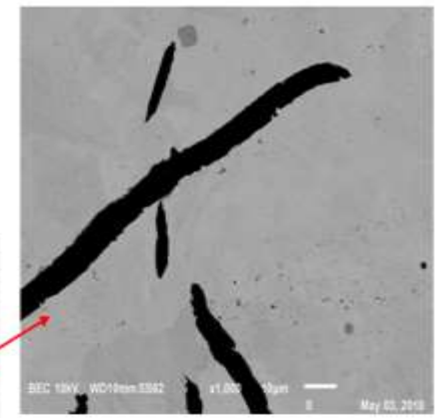


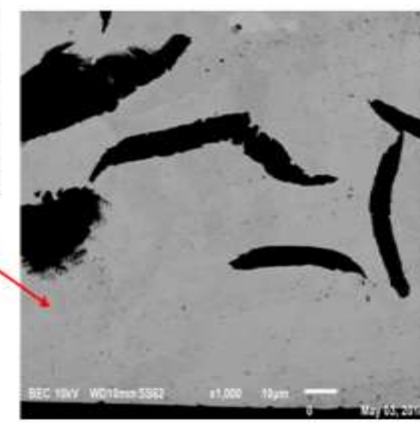
SEI x1000

PNB



Near OD Surface , SEI
x150



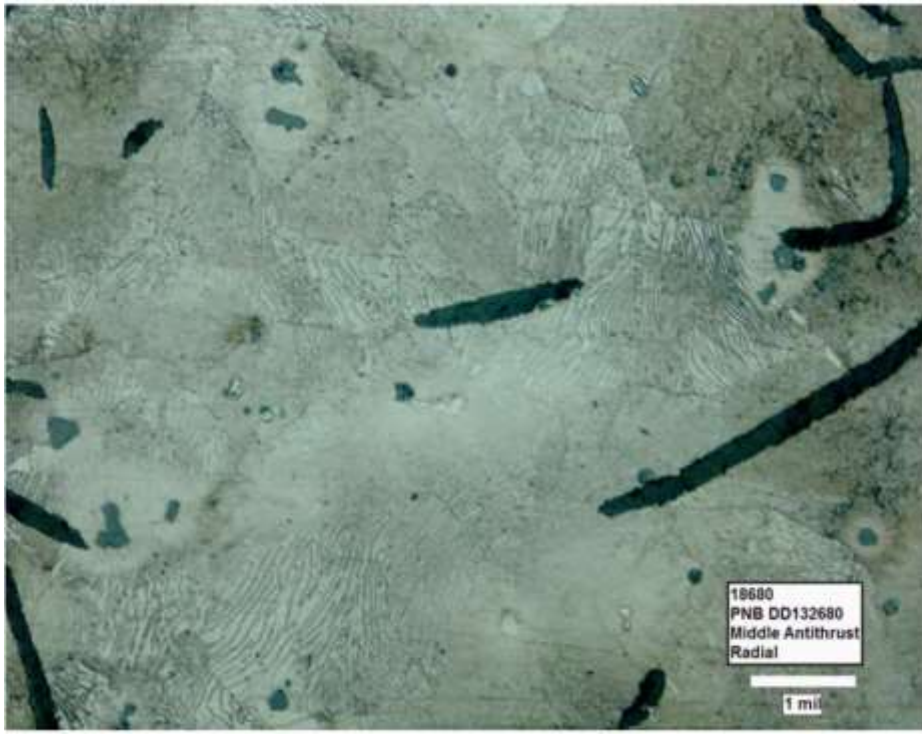


SEI x1000

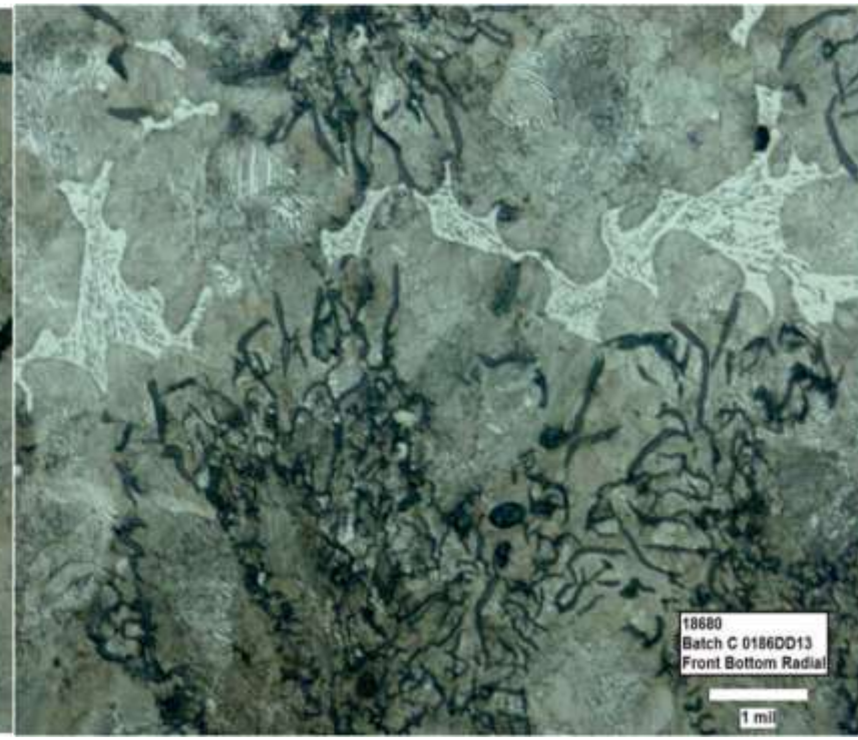
Infineum information shared with the
Daimler Surveillance Panel

Etched Cross Section

PNB



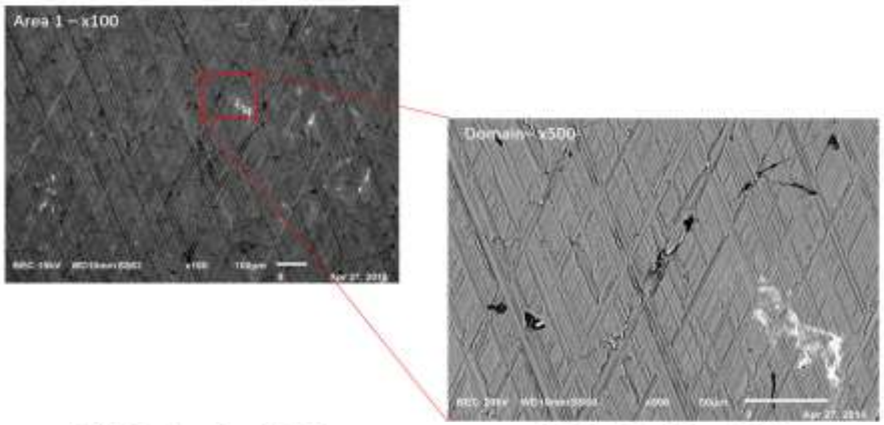
Batch C



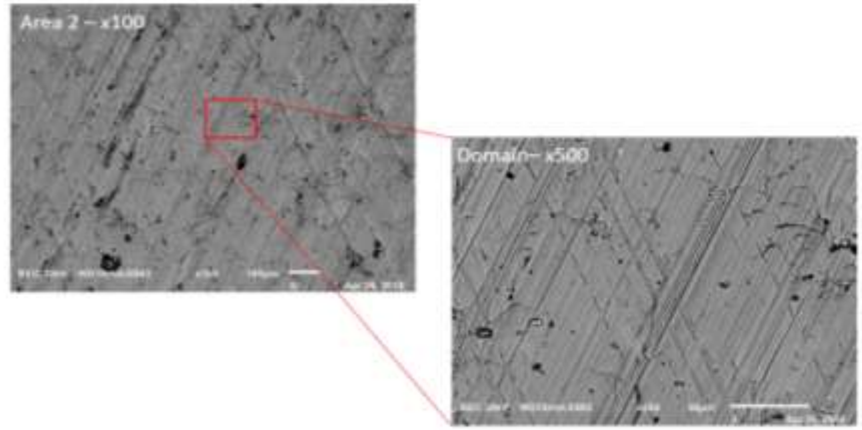
- PNB Liners show a predominant pearlite matrix with a course, randomly oriented graphite flake patterns
- Batch C shows a matrix of pearlite and ferrite with fine graphite flakes in an interdendritic and rosette pattern

EDS Batch C Vs PNB at TDC

PNB EDS Mapping



Batch C EDS Mapping



EDS Mapping – Area 1 x100

Element	Mass %	Mole %
C	5.89	22.21
O	nd	nd
Al*	0.06	0.10
Si	1.83	2.95
P*	0.04	0.06
S*	0.11	0.15
V*	0.03	0.02
Cr*	0.15	0.13
Mn*	0.61	0.51
Fe	90.38	73.28
Ni*	0.04	0.03
Cu*	0.65	0.47
Mo*	0.21	0.10

EDS Mapping – Domain x500

Element	Mass %	Mole %
C*	5.19	19.99
O	nd	nd
Al*	nd	nd
Si	1.81	2.97
P*	0.03	0.05
S*	0.08	0.11
V*	0.04	0.03
Cr	0.17	0.15
Mn	0.46	0.39
Fe	91.33	75.67
Ni*	0.05	0.04
Cu	0.75	0.55
Mo*	0.10	0.05

EDS Mapping – Area 2 x100

Element	Mass %	Mole %
C	9.15	31.35
O	nd	nd
Al*	0.08	0.12
Si	1.91	2.80
P	0.45	0.60
S*	0.06	0.08
V	nd	nd
Cr	0.51	0.41
Mn*	0.18	0.14
Fe	86.90	64.04
Ni*	0.08	0.06
Cu*	0.58	0.38
Mo*	0.09	0.04

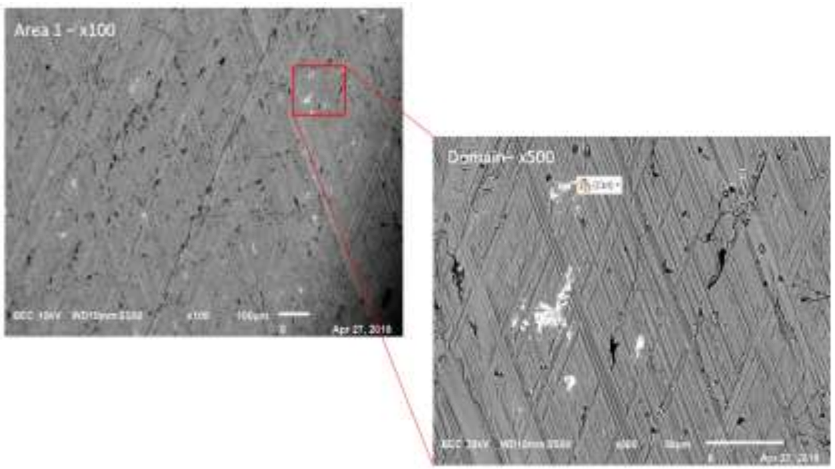
EDS Mapping – Domain x500

Element	Mass %	Mole %
C	7.79	27.73
O	nd	nd
Al*	0.07	0.11
Si	1.95	2.96
P	0.34	0.48
S*	0.04	0.05
V*	0.01	0.01
Cr	0.50	0.41
Mn*	0.19	0.15
Fe	88.36	67.63
Ni*	0.07	0.05
Cu	0.54	0.36
Mo*	0.15	0.07

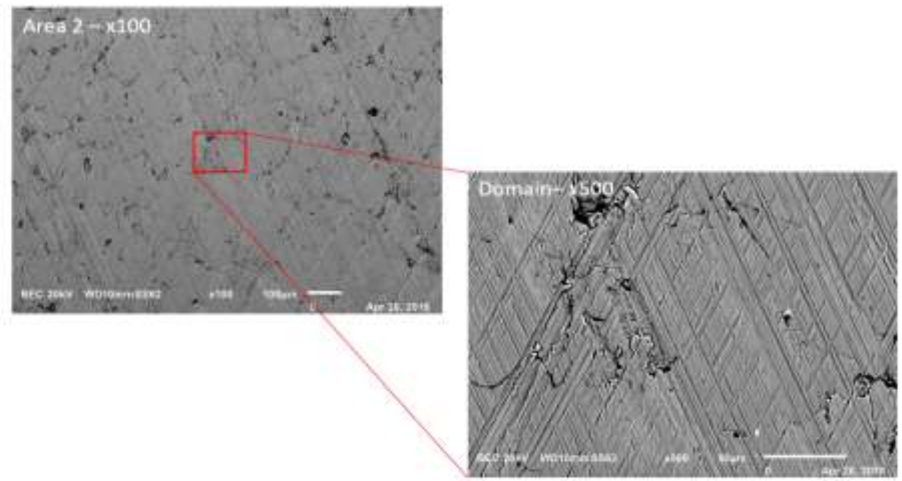
- Batch C and PNB liners show similar element composition

EDS Batch C Vs PNB at Mid Stroke

PNB EDS Mapping



Batch C EDS Mapping



EDS Mapping – Area 1 x100

Element	Mass %	Mole %
C*	6.31	23.50
O	nd	nd
Al*	0.06	0.10
Si*	1.84	2.92
P*	0.07	0.10
S*	0.13	0.18
V*	0.08	0.07
Cr*	0.18	0.16
Mn*	0.33	0.26
Fe	90.09	72.10
Ni*	0.05	0.04
Cu*	0.71	0.50
Mo*	0.15	0.07

EDS Mapping – Domain x500

Element	Mass %	Mole %
C	5.89	22.26
O	nd	nd
Al	nd	nd
Si	1.72	2.79
P*	0.06	0.08
S*	0.11	0.16
V*	0.01	0.01
Cr	0.25	0.22
Mn*	0.53	0.44
Fe	90.13	73.29
Ni*	0.05	0.04
Cu*	0.52	0.37
Mo*	0.74	0.35

EDS Mapping – Area 2 x100

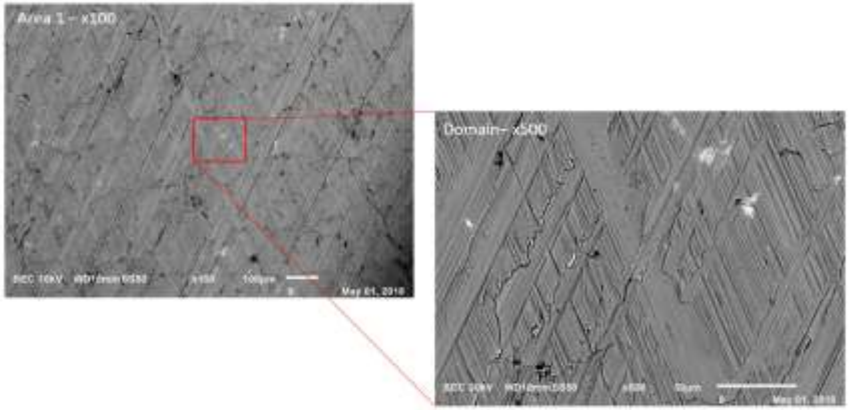
Element	Mass %	Mole %
C	5.77	21.81
O	nd	nd
Al*	0.04	0.06
Si	1.60	2.59
P*	0.40	0.59
S	0.06	0.09
V	nd	nd
Cr	0.49	0.43
Mn	0.35	0.29
Fe	90.51	73.61
Ni*	0.10	0.08
Cu*	0.55	0.39
Mo*	0.12	0.06

EDS Mapping – Domain x500

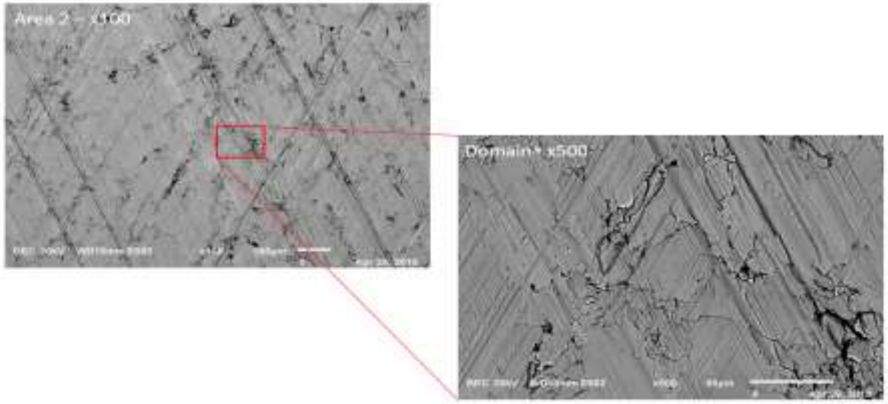
Element	Mass %	Mole %
C	6.18	23.10
O	nd	nd
Al	nd	nd
Si	1.52	2.43
P	0.53	0.76
S*	0.05	0.07
V*	0.03	0.02
Cr	0.58	0.50
Mn*	0.28	0.23
Fe	90.05	72.37
Ni*	0.06	0.04
Cu*	0.52	0.37
Mo*	0.20	0.09

EDS Batch C Vs PNB at BDC

PNB EDS Mapping



Batch C EDS Mapping



EDS Mapping – Area 1 x100

Element	Mass %	Mole %
C*	6.14	23.05
O	nd	nd
Al*	0.03	0.05
Si	1.74	2.78
P*	0.01	0.01
S*	0.03	0.04
V*	0.02	0.02
Cr*	0.17	0.14
Mn	nd	nd
Fe	90.72	73.20
Ni	nd	nd
Cu*	0.71	0.50
Mo*	0.44	0.21

EDS Mapping – Domain x500

Element	Mass %	Mole %
C	5.45	20.90
O	nd	nd
Al	nd	nd
Si	1.68	2.76
P*	0.06	0.09
S*	0.06	0.08
V	nd	nd
Cr*	0.21	0.19
Mn*	0.03	0.03
Fe	91.29	75.23
Ni	nd	nd
Cu*	0.59	0.43
Mo*	0.62	0.30

EDS Mapping – Area 2 x100

Element	Mass %	Mole %
C	6.59	24.30
O	nd	nd
Al*	0.04	0.06
Si	1.70	2.68
P	0.49	0.70
S*	0.05	0.06
V*	0.02	0.02
Cr	0.53	0.45
Mn*	0.26	0.21
Fe	89.48	70.97
Ni*	0.09	0.07
Cu*	0.57	0.40
Mo*	0.19	0.09

EDS Mapping – Domain x500

Element	Mass %	Mole %
C	6.74	24.76
O	nd	nd
Al*	0.03	0.05
Si	1.79	2.81
P*	0.23	0.33
S*	0.06	0.08
V*	0.01	0.01
Cr	0.45	0.38
Mn*	0.12	0.09
Fe	89.76	70.95
Ni*	0.09	0.07
Cu	0.58	0.40
Mo*	0.14	0.07

White Light Surface Analysis

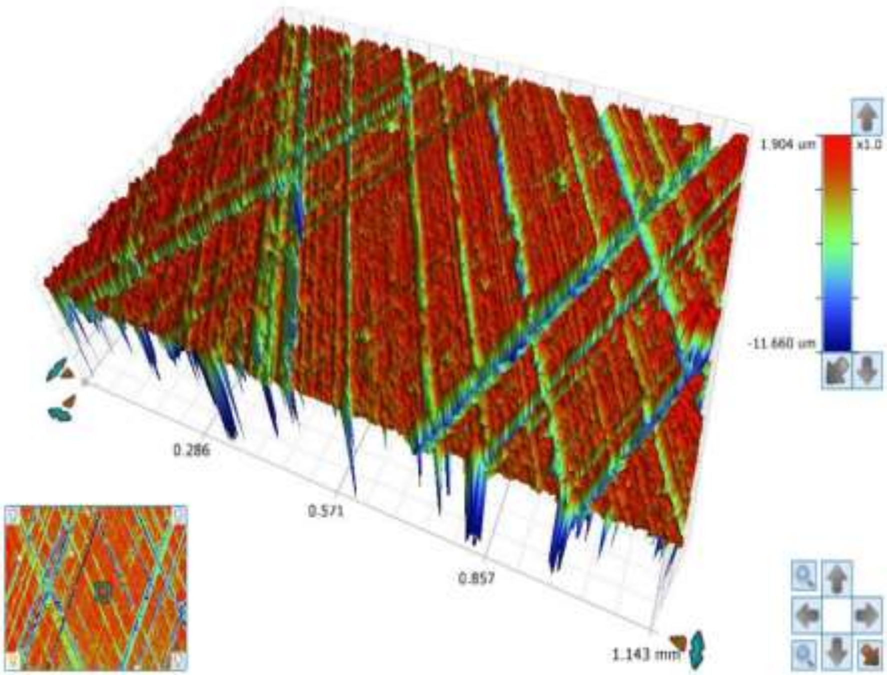
- Multiple measurements were taken and summarized in the table below
- The data suggests that the Batch C sample is smoother than the PNB sample
- The roughest sections of both liners were at BDC

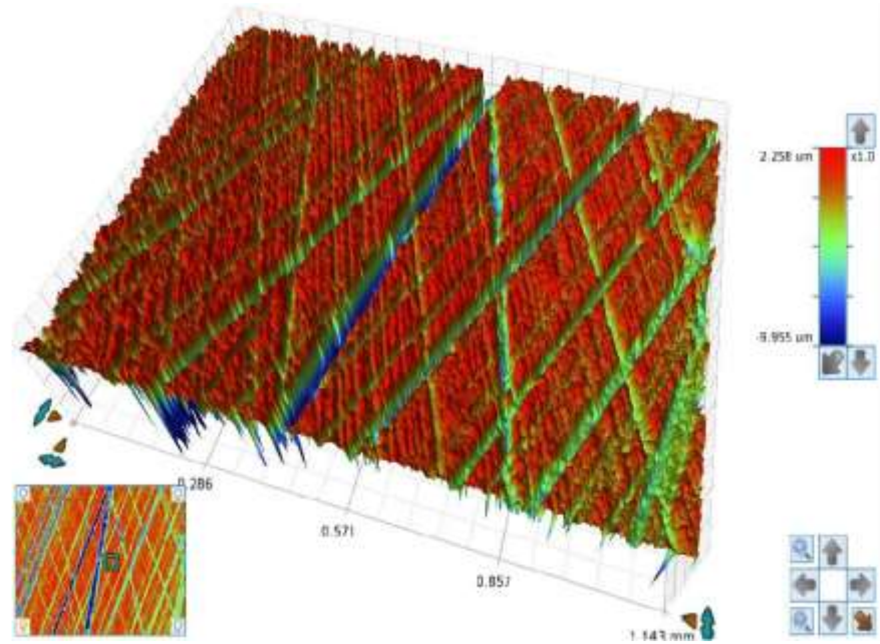
3D Surface Analysis Parameters (Microns)

LIMS ID	Sample ID	Average Ra (µm)	Average Rp (µm)	Average Rv (µm)	Average Rq (µm)	Average Rt (µm)
18680-1	PNB-DD13 2680 Top Rear.	0.33	2.65	-6.62	0.47	9.27
18680-2	PNB-DD13 2680 Middle Antithrust	0.45	2.18	-4.72	0.62	6.90
18680-3	PNB-DD13 2680 Bottom Rear	0.60	2.59	-7.03	0.83	9.63
18680-5	Batch C-0186-DD13 Top.Rear	0.20	2.37	-5.72	0.31	8.09
18680-6	Batch C-0186-DD13 Middle Thrust	0.30	1.84	-8.13	0.47	9.98
18680-7	Batch C-0186-DD13 Front Bottom	0.44	1.92	-9.50	0.62	11.42

White Light Surface Analysis

- Images from the roughest sample sections





Batch C BDC Rear

PNB BDC Front

Infineum information shared with the Daimler Surveillance Panel

Hardness Comparison

- Hardness Traces were performed on multiple samples tracing from the ID to the OD of the liner
- Batch C liners have a higher average hardness than PNB liners

Cylinder Liner ID	Sample ID	Average Hardness (HV0.5)	Overall Average Hardness (HV0.5)
PNB DD13 2680	Bottom Rear	282	**279**
	Middle Antithrust	278	
	Top Rear	276	
Batch C 0186DD13	Front Bottom	342	**324**
	Middle Thrust	315	
	Top Rear	314	

Infineum information shared with the Daimler Surveillance Panel

Conclusions

- Both Liners are very similar in composition
- Inclusions are present in both liners although they are more present in the Batch C liner
- PNB Liners show a rougher overall surface than the Batch C
- Most notable difference is in the microstructure of the liners

PNB

- Randomly oriented graphite flake patterns
- Primarily fine pearlite matrix
- Inclusions of course manganese sulfide and disperse carbides

Batch C

- Graphite flakes are smaller in size and in a rosette pattern
- Ferrite patches present in the pearlite matrix
  - Ferrite sites will be softer in nature
- Inclusions of manganese sulfide are higher in numbers but smaller in size

Appendix

SEM / EDS Analysis

- All samples analyzed with 10kV bean energy, 10mm working distance and X100 magnification (excluding EDS)
  - SEI - Secondary electron imaging
  - BEC – Backscattered electron imaging
  - BET – Topography
- One PNB Liner and one Batch C liner were used in the analysis.
- Liners were sectioned into the following samples, liner location was oriented utilizing the QR code.

PNB: Liner #2680

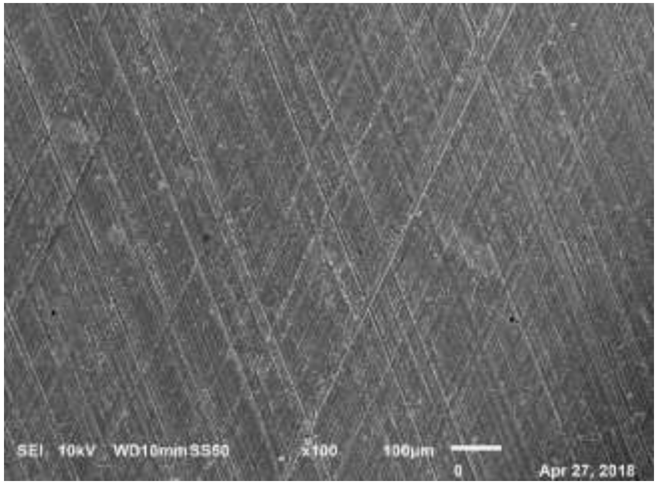
- TDC
  - Rear, Front and Thrust
- Mid-Stroke
  - Anti-Thrust, Front and Thrust
- BDC
  - Rear, Front and Thrust

Batch C: Liner #0186

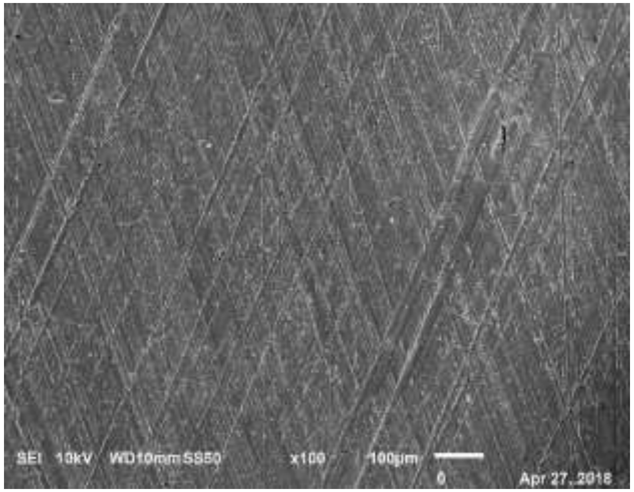
- TDC
  - Front, Thrust and Rear
- Mid-Stroke
  - Thrust, Rear and Anti-Thrust
- BDC
  - Front, Anti-Thrust and Rear

SEI Mode TDC

PNB

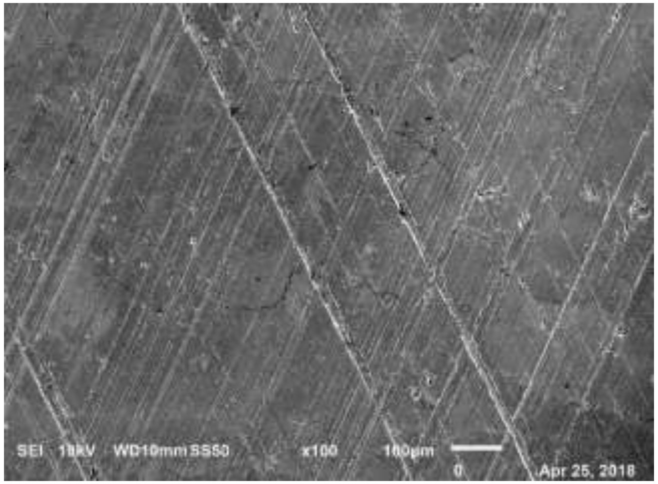


Front

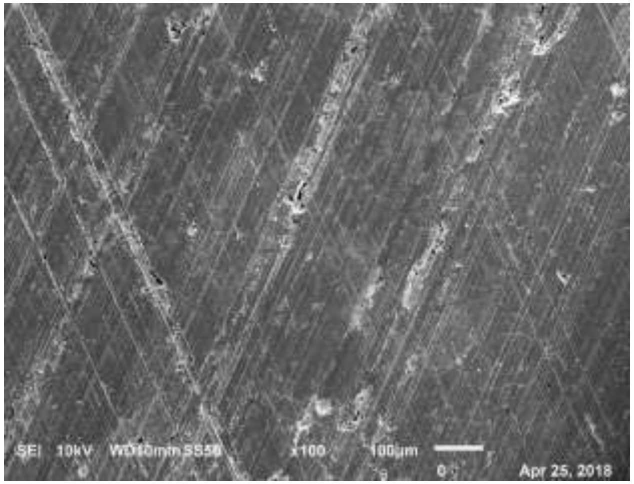


Thrust

Batch C



Front

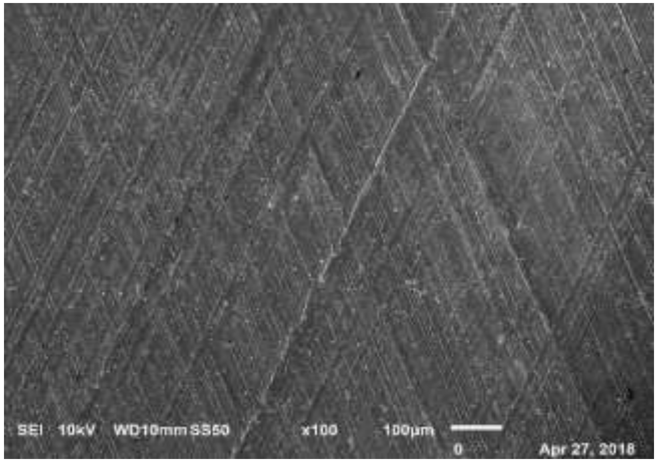


Thrust

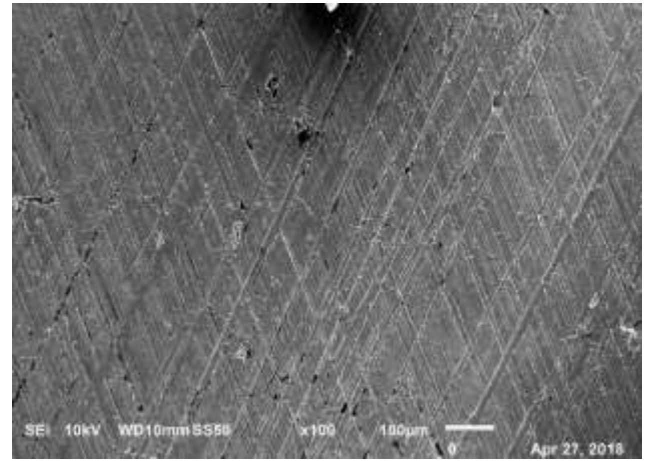
Infineum information shared with the Daimler Surveillance Panel

SEI Mode Mid-Stroke

PNB

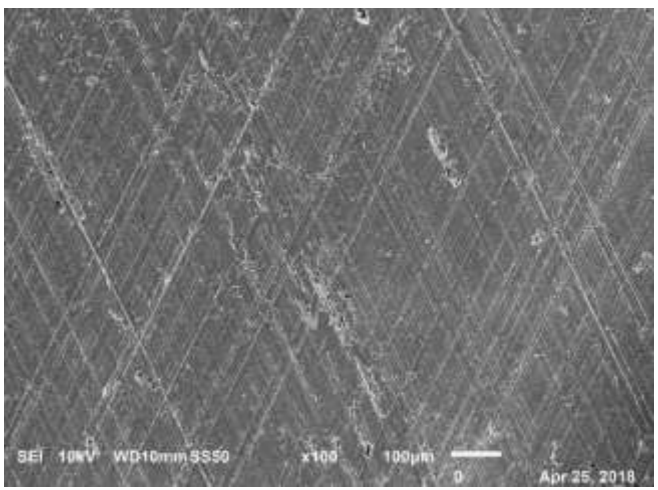


Front

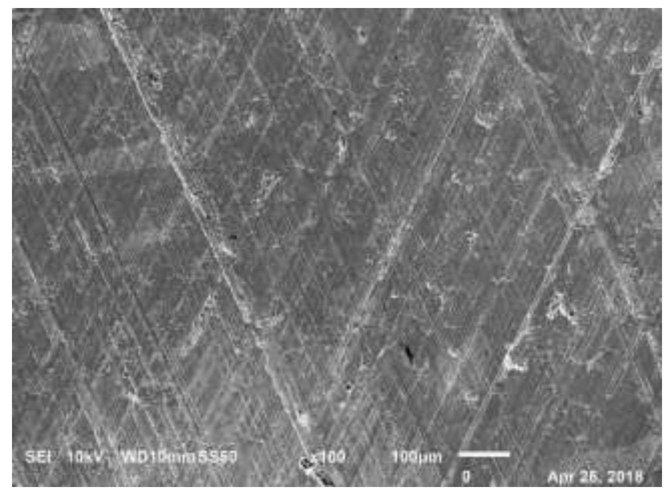


Thrust

Batch C



Rear

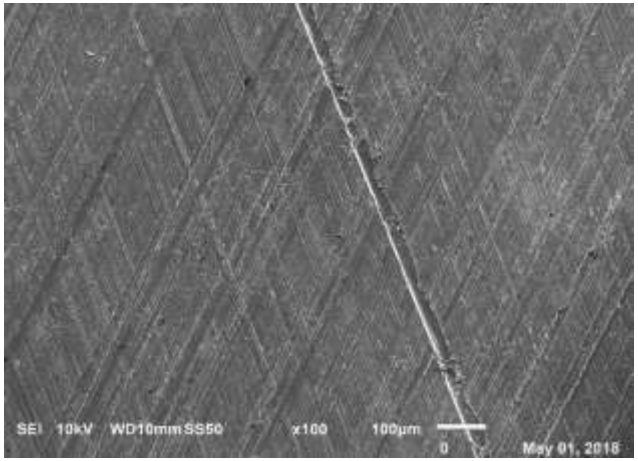


Anti-Thrust

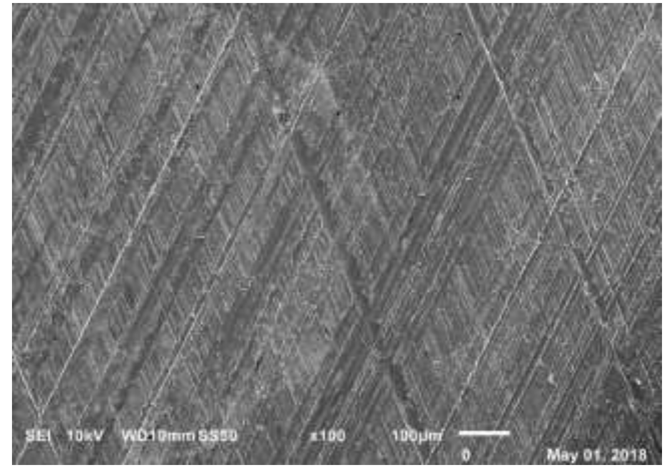
Infineum information shared with the Daimler Surveillance Panel

SEI Mode BDC

PNB

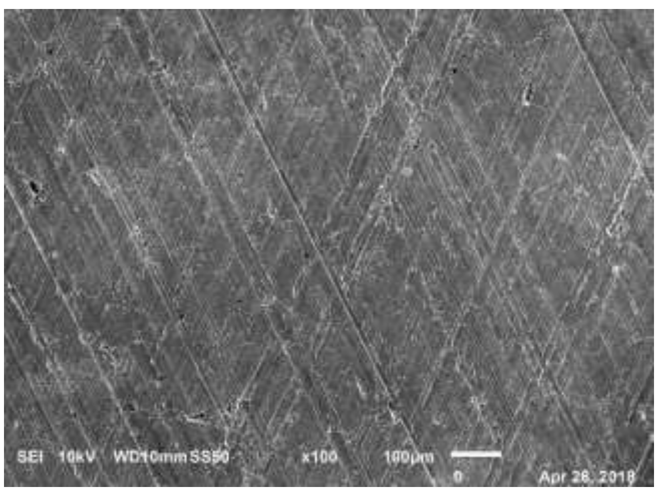


Front

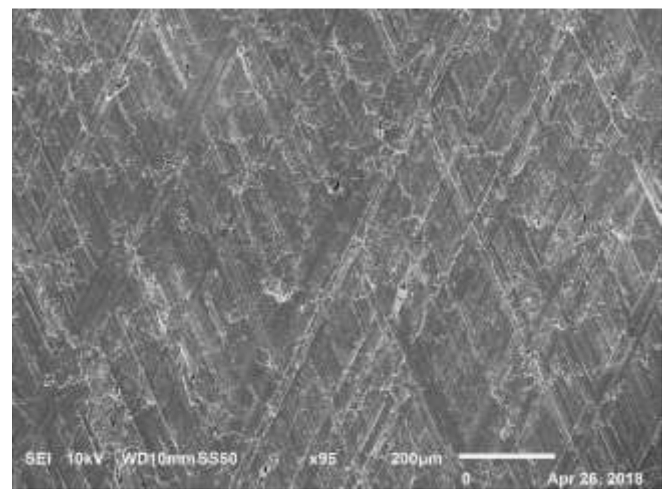


Thrust

Batch C



Anti-Thrust

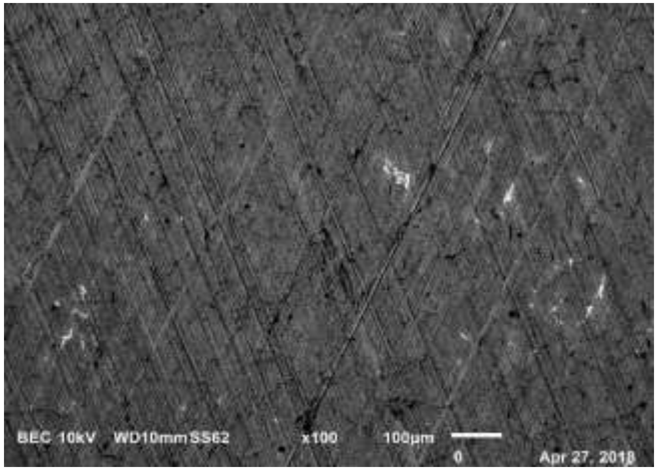


Rear

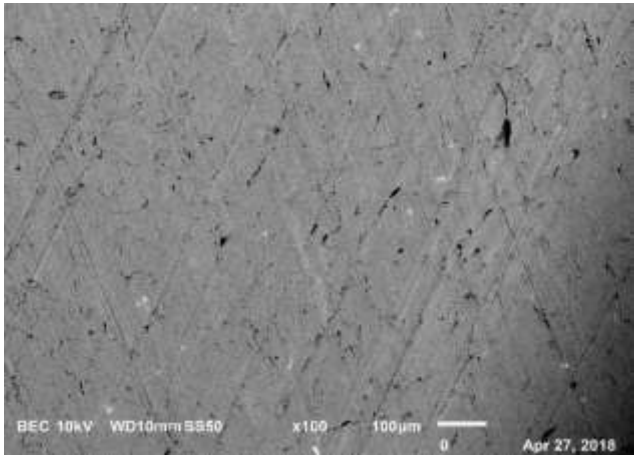
Infineum information shared with the
Daimler Surveillance Panel

BEC Mode TDC

PNB

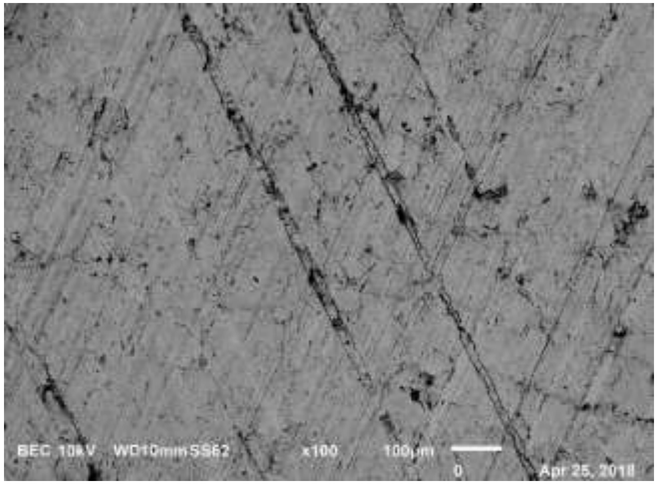


Front

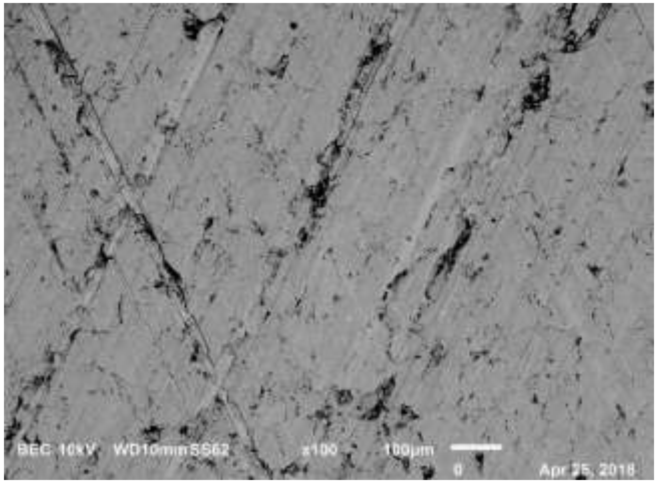


Thrust

Batch C



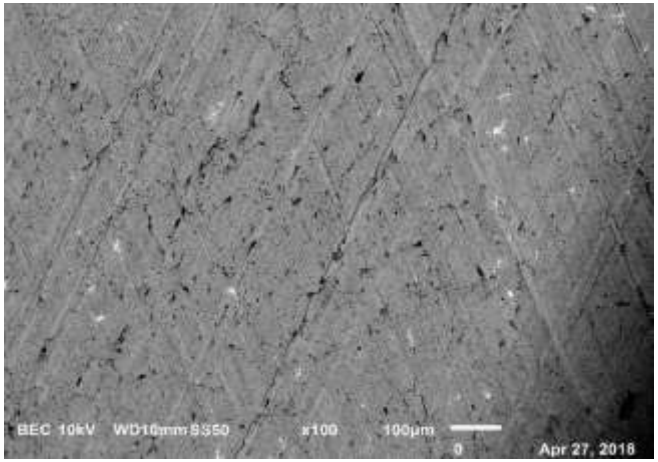
Front



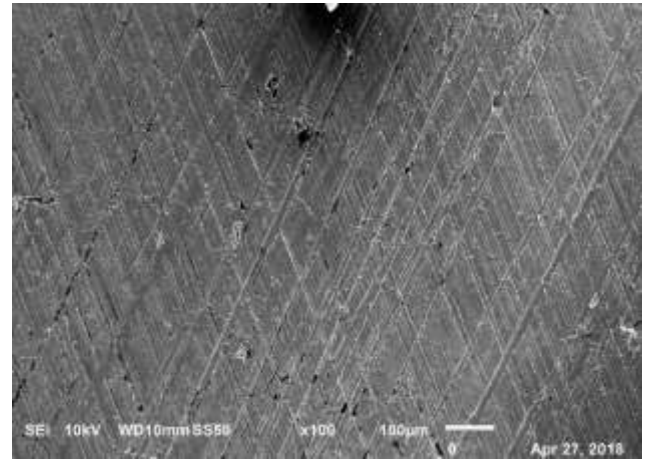
Thrust

BEC Mode Mid-Stroke

PNB

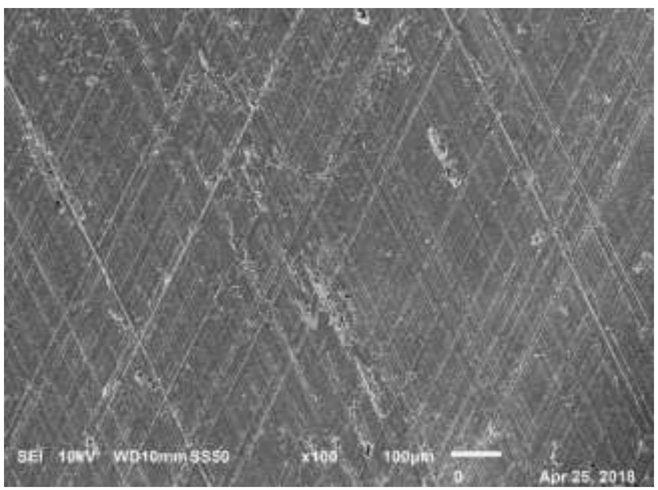


Front

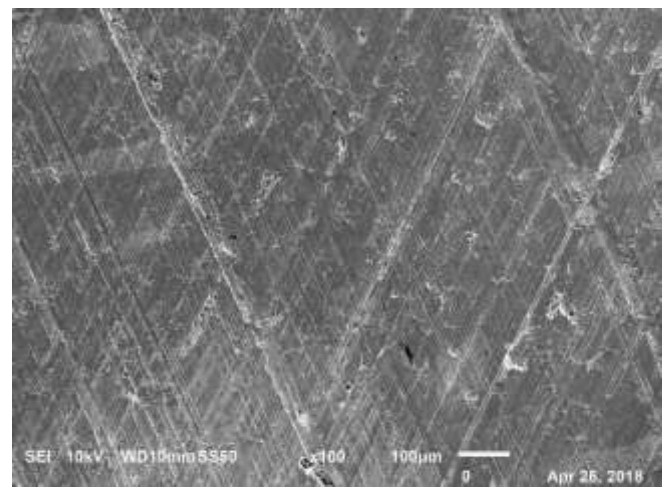


Thrust

Batch C



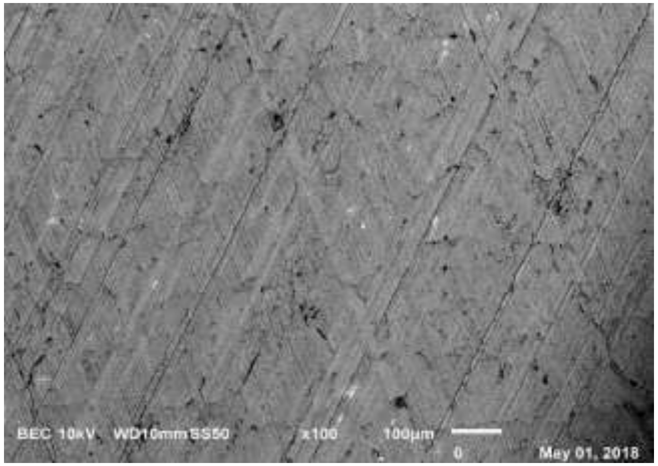
Rear



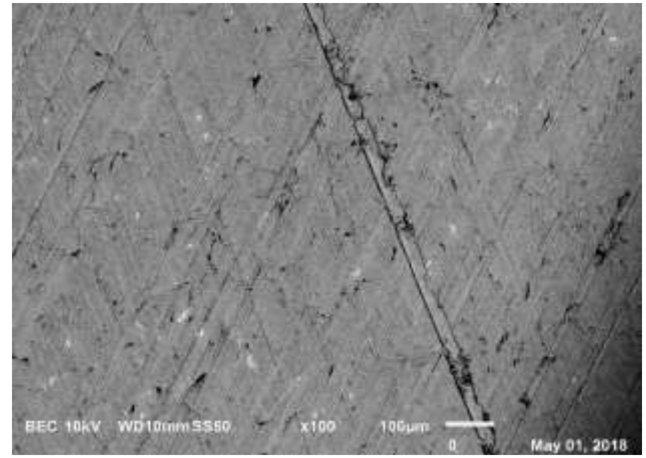
Anti-Thrust

BEC Mode BDC

PNB

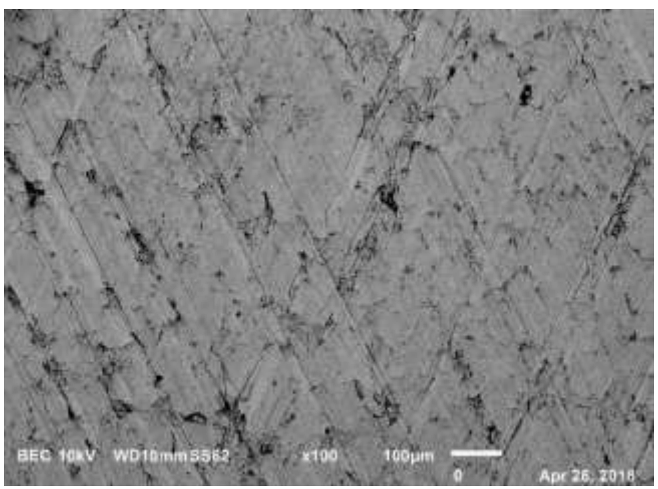


Thrust

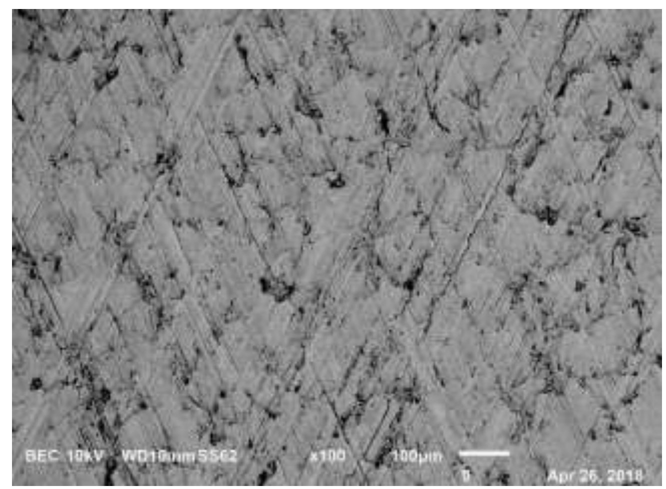


Front

Batch C

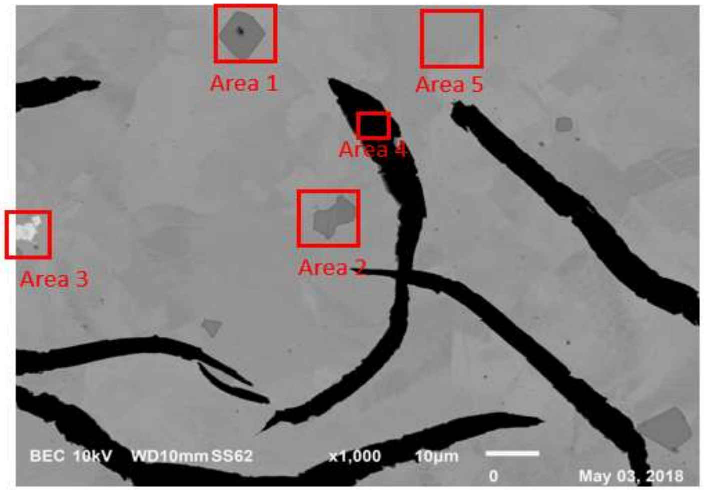


Anti-Thrust

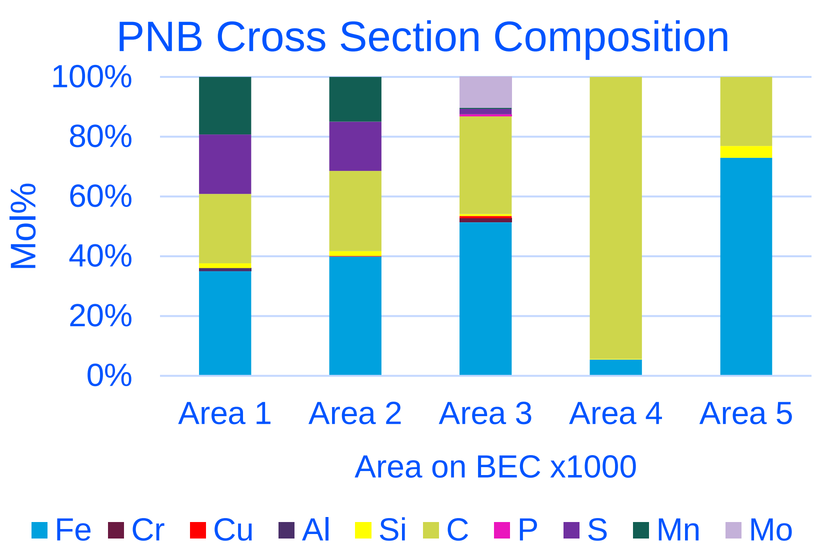


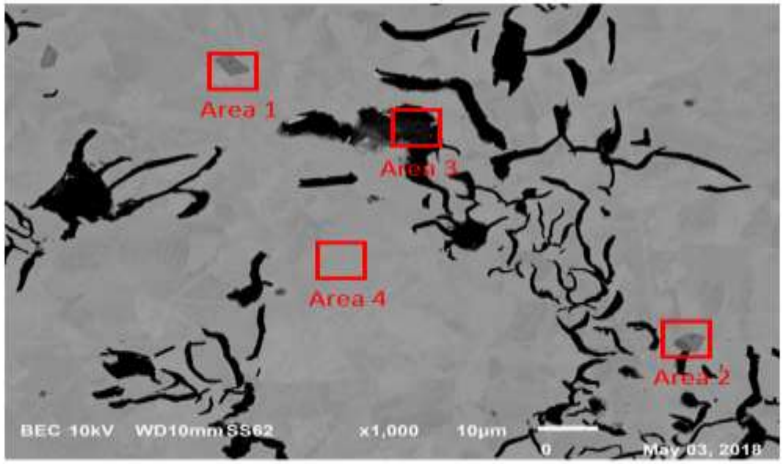
Rear

Cross Section EDS

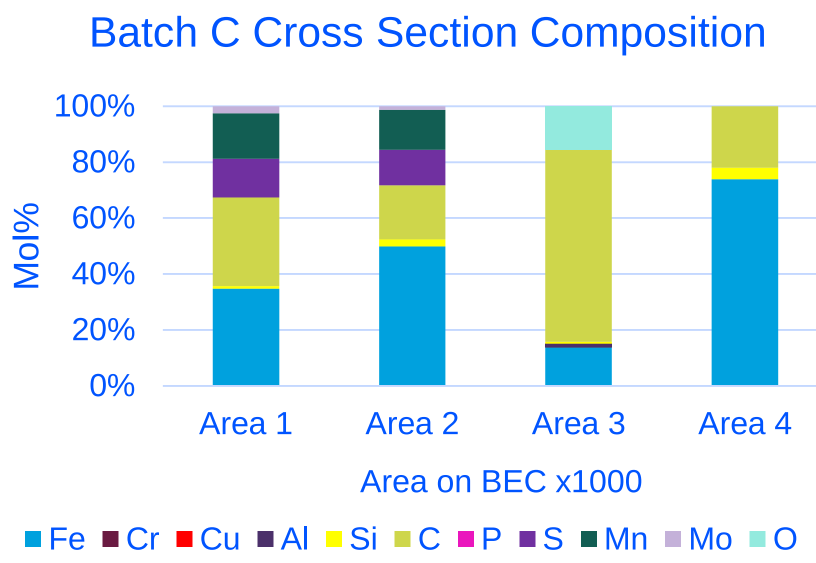


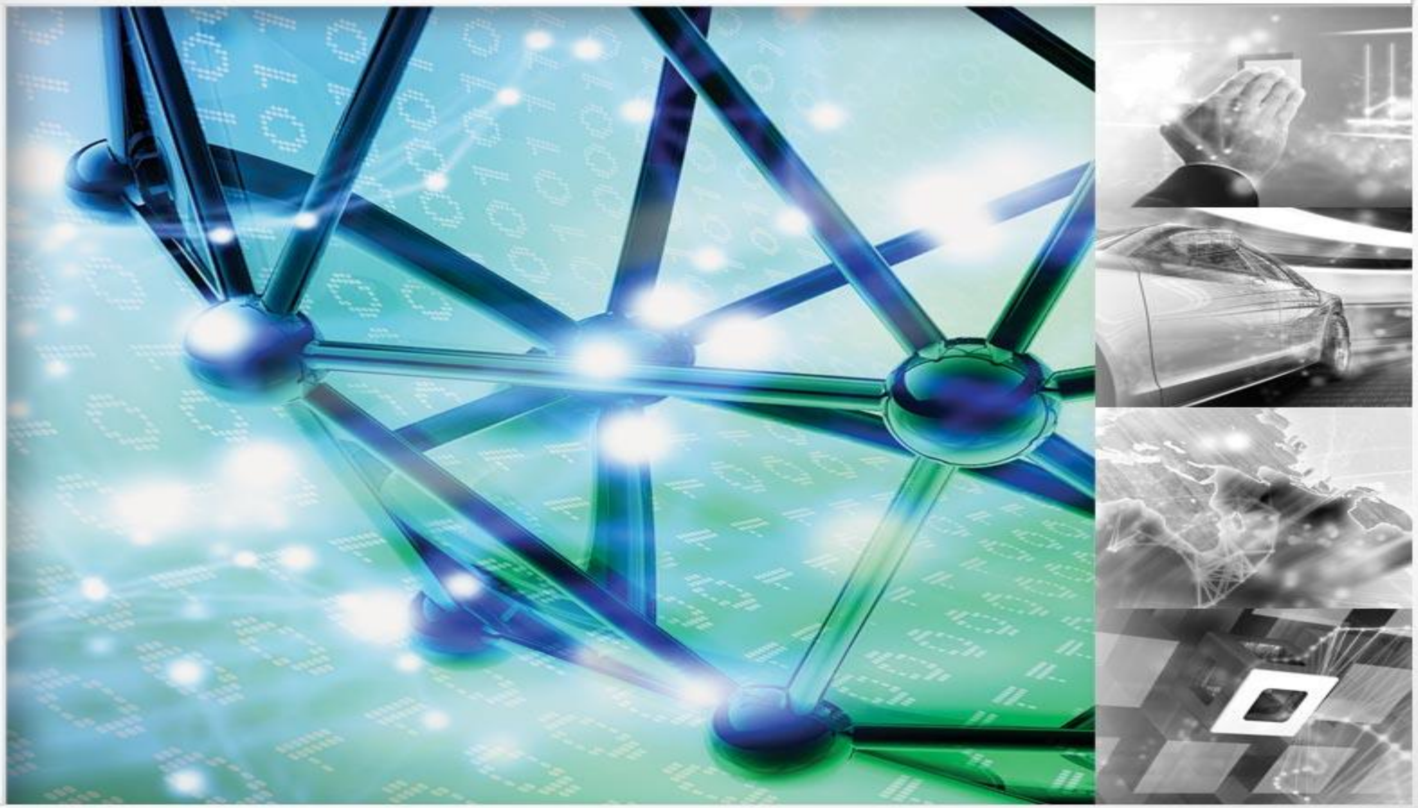
BEC x1000





BEC x1000





DD13 Scuffing Test
Liner Analysis

The Lubrizol Corporation

May 2018

Summary of Analyses

- Statistically, we can’t simultaneously obtain independent estimates for Labs, Stands, Oils, Top Ring Batches, and Liner Batches. Thus, we can’t say for sure whether any of these changes impact severity

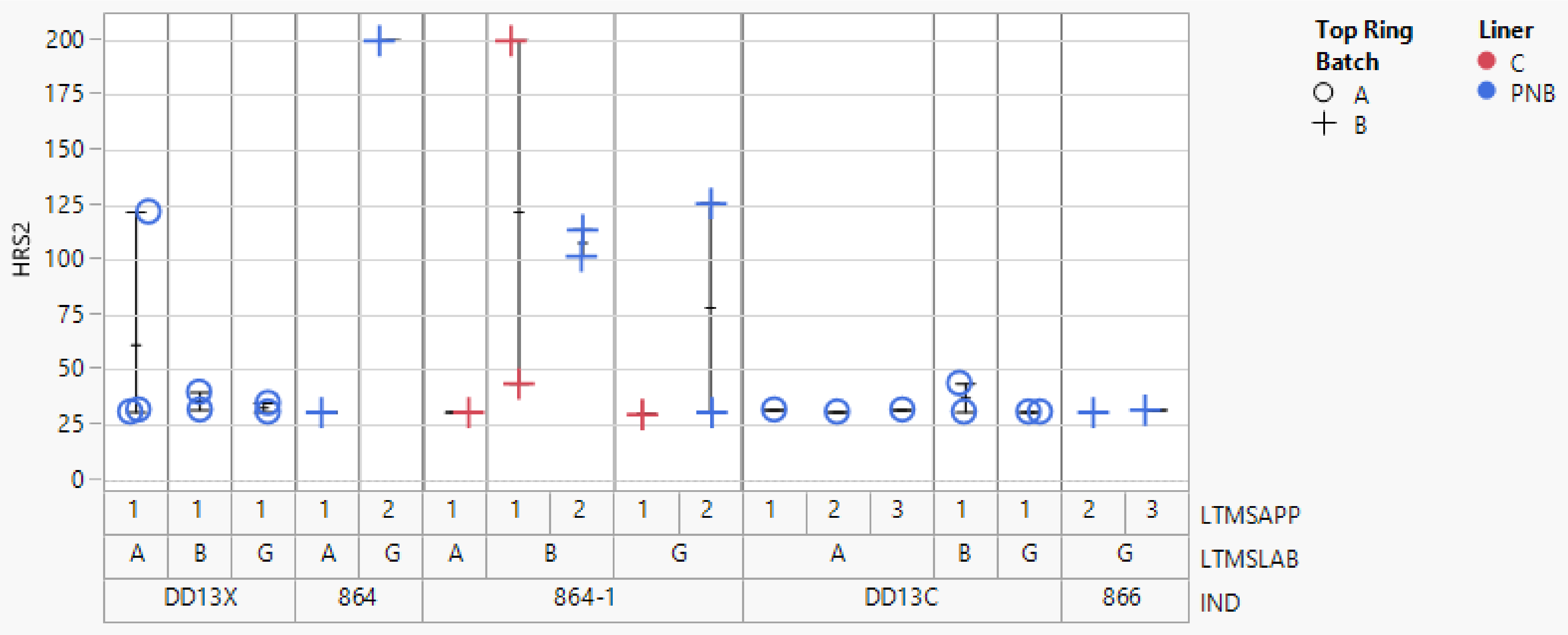
- Various models can be fit to the data; none of them are truly appropriate given the collinearity; their results can be misleading

- This collinearity also makes evaluating the need for a transformation difficult;
  - 1/(Hours to Scuff^2) is a contender
  - This transformation won’t be appropriate for oils that don’t scuff within 200 hours
  - Seeing results from oils that perform at the extremes of the scuffing range could help determine a transformation

Hours to Scuff

SUCCESS TOGETHER

Historically, we have been comfortable grouping DD13X & 864 and DD13C & 866

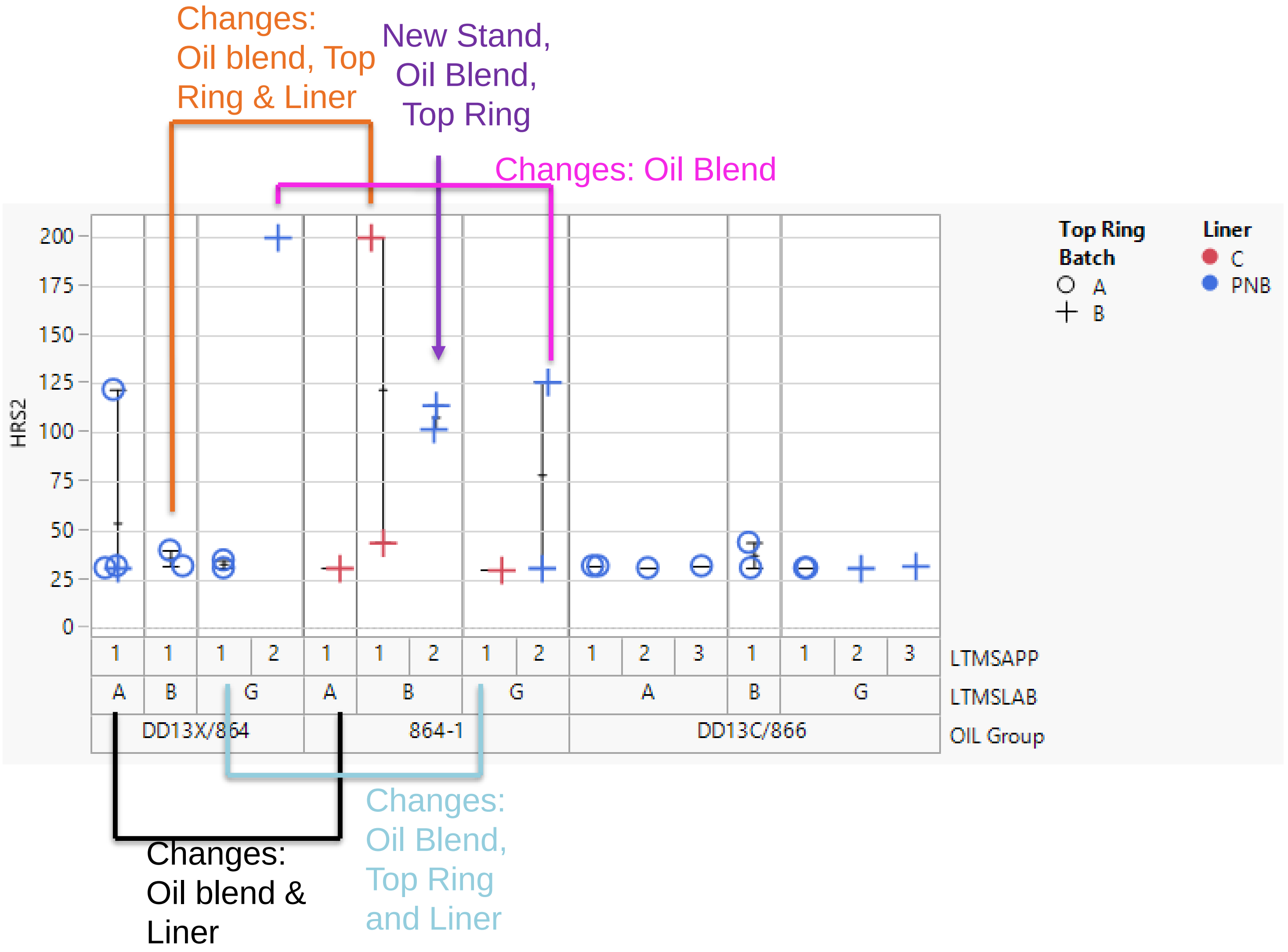


Lubrizol

Hours to Scuff

SUCCESS TOGETHER

Past conversations have focused on Top Ring, Liner, and Oil Blend changes



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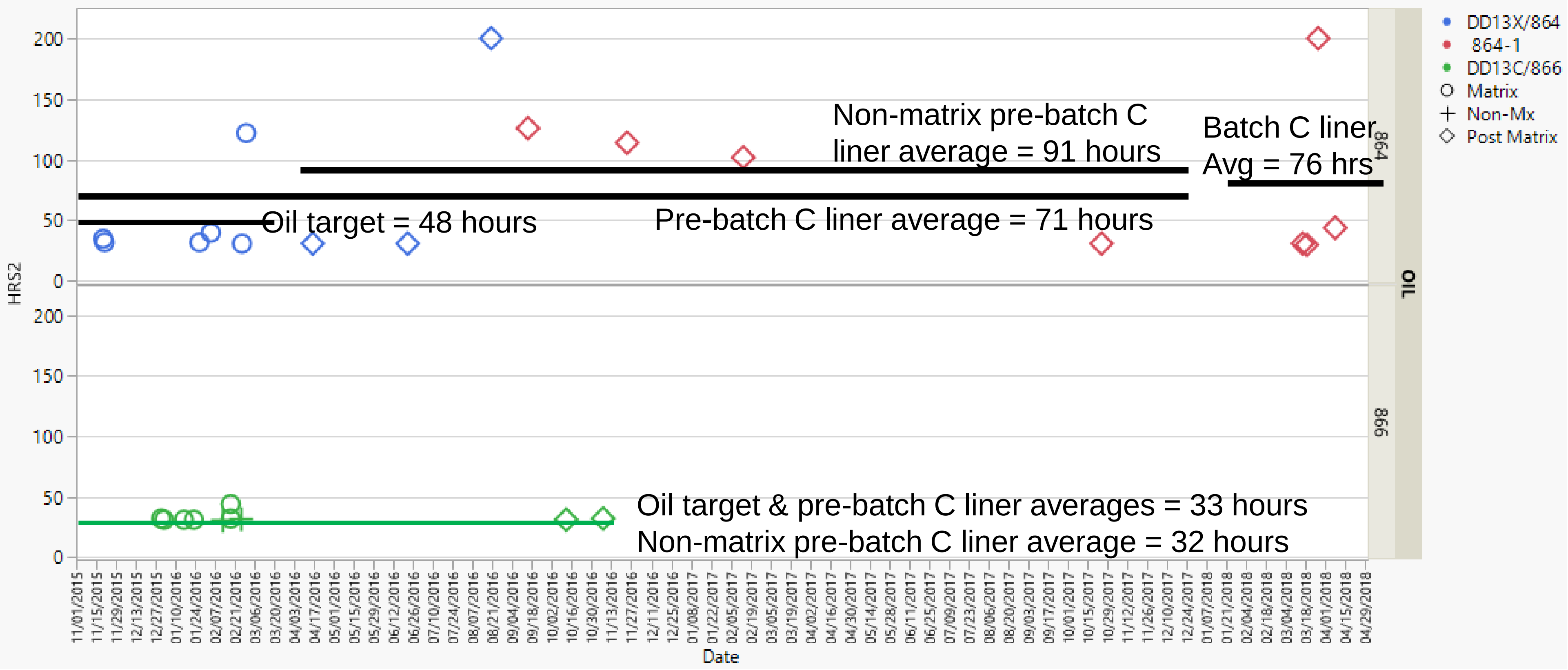
Hours to Scuff Over Time

SUCCESS TOGETHER



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Some Options to Consider

SUCCESS TOGETHER

- Continue monitoring as additional references are conducted; don't implement any changes at this time
- Conduct testing to separate the impact of stand, oil blend, top ring and liner changes
- Discuss whether, from an engineering point of view, we can rule out any effect due to stand, oil blend, top ring or liner differences; conduct statistical analyses with all data, but without effects believed not to affect severity.
- Compare Oil targets to 864-1 and 866 tests run using Top Ring Batch B and Liner Batch C once 866 results become available; assess the need for a correction factor

	LTMS Oil Target		Average Hours to Scuff of Top Ring Batch B & Liner Batch C Reference tests	
	Mean	Standard Deviation	Mean	Standard Deviation
866	33	26		
864	48	26	76	83

Note: no transformation or model was applied to obtain these estimates

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Appendix

Data Utilized

TESTKEY	LTMSDATE	LTMSLAB	LTMSAPP	VAL	CHART	DTCOMP	IND	Liner	HRS2
116652-DD13	20151120	G	1	AC	Y	20151120	DD13X	PNB	35
116656-DD13	20151121	B	1	AC	Y	20151121	DD13X	PNB	32
116648-DD13	20151231	A	1	AC	Y	20151231	DD13C	PNB	32
116653-DD13	20160102	G	1	AC	Y	20160102	DD13C	PNB	31
116657-DD13	20160116	B	1	AC	Y	20160116	DD13C	PNB	31
116654-DD13	20160123	G	1	AC	Y	20160123	DD13C	PNB	31
116649-DD13	20160127	A	1	AC	Y	20160127	DD13X	PNB	32
116658-DD13	20160204	B	1	AC	Y	20160204	DD13X	PNB	40
120064-DD13	20160212	A	2	AC	Y	20160212	DD13C	PNB	31
116659-DD13	20160218	B	1	AC	Y	20160218	DD13C	PNB	44
116650-DD13	20160218	A	1	AC	Y	20160218	DD13C	PNB	32
120065-DD13	20160225	A	3	AC	Y	20160225	DD13C	PNB	32
116655-DD13	20160226	G	1	AC	Y	20160226	DD13X	PNB	31
116651-DD13	20160229	A	1	OC	Y	20160229	DD13X	PNB	122
117347-DD13	20160416	A	1	AC	Y	20160416	DD13X	PNB	31
118393-DD13	20160622	A	1	AC	Y	20160622	864	PNB	31
119058-DD13	20160820	G	2	OC	Y	20160820	864	PNB	200
119743-DD13	20160915	G	2	OC	Y	20160915	864-1	PNB	126
120881-DD13	20161012	G	2	AC	Y	20161012	866	PNB	31
120882-DD13	20161107	G	3	AC	Y	20161107	866	PNB	32
121505-DD13	20161124	B	2	OC	Y	20161124	864-1	PNB	114
121506-DD13	20170214	B	2	AC	Y	20170214	864-1	PNB	102
119744-DD13	20171025	G	2	AC	Y	20171025	864-1	PNB	31
121501-DD13	20180316	A	1	PC	Y	20180316	864-1	C	31
134325-DD13	20180319	G	1	PC	N	20180319	864-1	C	30
134612-DD13	20180327	B	1	PC	Y	20180327	864-1	C	200
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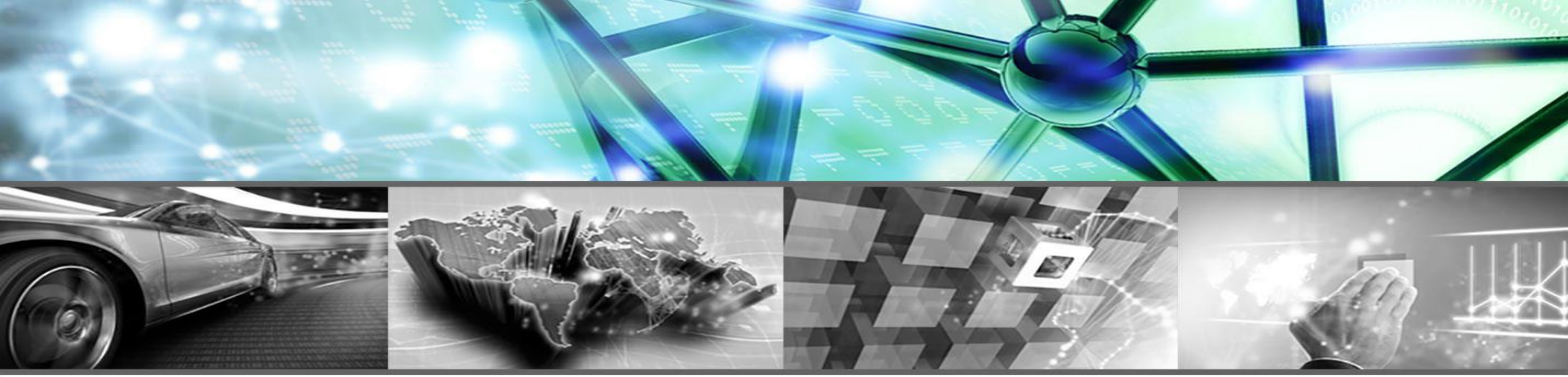

SUCCESS TOGETHER

Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We’ll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.

Lubrizol