

Daimler Surveillance Panel Meeting Minutes

May 8, 2018

11:00 A.M. CST

Call Participants:

Lubrizol - Patrick Joyce, Kevin O'Malley
Southwest Research Institute – Jose Starling, Jim McCord, John Macha
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
TEI – Derek Grosch
TMC – Sean Moyer
Afton – Bob Campbell
ExxonMobil – Ray Burns

Unfinished Business

Review Liner Metallurgical Analysis – Lubrizol/Southwest

Kevin presented the metallurgical analysis conducted by Lubrizol for this meeting. This additional analysis was at the request of the panel to acquire additional data in regards to the material properties of the liner on more than one Batch C liner. The analysis measured the properties of one PNB liner and 6 Batch C liners. It was concluded in the presentation of this analysis that the PNB liners differed slightly from batch C liners in chemistry and surface roughness. It was noted in this presentation that the distribution of graphite in the PNB liners is a little more randomly distributed. Please see attached presentation for complete review of the data presented.

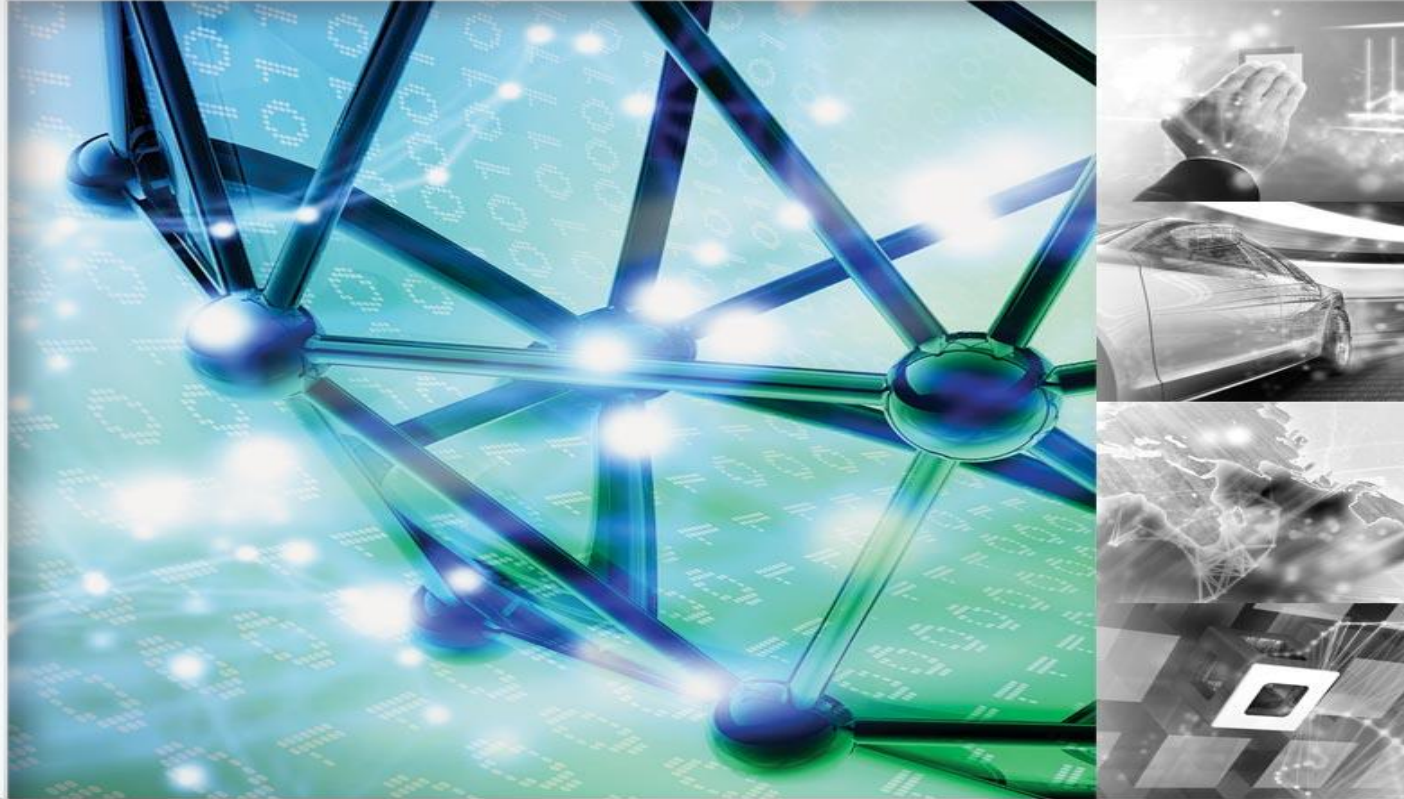
Southwest Research also conducted an additional material analysis focused on the microstructure which compared one PNB and one Batch C liner. This analysis was also presented during this meeting with the following general conclusions. The material analysis showed the microstructure differences between the PNB/Batch C liners and pointed at a significant difference in graphite flake length (~100 micron length for the PNB vs ~10 micron length for the Batch C liners). It was mentioned by Southwest's materials engineer who presented the analysis that the cooling rates of the liners likely had the major impact on the different appearing microstructures. Please see attached presentation for additional details.

Batch C Liner Next Steps – SP

Intertek and Lubrizol are both currently running a reference test on Oil C using the new batch C liners. At the time of this call both tests were at 60 hours with no signs of scuffing which would indicate a mild trend on these new liners. The previous highest result on Oil C was 44 hours. Non-industry data previously presented indicated that new liners were possibly more severe.

Next Meeting:

This meeting was shortened slightly due to technical difficulties logging into the Webex conference but a follow up meeting was scheduled to review additional material. ***Next meeting is scheduled for Monday 14th, 2018 from 11:00 AM to 1:00 PM CST.***



DD13 Scuffing Test Liner Analyses

The Lubrizol Corporation
May 2018

Testing Conducted



Background:

- LZ metrology lab measured liner properties of 1 PNB liner (#2655) and 6 Batch C liners (0003, 0393, 0397, 0399, 0400, 0404)
 - 2D and 3D roughness measurements were taken
 - 2D: Ra, Rk, Rpk, Rvk, Vo
 - 3D: Sa, Sk, Spk, Svk
 - Measurements were taken in three locations (top, middle, bottom)
- Liner 0003 was included in analysis shared with SP in March 2018; thus, we have TEI and LZ measurements by liner location for this liner
- The average TEI measurements for 0397, 0399, 0400, and 0404 are available
- Liner surface, chemical make-up, and hardness were evaluated using SEM, EDS, and Rockwell C

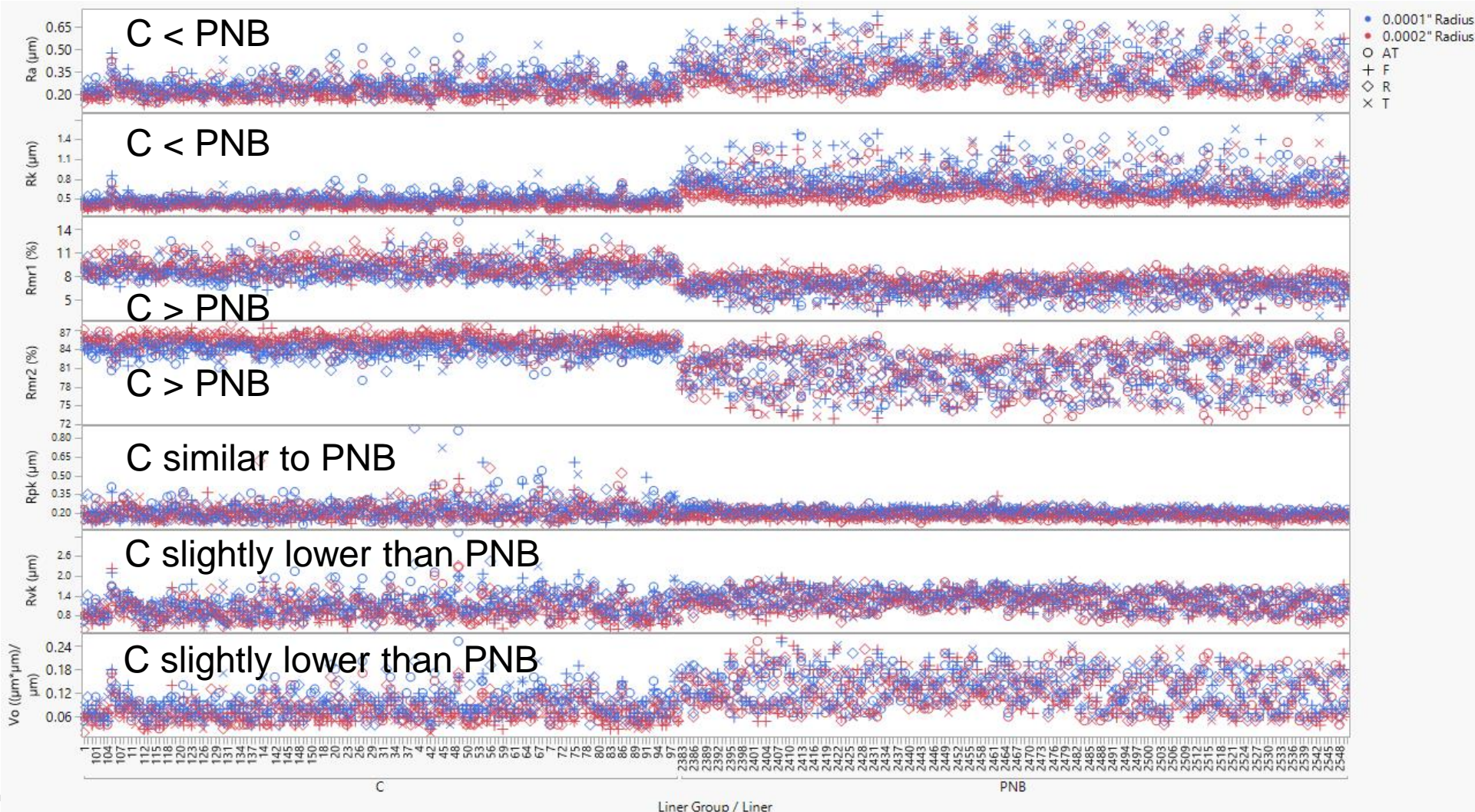
Findings:

- Differences between PNB and Batch C liners are consistent with what was observed when TEI measurements were compared between batches
 - Batch C liners have lower Ra, Rk and slightly lower Rvk and Vo
 - TEI measurements also show Batch C liners having higher Rmr1 and Rmr2
- Conclusions based on 3D measurements are consistent with the conclusions drawn from a review of the 2D measurements
 - Batch C liners have lower Sk, Sa, and slightly lower Svk results
- PNB liner differs slightly from batch C liners in chemistry and surface roughness; The distribution of graphite in the PNB liner is a little more randomly distributed than Batch C liners tested; Hardness of all liners tested are within spec

TEI Liner Measurements



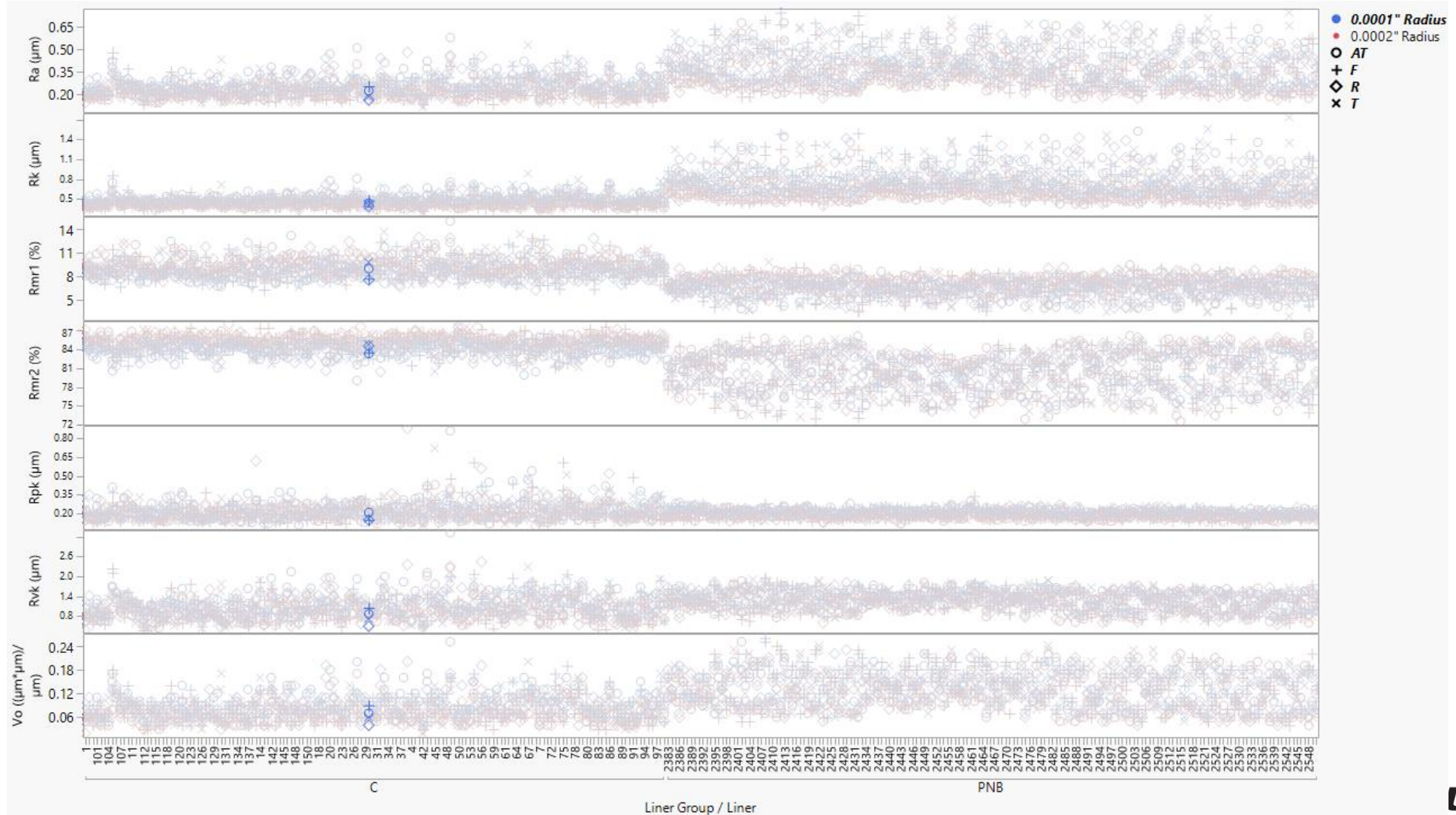
Plot of TEI Liner Measurements shared during March SP Meeting; Recall, liner batches differ for some liner attributes; Batch C liner specs were finalized at that time



TEI Liner Measurements



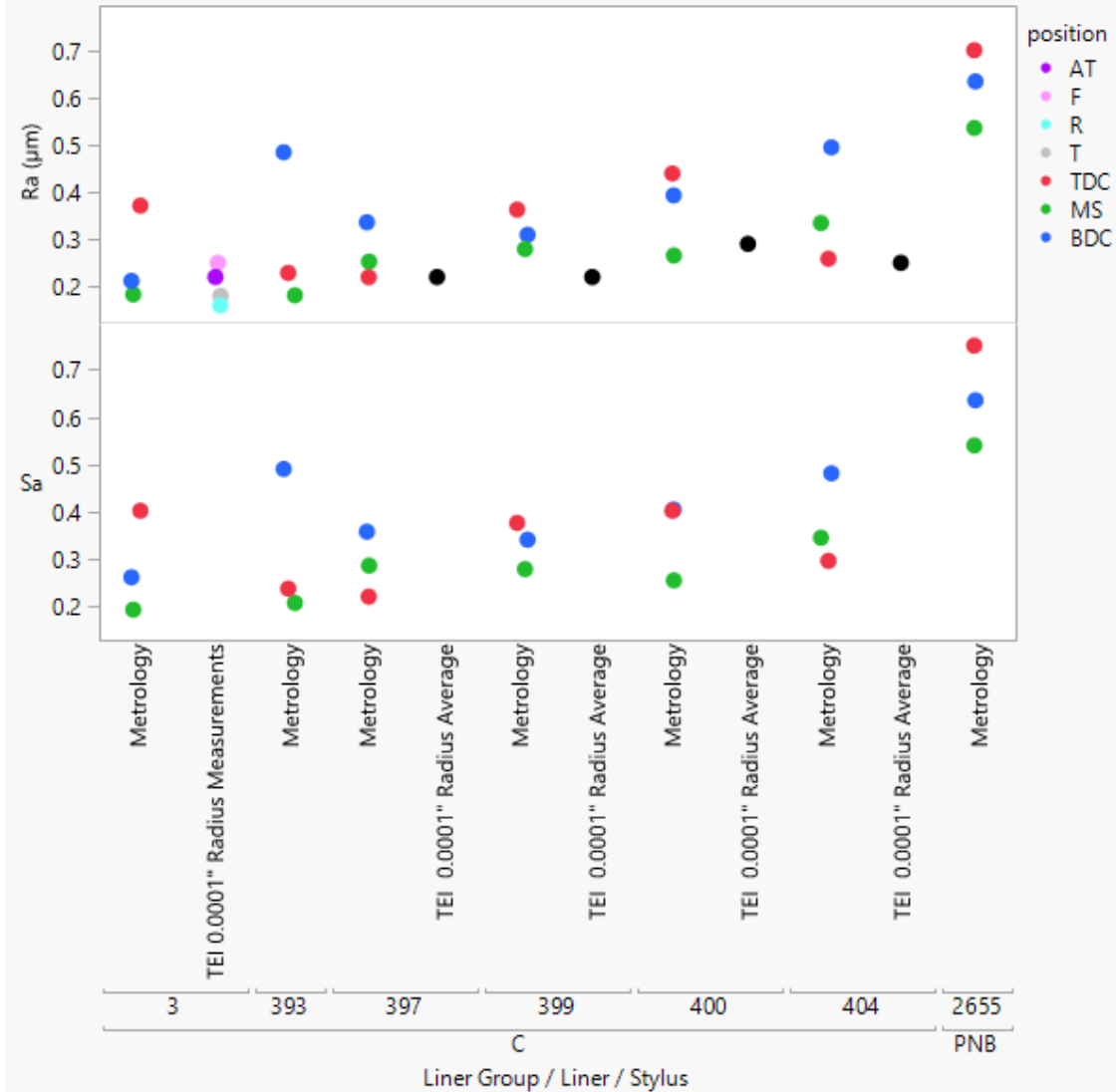
Batch C Liner 0003 highlighted (using 0.0001" stylus); in line with other Batch C liners



Ra & Sa

The difference between PNB and Batch C liners is consistent with what was observed when TEI measurements were compared between batches (PNB > C)

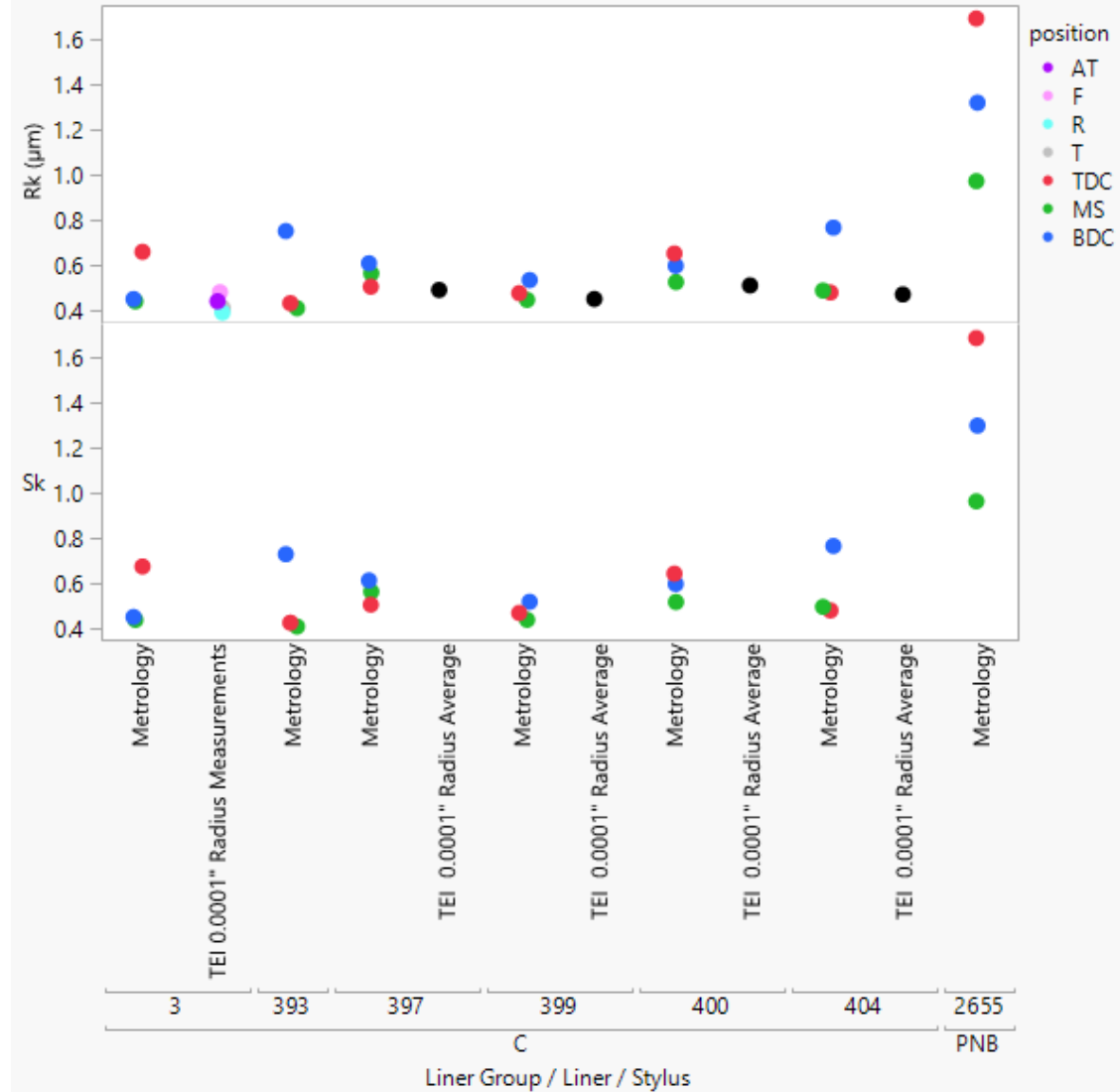
Metrology measurements appear slightly higher than TEI measurements



Rk & Sk

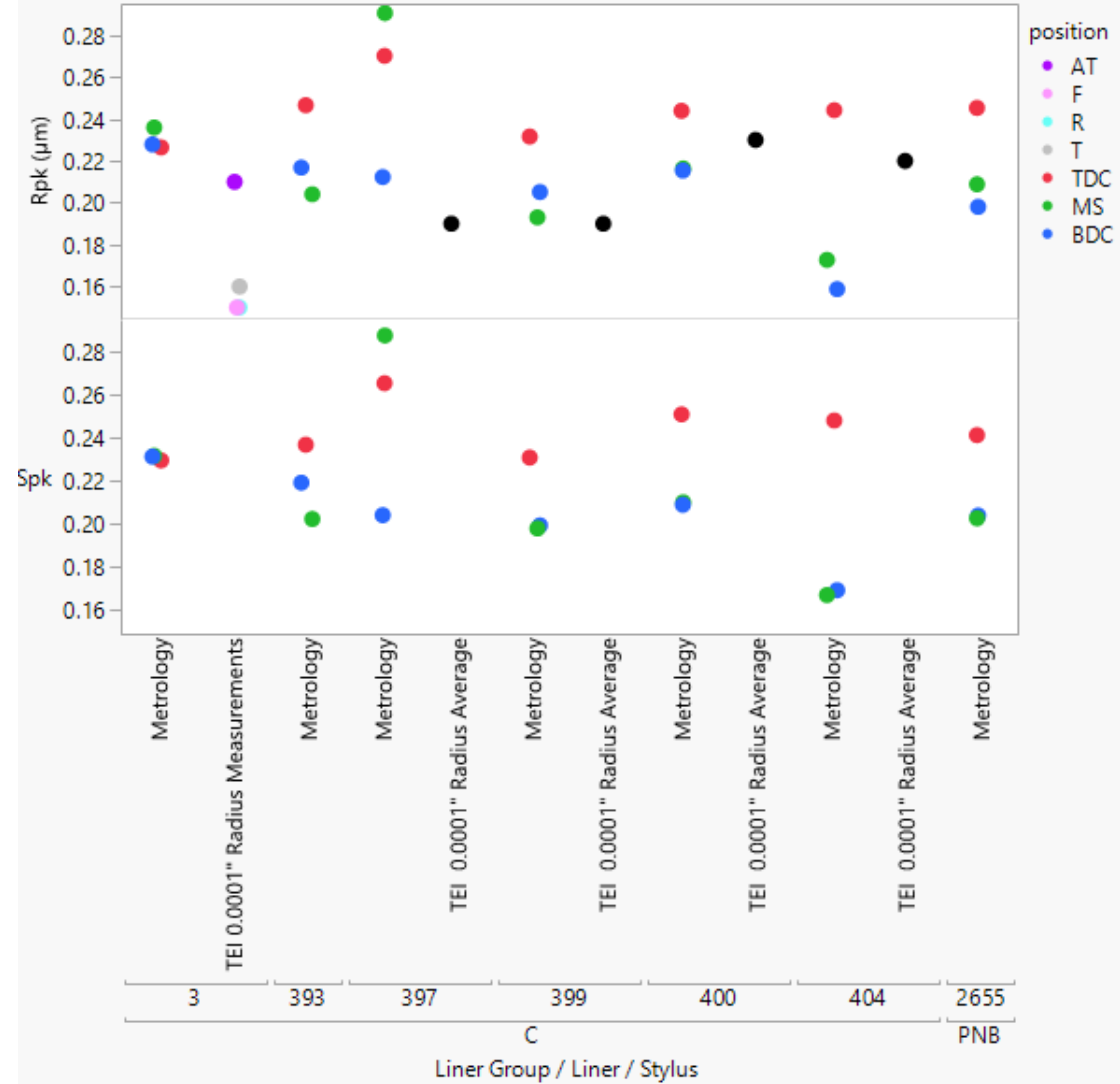
The difference between PNB and Batch C liners is consistent with what was observed when TEI measurements were compared between batches (PNB > C)

Metrology measurements appear slightly higher than TEI measurements



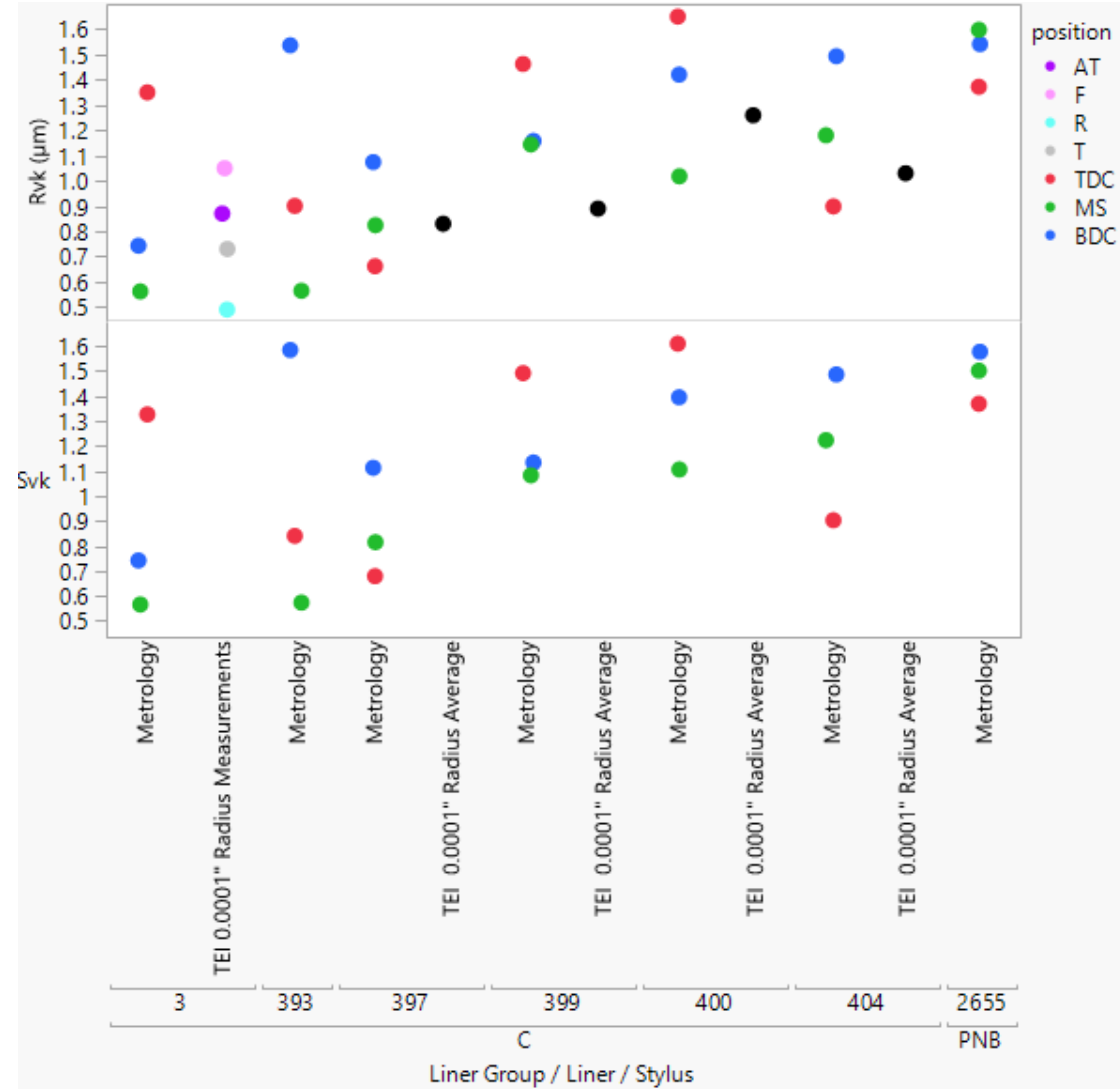
Rpk & Spk

There is no visual difference between Batch C and PNB liners. This is consistent with what was observed when TEI measurements were compared between batches



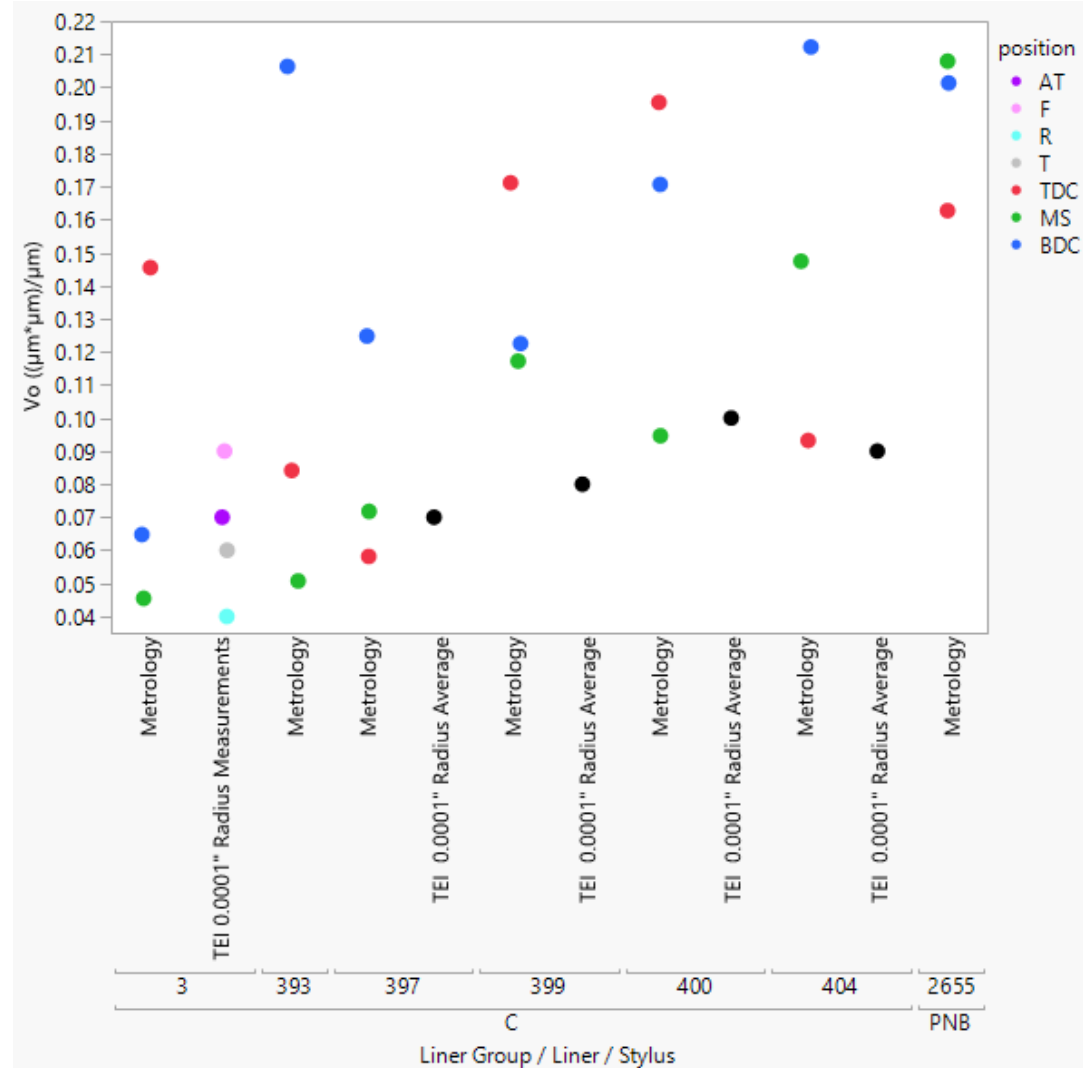
Rvk & Svk

The difference between PNB and Batch C liners is consistent with what was observed when TEI measurements were compared between batches (PNB slightly higher than C)



The difference between PNB and Batch C liners is consistent with what was observed when TEI measurements were compared between batches (PNB slightly higher than C)

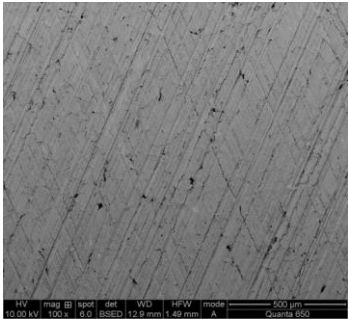
Metrology measurements appear slightly higher than TEI measurements



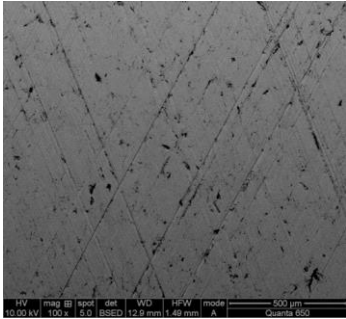
SEM Images of surface



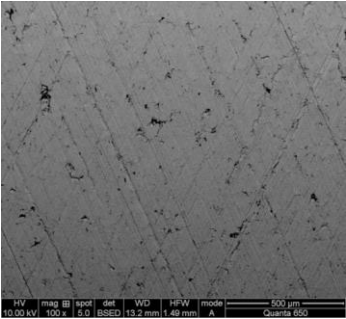
All the Batch surfaces are similar. The PNB looks slightly different.



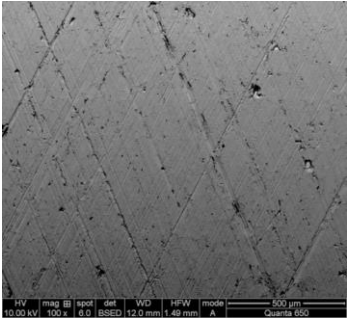
PNB 2655



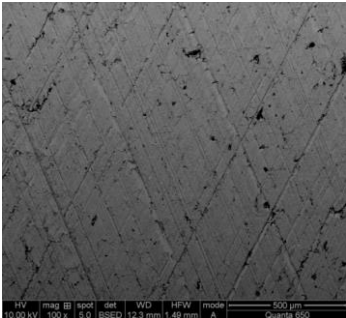
BATCH C
0003



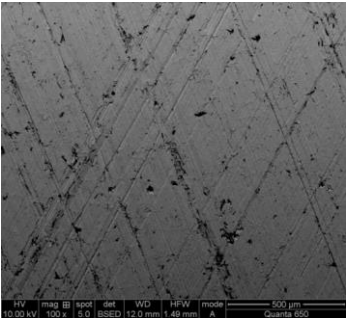
BATCH C
0393



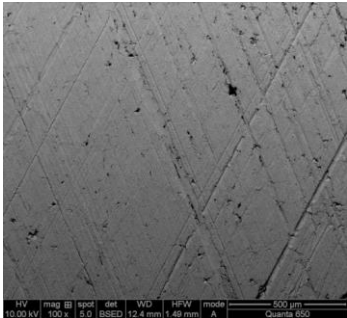
BATCH C
0397



BATCH C
0399



BATCH C
0400

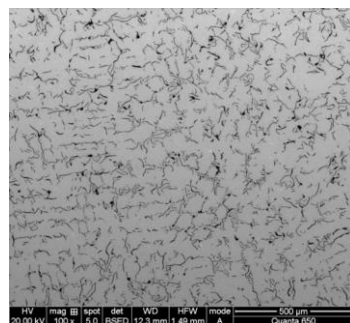


BATCH C
0404

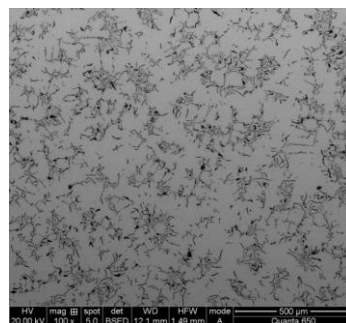
SEM images of cross section

The cross sections show how the graphite flakes are distributed throughout the microstructure.

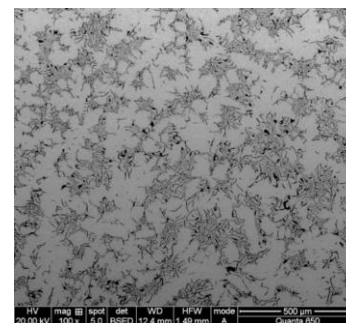
The random distribution is about the same, except for the PNB which has a little bit of direction to it. This may be due to a different casting technique.



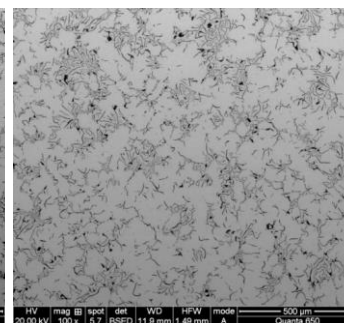
PNB 2655



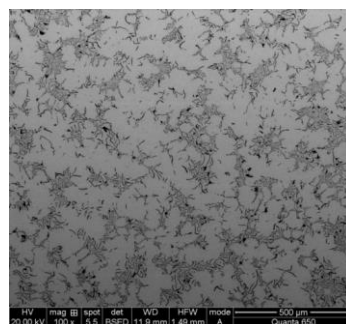
BATCH C
0003



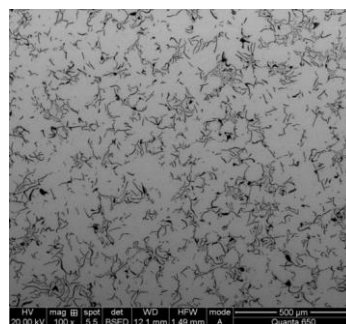
BATCH C
0393



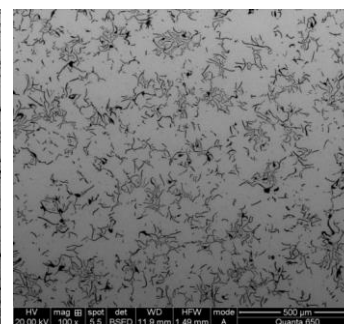
BATCH C
0397



BATCH C
0399



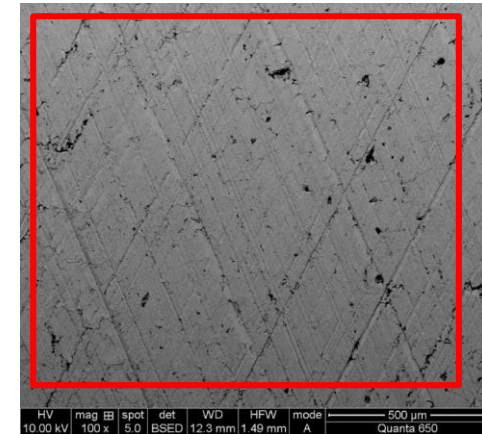
BATCH C
0400



BATCH C
0404

Slight differences in chemistry.

Spectrum Label	PNB 2655	BATCH C 0003	BATCH C 0393	BATCH C 0397	BATCH C 0399	BATCH C 0400	BATCH C 0404
C	9.64	9.85	7.00	7.22	7.98	9.01	9.83
O	1.22	1.14	1.05	0.83	1.07	0.95	1.06
Si	1.96	1.93	2.03	1.97	2.08	1.98	1.93
P	0.06	0.40	0.40	0.36	0.35	0.31	0.33
S	0.19	0.09	0.07	0.07	0.04	0.03	0.03
Cr	0.21	0.49	0.49	0.48	0.49	0.49	0.51
Mn	0.73	0.67	0.67	0.65	0.68	0.64	0.63
Fe	85.29	84.88	87.77	87.87	86.79	86.06	85.15
Cu	0.69	0.54	0.52	0.55	0.52	0.54	0.53
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00



Hardness data



Lubrizol WKF does not have Brinell capability for hardness testing. Hardness testing was done with HRC (Rockwell C) and then converted to HBW 30.

Old spec (Current FM) calls for minimum 225 HB, future Mahle calls for minimum 250 HBW 30.

All liners are within spec:

LINER	HRC Measured	Converted HBW 30
PNB	23	254
C 0003	27	279
C 0393	24	260
C 0397	25	266
C 0399	25	266
C 0400	25	266
C 0404	25	266



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Microstructure Analysis of Batch C & PNB Liners

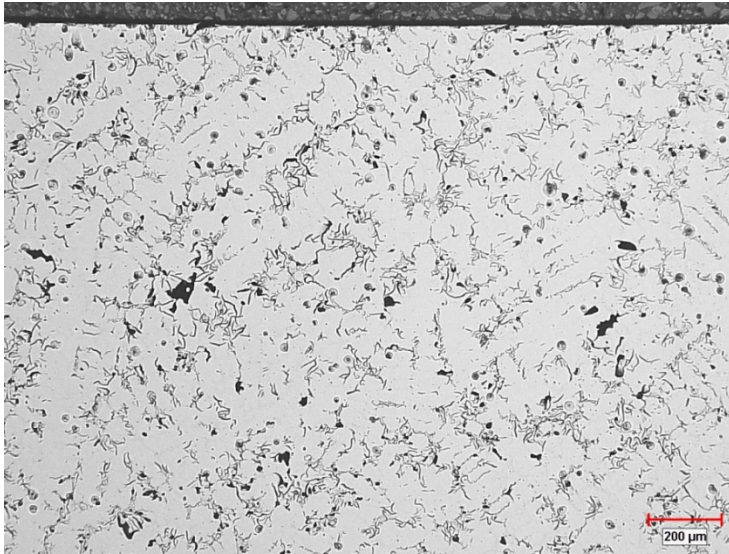
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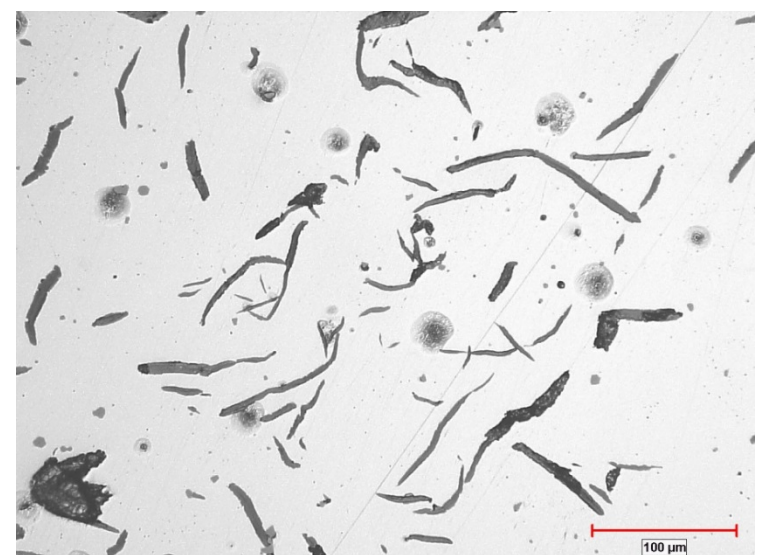
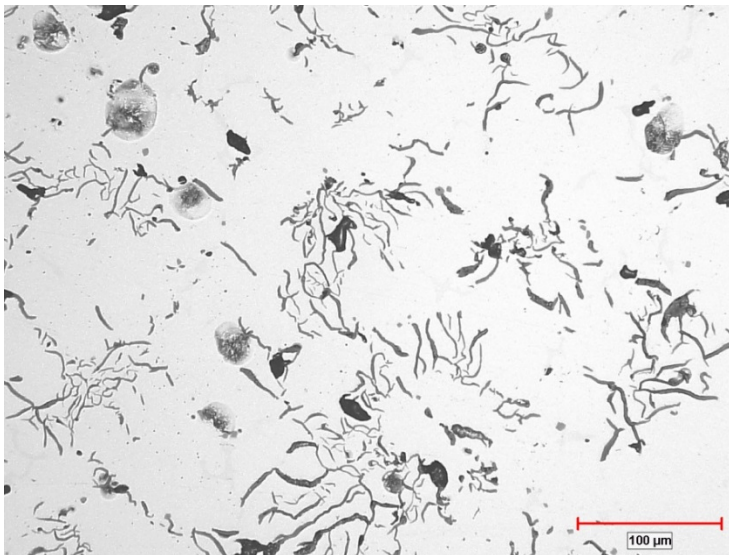
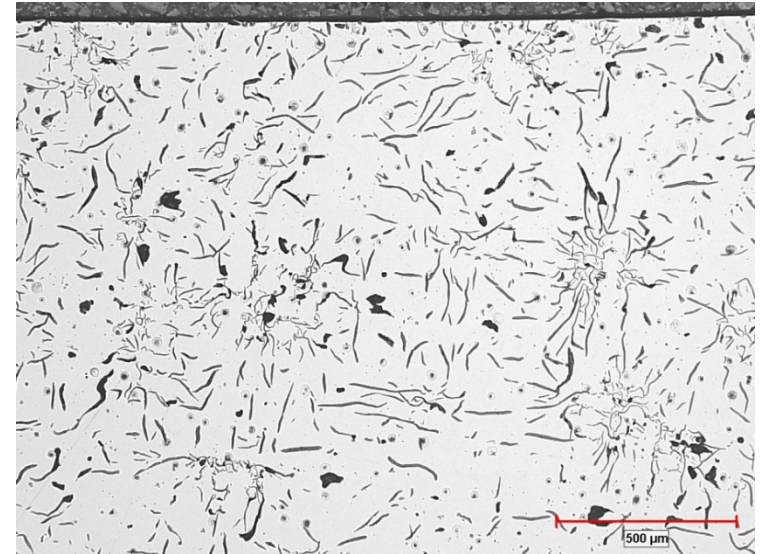


Piston Liner Comparisons — As-Polished Near Liner ID

Batch C Transverse Section

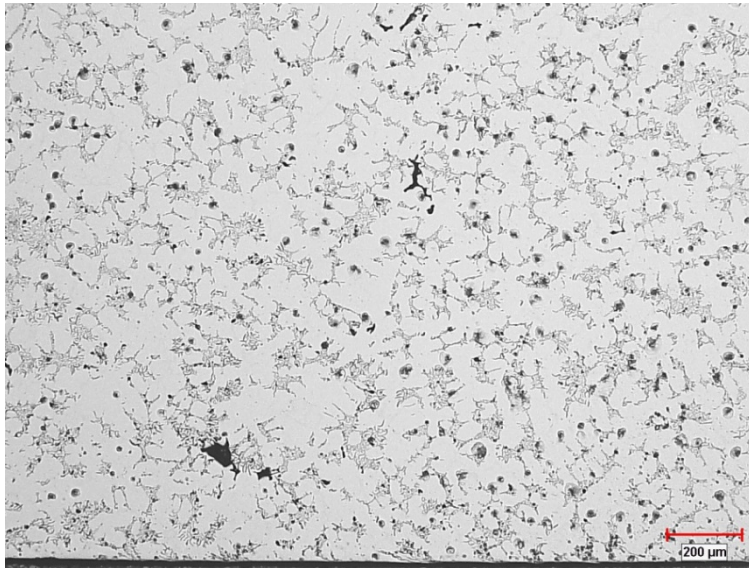


PNB Transverse Section

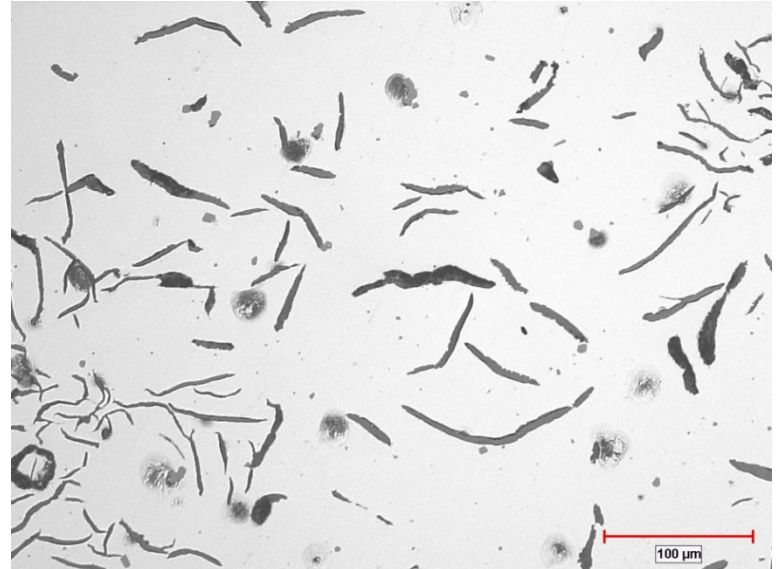
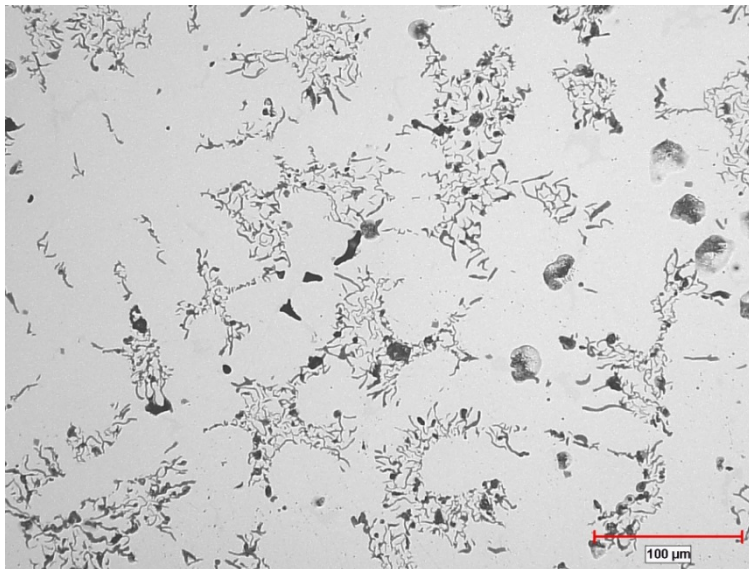
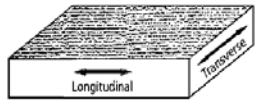
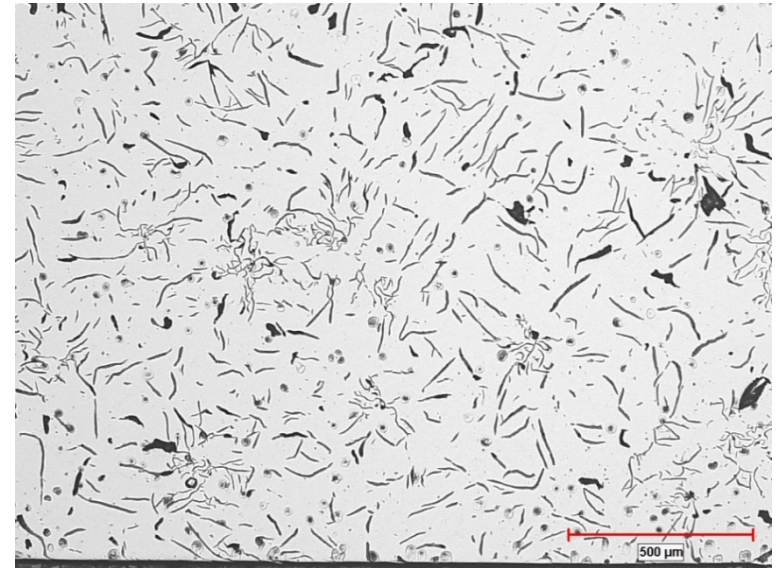


Piston Liner Comparisons — As-Polished Near Liner OD

Batch C Transverse Section



PNB Transverse Section

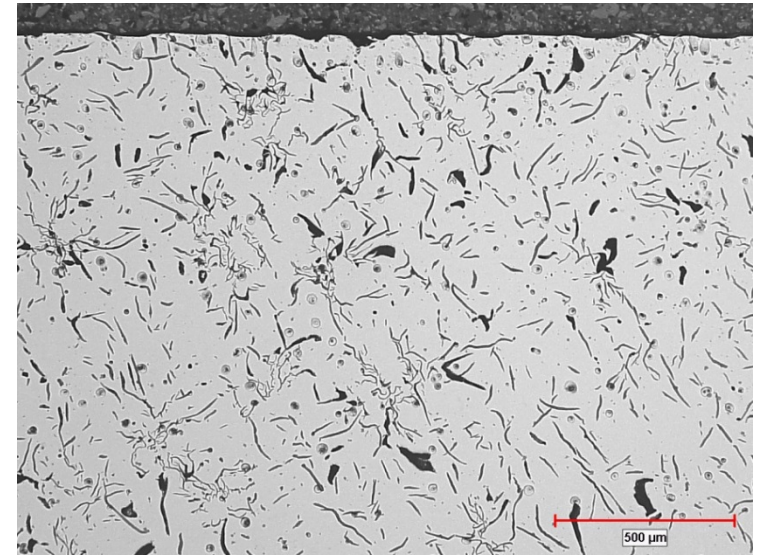
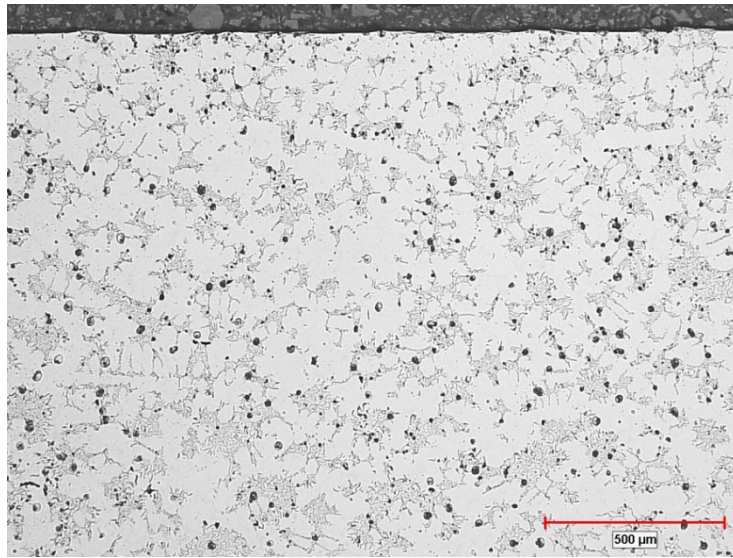


Piston Liner Comparisons—Longitudinal Specimens

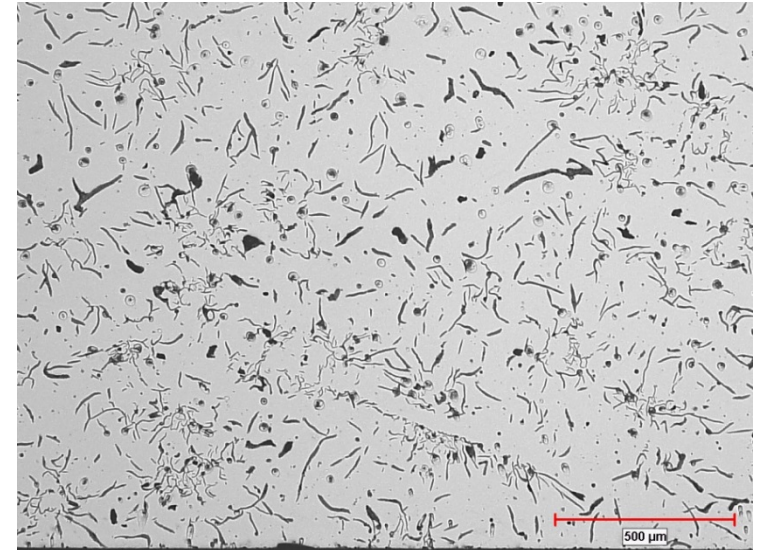
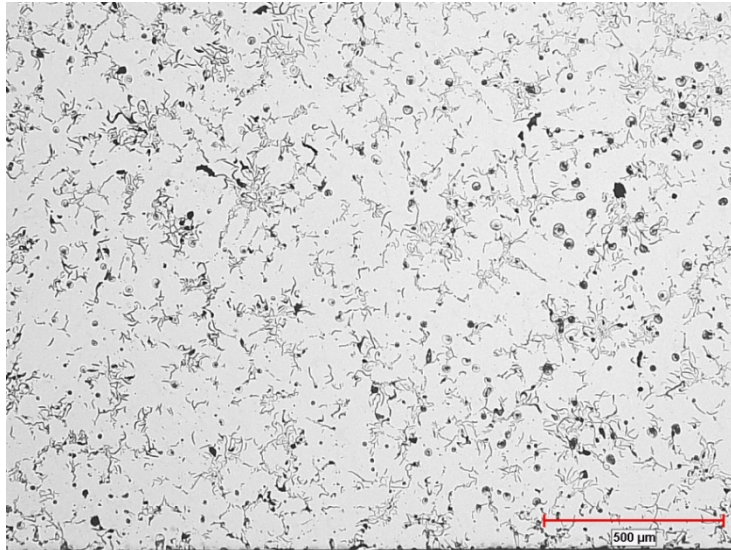
Batch C Longitudinal Section

PNB Longitudinal Section

OD
Region

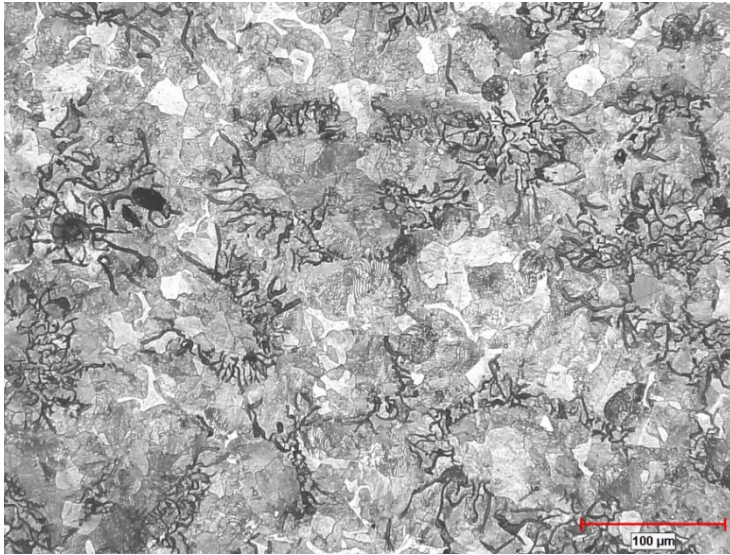


ID
Region

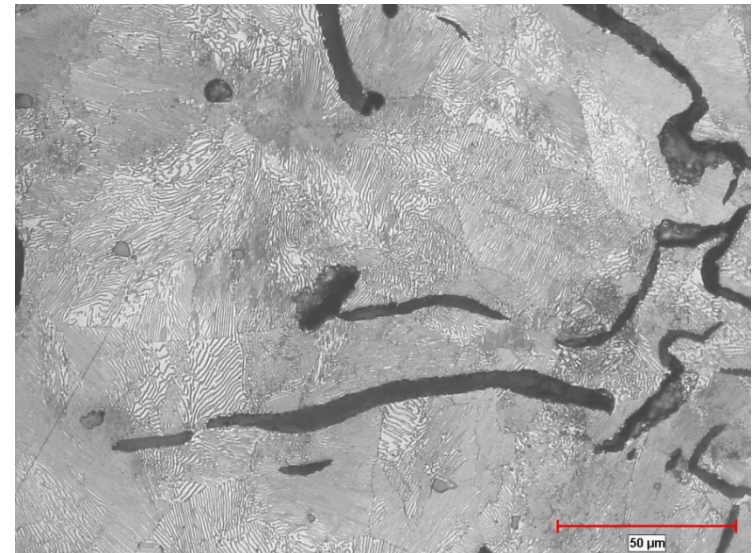
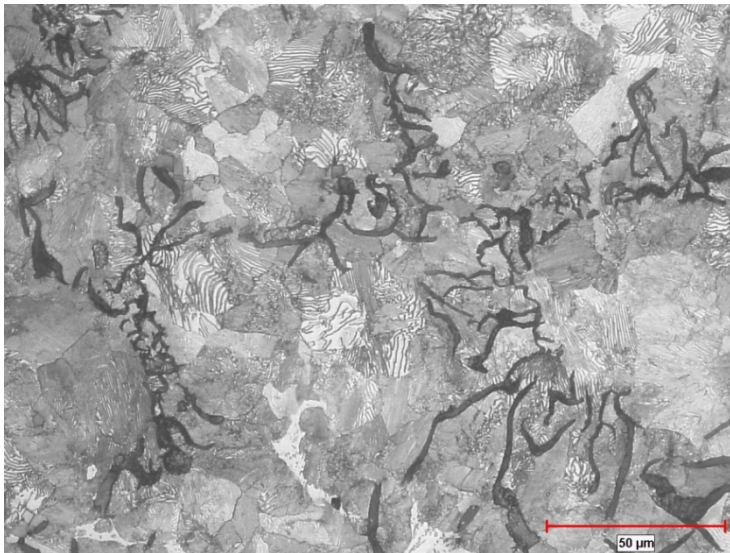
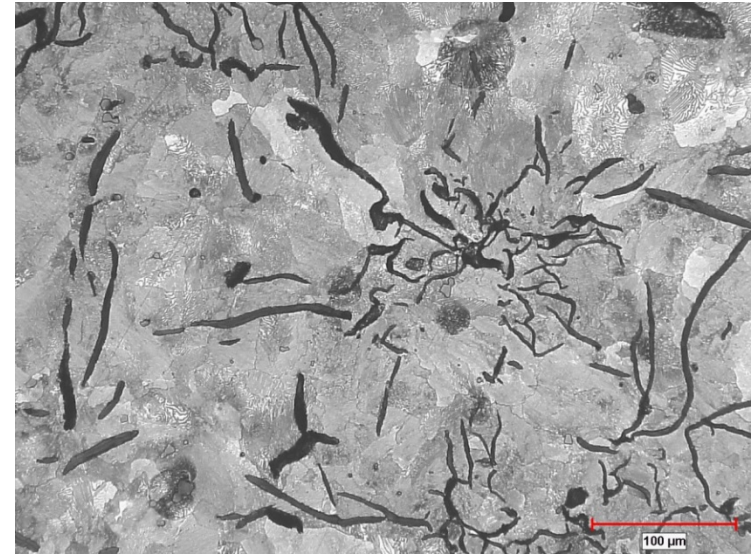


Piston Liner Comparisons—Transverse Specimens Etched

Batch C

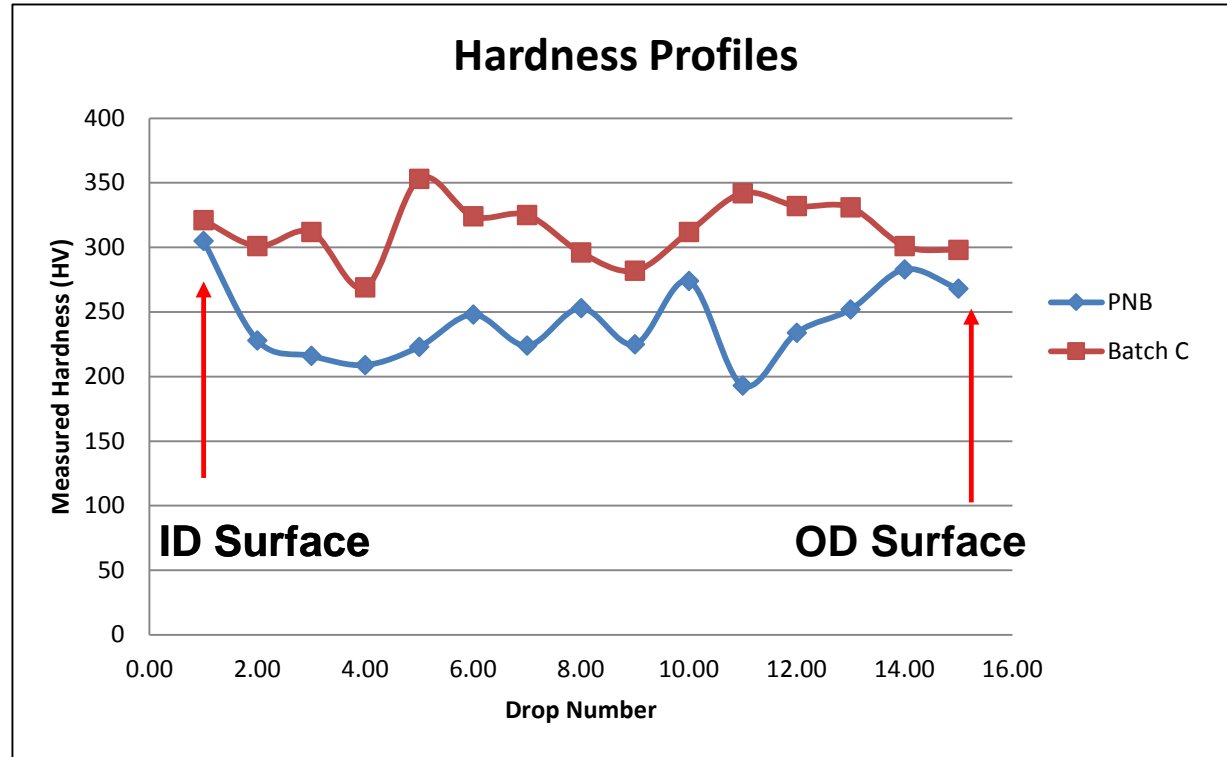


PNB



Hardness Measurements

ID	Drop	PNB		Batch C	
		HV	HRB	HV	HRC
ID Surface	1	305	96.48	321	32.32
	2	228	96.48	301	29.96
	3	216	94.11	312	31.23
	4	209	93.98	269	25.42
	5	223	95.54	353	35.86
	6	248	99.24	324	32.64
	7	224	95.84	325	32.78
	8	253	100.11	296	29.28
	9	225	95.98	282	27.32
	10	274	102.68	312	31.19
	11	193	90.12	342	34.66
	12	234	97.2	332	33.56
	13	252	99.84	331	33.41
	14	283	104.83	301	29.86
OD Surface	15	268	101.76	298	29.59
	Average	242.3	97.6	313.3	31.3



- Hardness profiles were taken across both transverse samples
- The average hardness value obtained from the PNB sample was significantly lower than the Batch C sample
- Neither profile exhibited clear evidence of case hardening/other trends

Light Microscopy Findings

- Examination of the as-polished samples revealed significant differences in the microstructures. The Batch C sample exhibited a cellular dendritic structure defined by clusters of relatively short (~10 microns) graphite flakes.
- The PNB sample exhibited much larger graphite flakes (~100 microns in length). These flakes tended to be less tightly clustered compared to the Batch C sample flakes
- Etching the samples revealed each samples matrix was principally composed of pearlite
- Neither sample exhibited a significant difference in morphology with respect to location. The material adjacent to the ID surface of the sample appeared to have a similar density and size distribution of graphite flakes compared to the material adjacent to the OD surface
- Only one Batch C and one PNB liner was analyzed.