Cummins SP Teleconference – June 14th, 2017

<u>Attendees:</u>

Lubrizol - Kevin O'Malley, Patrick Joyce, Nick Secue, Jonathan Ahlborn
Cummins - Corey Trobaugh, Christie Jackson, Ryan Denton
Afton - Bob Campbell
Southwest Research - Jose Starling
TEI - Dan Lanctot
Infineum - Bob Salgueiro, Elisa Santos, Jim Gutzwiller
TMC - Sean Moyer
Chevron Oronite - Mark Cooper, Jim Rutherford
Intertek – Jim Moritz, Josh Ward

<u>Agenda Items</u>

ISB Oil weigh pump replacement

The external oil weigh pump specified for the ISB is no longer available, we need a plan for a replacement.

-Jose said SW supplier can procure them from Viking in lots of 5.
-All labs should look at flow rates and determine whether flow rates are too slow.
-Any switchover to a new pump needs to be coordinated across labs

ISB Push rod socket end variability

-External visual differences have led to rejected parts. Visually cup appears to not be center on pushrod axis
-Corey Trobaugh said Cummins has had pushrods analyzed and compared to prints and all returned "bad" parts are within specs of the print
-Cummins can add a spec for centering the cup but price would increase, they have no concerns in warranty so there would be little to no drive to update production parts
-TEI always checks pushrod straightness but IAR brought the pushrod end socket visual skewness to TEI's attention
-Cummins will determine if the socket is friction welded after the cup is cut or if the cup is cut after the socket is attached and is that cup in-line with pushrod centerline

ISB Tappet wear severity

-Kevin presented his attached powerpoint (Cummins ISB Industry Analysis June 2017.pptx)
-Discussion about what data to include in calculations. Sean will look into adding LTMS field to denote whether a test is included in correction factor datasets
-Kevin brought up that this would be a good time to discuss moving the test to improved LTMS. Kevin and stats group will begin working up a proposed system.

ISB & ISM Standard Deviation (Outlier screened STD)

This is a small detail in the final report to clarify what standard deviation to use for the outlier screened STD.

-Editorial update to add std and min/max. Sean will issue information letter

Re-blend of ISB and ISM reference oil
Both test types have re-blends of their reference oil.
Generally, re-blends are just issued and the previous blend targets are used.

831-4 can be rolled into testing without need for coordinated references.
830-3 needs to have coordinated references due to changes in components used. Supplier has stated that since it has been so long since the last re-blend of the reference oil some components were no longer available. While they made every effort to select components that would yield the same results they would not categorize this as an exact re-blend and coordinated reference testing should be done to introduce this blend.

Cummins ISB Industry Severity

June 14, 2017

Kevin O'Malley
Statistician
The Lubrizol Corporation

Lubrizol

Data Considered

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87 chart="Y" data prior to 5/23/2017

+

Additional tests:

TESTKEY	LTMSLAB	IND	LTMSAPP	ENGINE	ENHOURS	VAL	LTMSDATE	CHART	ENKIT	COM1	COM2	COM3	COM4	TAPBID	CRHBID	CAMBID
106978-ISB	G	831-2	1	46560896	7910	AG	20150308	N	ISB-826	K CAM	D TAP		HARDWARE	D	D	K
106854-ISB	B	831-2	3	46562869	5280	AG	20150313	N	ISB-821	NEW CAM	NEW TAP			D	D	K
116611-ISB	G	831-3	6	440021	2593	OC	20161020	N	ISB-967	ATWL SEV				D	E	K
120532-ISB	G	831-3	5	49342610	1500	NN	20161029	N	ISB-969	STAND	INFO	RUN		D	E	K

106978 and 106854 were used in the prior severity analysis and correction factor calculations in 2015

116611 and 120532 are more recent non-chartable tests

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General Comments

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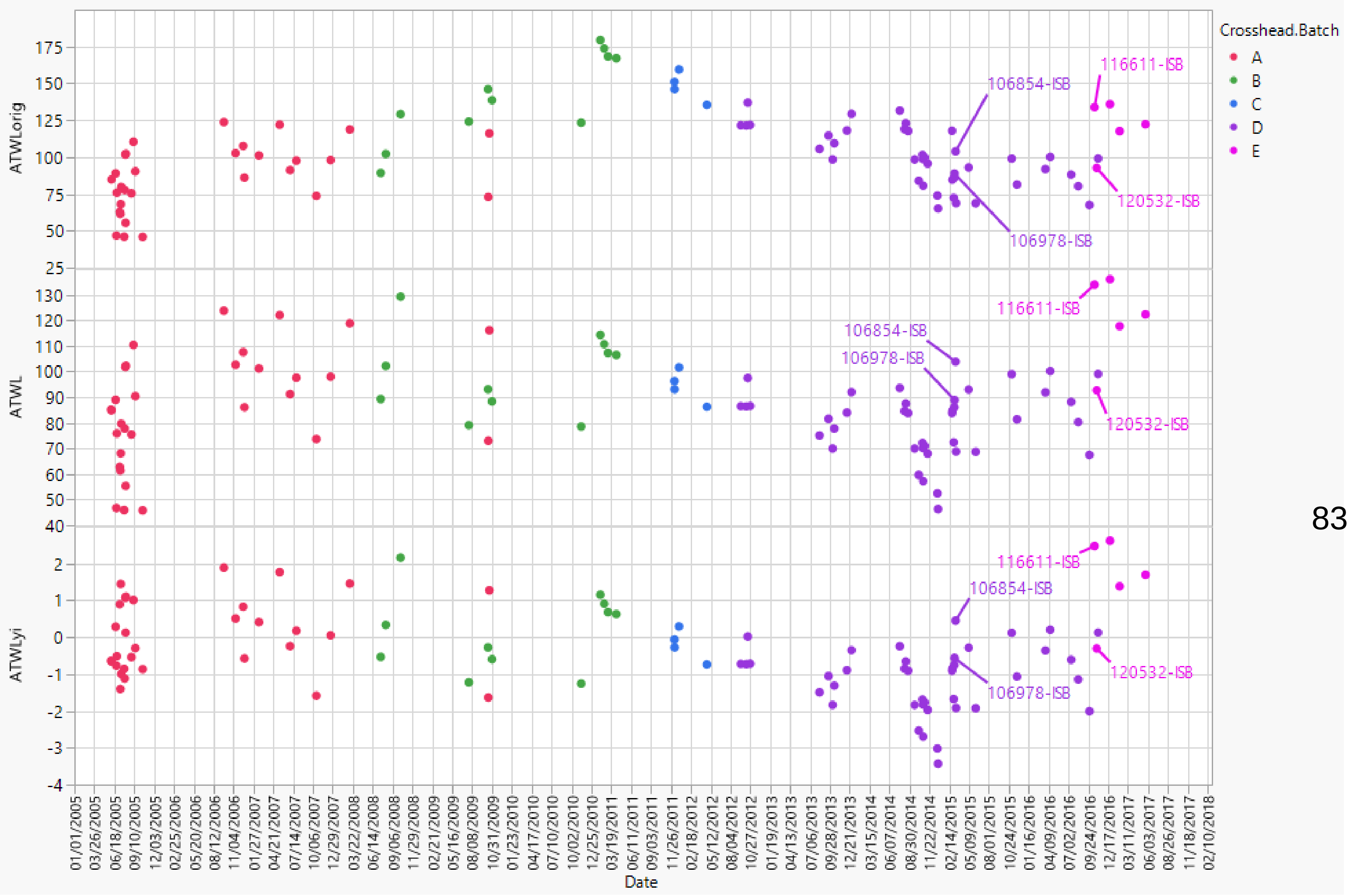
Tappet Weight Loss severity may have shifted with the introduction of Batch E Crossheads



4 of the 5 results with batch E are severe of target

831 Target mean = 97.2

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General Comments

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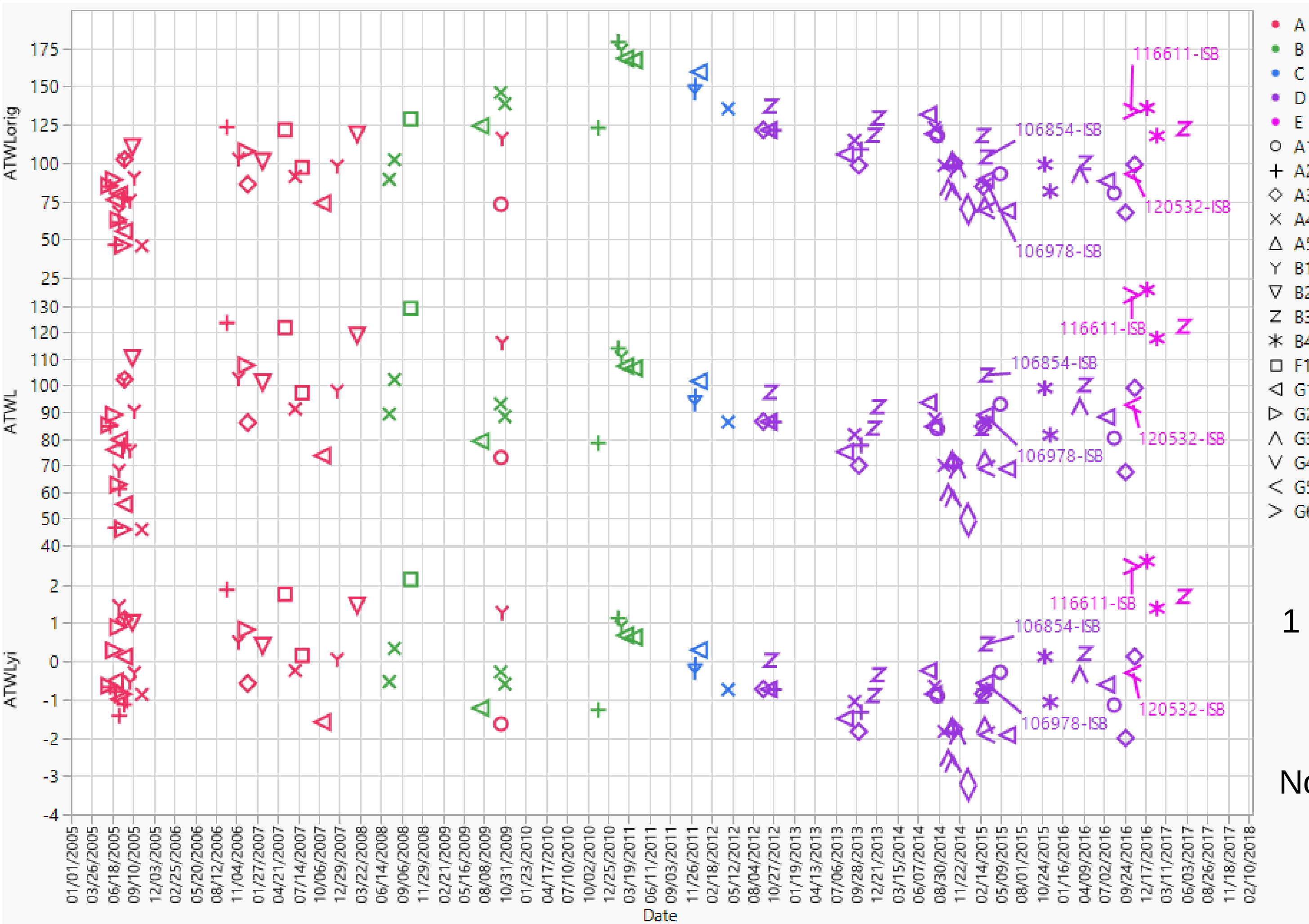
Labs and/or stands may or may not be impacted the same by the new batch of crossheads



Batch E results:
1 Lab G result near target;
1 severe Lab G result;
3 severe Lab B results

Note: No Lab A Batch E results yet

831 Target mean = 97.2

Some Options

1. Do nothing now; Revisit test severity when additional data have been obtained
2. Update the correction factor for Tappet Weight Loss:
   (current CF for Avg. Camshaft Wear appears appropriate)

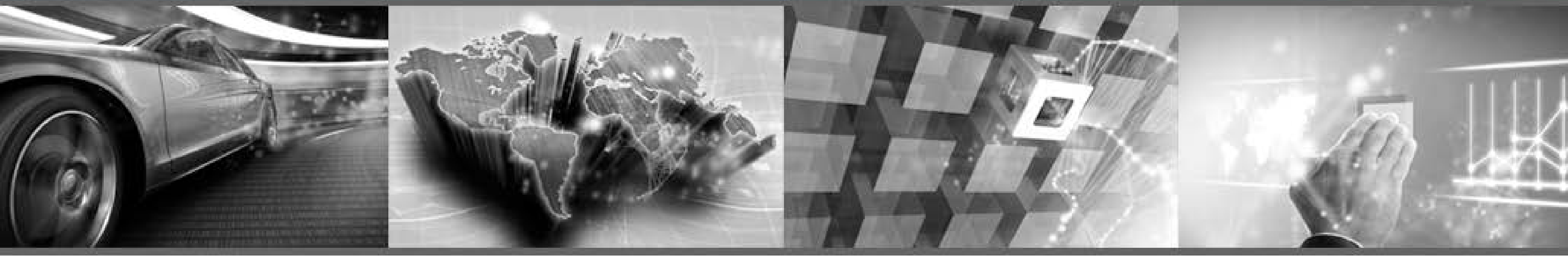
Some CFs:

Number of Tests	Multiply ATWL by:
n=91 (87 Chart=Y + 4)	0.801
n=89 (87 Chart=Y + 2)	0.811
n=87 (87 Chart=Y)	0.814

TESTKEY	LTMSLAB	IND	LTMSAPP	ENGINE	ENHOURS	VAL
106978-ISB	G	831-2	1	46560896	7910	AG
106854-ISB	B	831-2	3	46562869	5280	AG
116611-ISB	G	831-3	6	440021	2593	OC
120532-ISB	G	831-3	5	49342610	1500	NN

Model based estimates were used to generate Batch E Crosshead means.
Model terms include: LabStand (this is a combined term), IND, Crosshead Batch.
Refer to Appendix D for model output.
The ratio of the target to the estimated mean was used to calculate the CF.
Example: n = 91
The oil target for 831-1 = 97.2
The model estimated mean for crosshead batch E = 121.3
(assumes the use of 831-3 and an average across the lab-stand combinations)
CF = 97.2/121.3 = 0.801
Note: Various models were evaluated which involved combining oil blends, combining the crosshead batch and oil into one term, excluding non-chartable tests, and excluding three lab F tests. CFs based on these models are similar to estimates shown above.

3. Apply LTMS improvements



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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.

APPENDIX A

LTMS Details

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Hardware History

Current State of LTMS for ISB

LTMS file contains test results from 20041115 to 20150315

Severity adjustments are not currently applicable

1. These would affect candidate results only

Values used in ISB LTMS calculations

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart				Shewhart Chart	
		LAMBDA		K		K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Stand	Action	0.3	0.3	2.10	2.36	2.10	1.96
Industry	Warning	0.2	0.2	2.10	2.36	--	--
	Action	0.2	0.2	2.80	3.00	--	--

Current State of LTMS for ISB

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Correction factors are currently in place for Average Camshaft Wear (ACSW)

ISB	April 21, 2011	***	All tests using batch B tappets with batch E, F, and G cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
ISB	December 11, 2011	November 12, 2012	All tests using batch C Tappets with batch H cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
ISB	November 13, 2012	***	All tests using batch C tappets with batch H and J cams	Multiply ATWL by 0.711; Add -5.6 to ACSW
ISB	February 27, 2015	***	All tests using Batch D Tappets and Batch K Camshafts	Multiply ATWL by 1.0; Add -11.3 to ACSW

History of Reference Oil Targets (831-3 is new batch introduced in 2015)

ISB Reference Oil Targets							
Oil	n	Effective Dates		Average Camshaft Wear		Average Tappet Weight Loss	
		From	To[1]	$\overline{X}$	s	$\overline{X}$	s
821 (PC10E)	6	6-4-05	12-31-05	34.6	4.6	56.2	9.6
830-2	6	6-4-05	12-31-05	39.8	9.0	85.9	16.0
831 (PC10B)	6	6-4-05	1-24-07	41.9	5.6	88.7	15.9
	10	1-25-07	8-6-07	42.8	5.4	94.9	15.3
	14	8-7-07	***	42.5	5.0	97.2	14.8
831-1[2]	--	8-7-07	***	42.5	5.0	97.2	14.8
831-2[2]	--	8-6-13	***	42.5	5.0	97.2	14.8
831-3[2]	--	8-11-15	***	42.5	5.0	97.2	14.8

1 *** = currently in effect
2 Targets based on oil 831

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Cummins ISB Critical Engine Parts Batch Changes		
ISB Camshaft Batch	Starting Kit #	Date
A	1	Jun-2004
B	135	Feb-2006
C	244	Aug-2007
D	290	Jul-2008
E	337	Apr-2009
F	389	Mar-2010
G	441	Mar-2011
H	486	Nov-2011
J	569	Aug-2012
K	821	Jan-2015
ISB Tappet Batch	Starting Kit #	Date
A	1	Jun-2004
B	279	Jan-2008
C	475	Aug-2011
D	821	Jan-2015
ISB Crosshead Batch	Starting Kit #	Date
A	1	Jun-2004
B	279	Jan-2008
C	475	Aug-2011
D	569	Aug-2012

Batch E crossheads are being utilized

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Pushrod Batches

New pushrods estimated to start with Kit# 556

- 5000 were obtained on June 22, 2012
- We cannot guarantee these 5000 came from the same batch

Prior to new pushrod “batch”, pushrods came in small quantities from different batches

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APPENDIX B

Average Camshaft Wear Graphs

Average Camshaft Wear
By OIL and LAB

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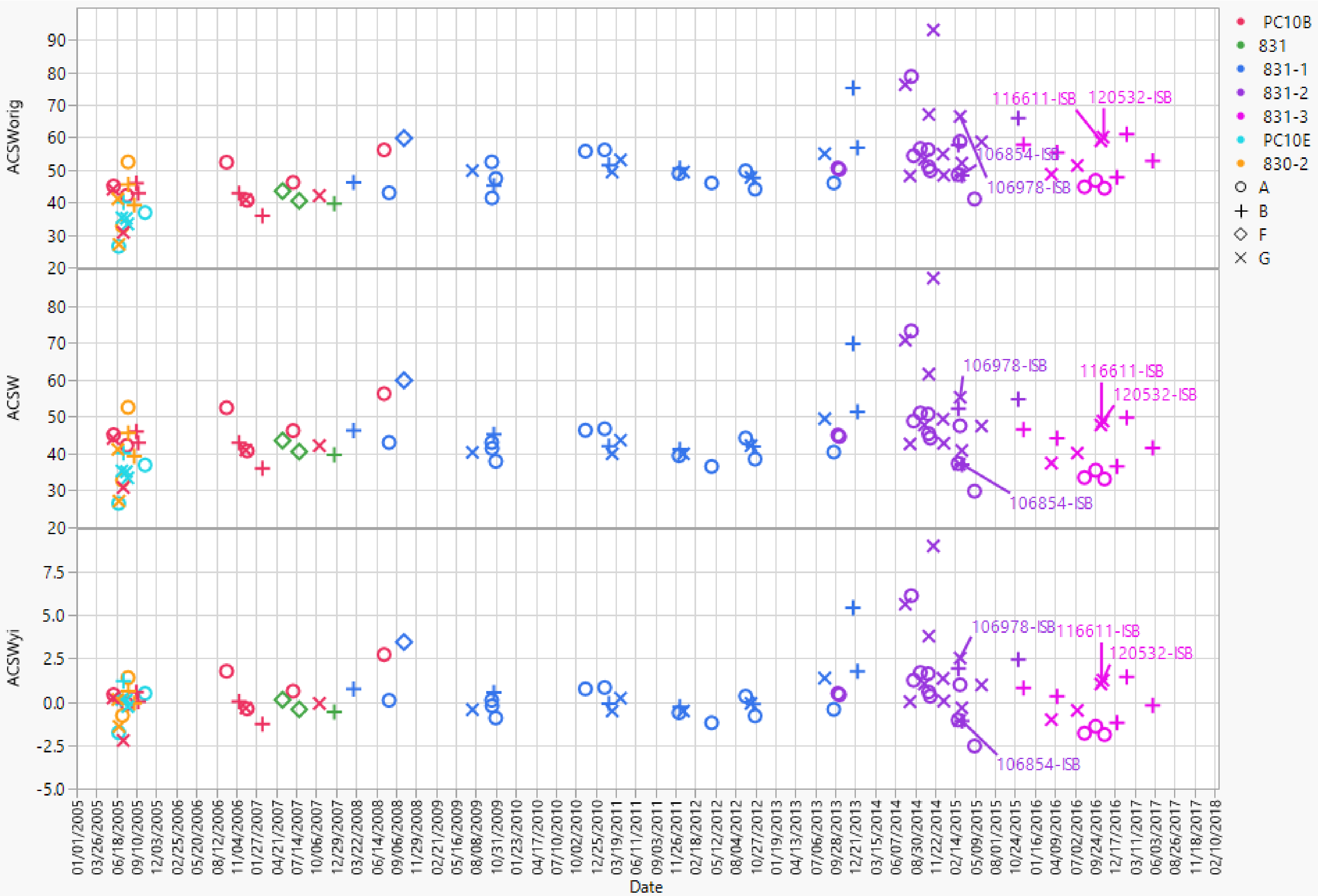

831 Target mean = 42.5

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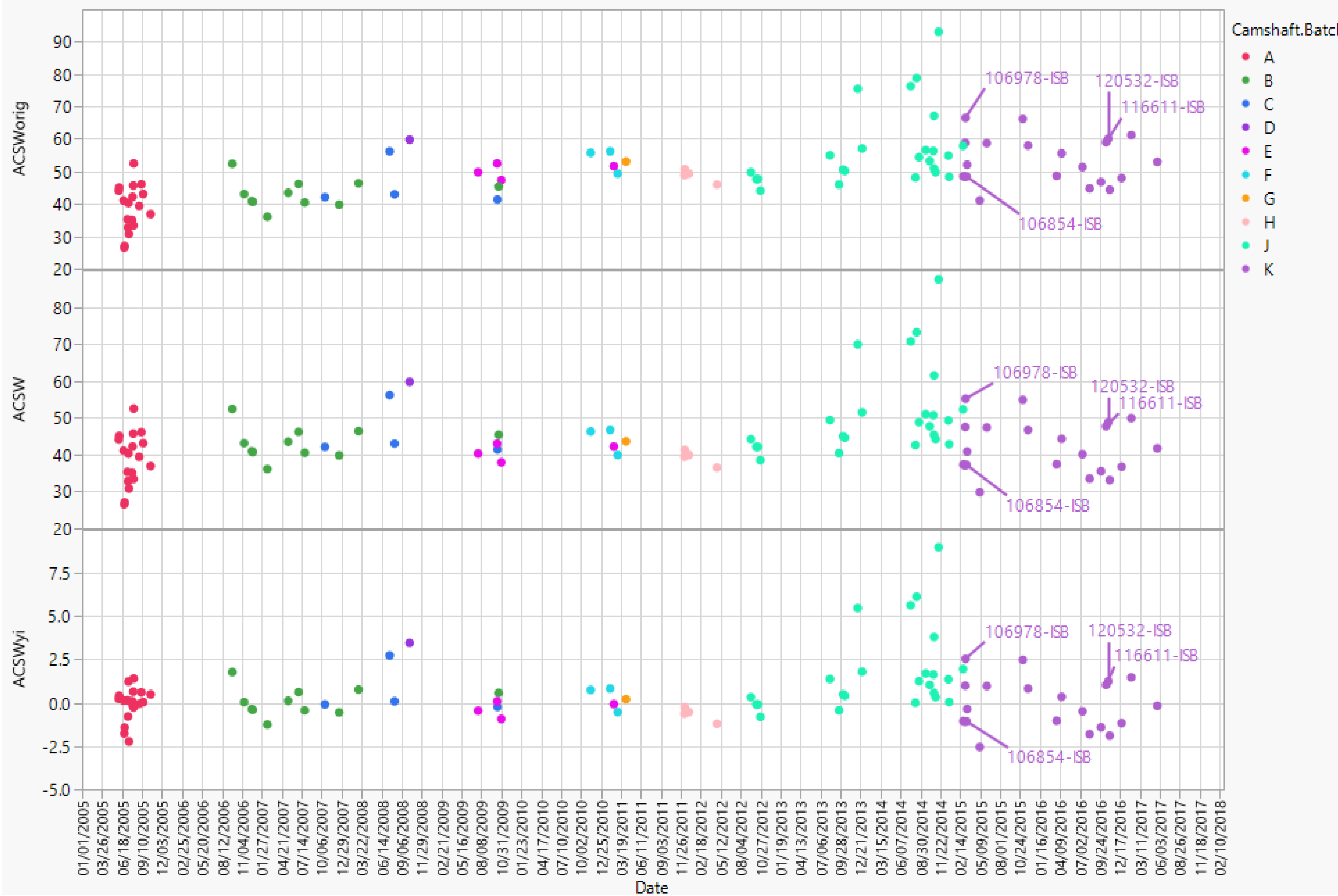
Average Camshaft Wear
By Camshaft Batch



831 Target mean = 42.5

Average Camshaft Wear By Tappet Batch

831 Target mean = 42.5

Average Camshaft Wear By Crosshead Batch

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831 Target mean = 42.5

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Average Camshaft Wear By Pushrod "Batch"

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831 Target mean = 42.5

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APPENDIX C

Average Tappet Weight Loss Graphs

Average Tappet Weight Loss (ATWLorig): By Oil and Lab

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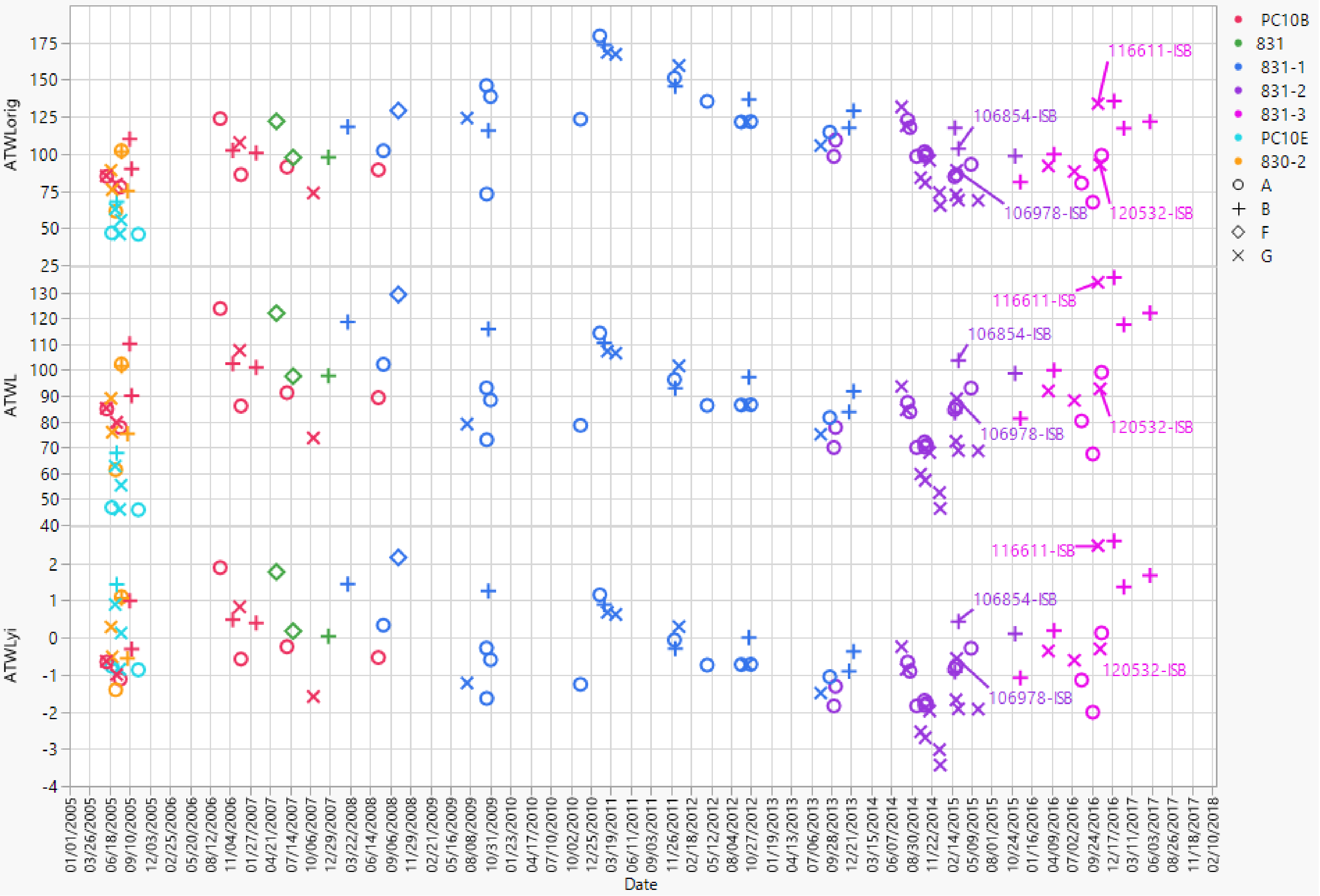

831 Target mean = 97.2

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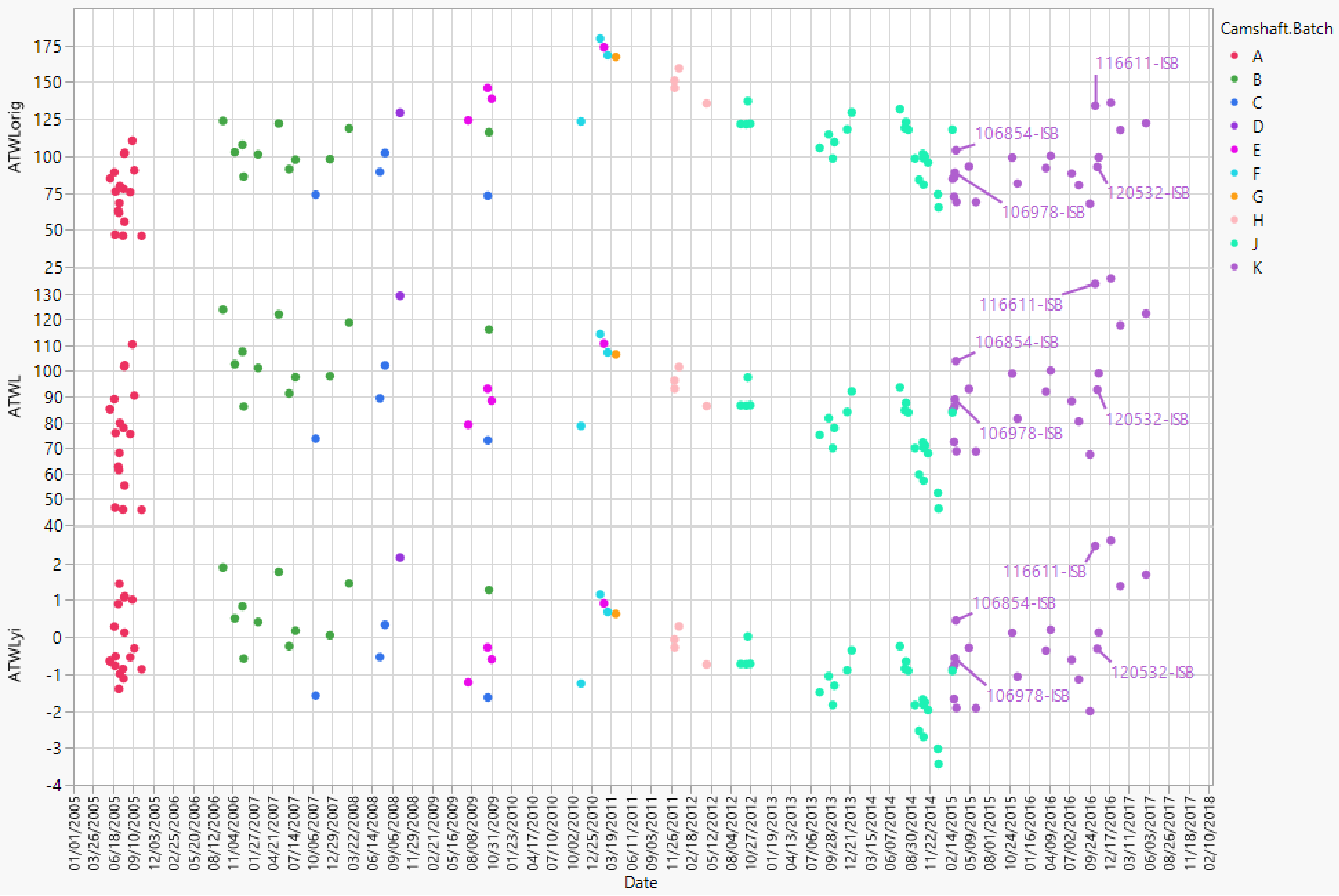
Average Tappet Weight Loss (ATWLorig): By Camshaft Batch



831 Target mean = 97.2

Average Tappet Weight Loss (ATWLorig): By Tappet Batch

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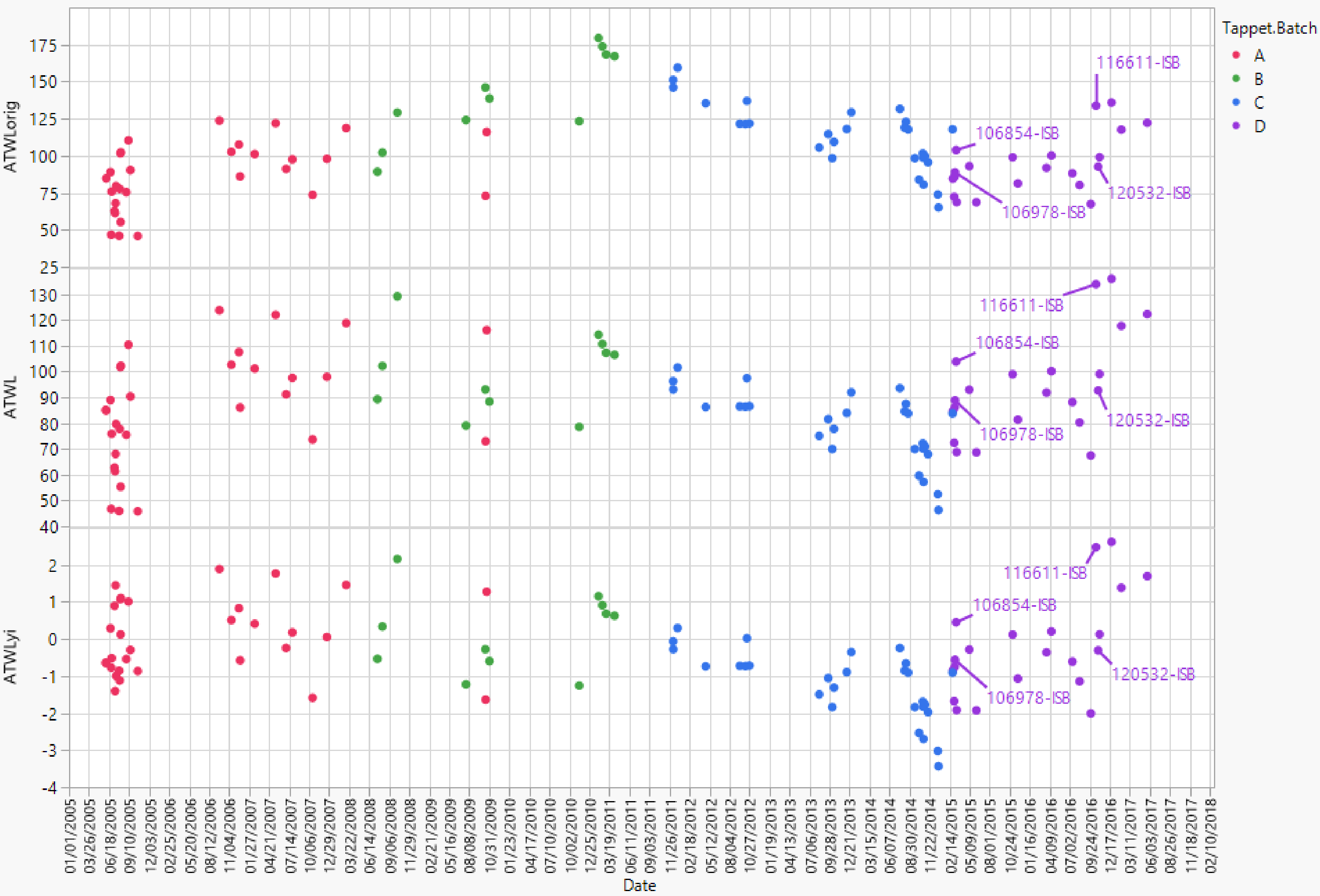

831 Target mean = 97.2

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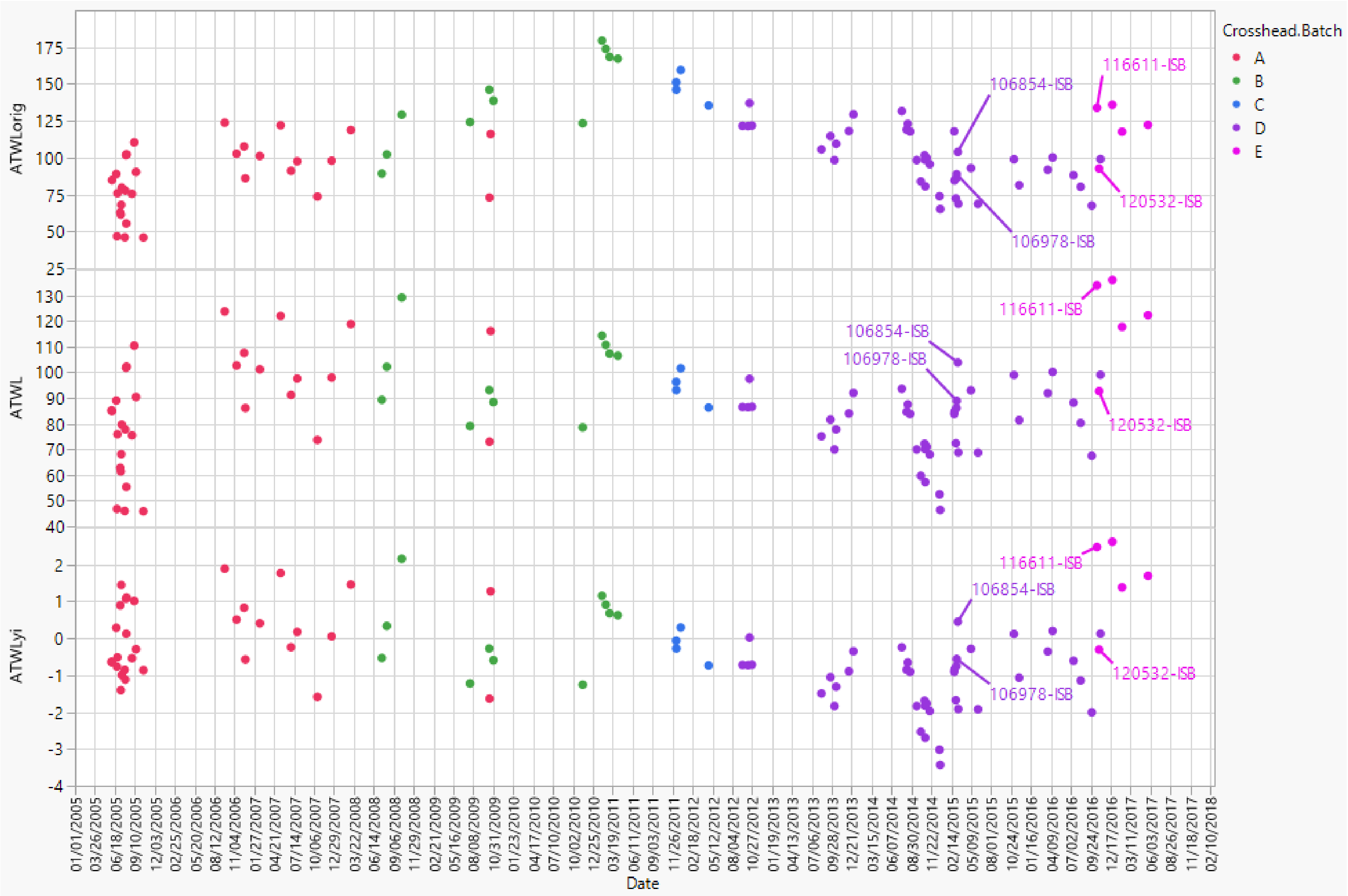
Average Tappet Weight Loss (ATWLorig): By Crosshead Batch



831 Target mean = 97.2

Average Tappet Weight Loss (ATWLorig): By Pushrod Batch

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831 Target mean = 97.2

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APPENDIX D

Model Output

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ATWLorig
N=91 (Chart = Y + 4)

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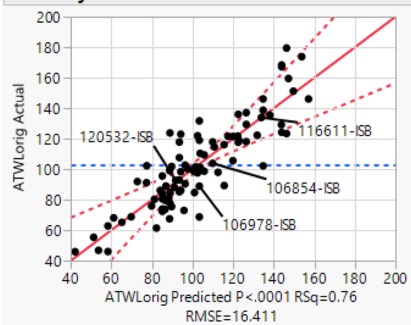
Chart = Y plus the following tests:

TESTKEY	LTMSLAB	IND	LTMSAPP	ENGINE	ENHOURS	VAL	LTMSDATE	CHART	ENKIT	COM1	COM2	COM3	COM4	TAPBID	CRHBID	CAMBID
106978-ISB	G	831-2	1	46560896	7910	AG	20150308	N	ISB-826	K CAM	D TAP		HARDWARE	D	D	K
106854-ISB	B	831-2	3	46562869	5280	AG	20150313	N	ISB-821	NEW CAM	NEW TAP			D	D	K
116611-ISB	G	831-3	6	440021	2593	OC	20161020	N	ISB-967	ATWL SEV				D	E	K
120532-ISB	G	831-3	5	49342610	1500	NN	20161029	N	ISB-969	STAND	INFO	RUN		D	E	K

Actual by Predicted Plot



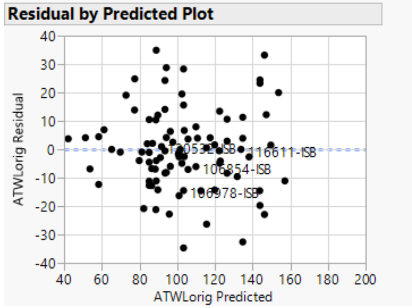
Summary of Fit

RSquare	0.764482
RSquare Adj	0.673898
Root Mean Square Error	16.41112
Mean of Response	102.933
Observations (or Sum Wgts)	91

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LabStand	15	15	6964.782	1.7240	0.0678
Crosshead.Batch	4	4	7810.389	7.2500	<.0001*
IND	6	6	10397.072	6.4340	<.0001*

Residual by Predicted Plot



Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	109.06925	5.312526	20.53	<.0001*
LabStand[A1]	-5.826798	8.563338	-0.68	0.4986
LabStand[A2]	6.4093749	5.786363	1.11	0.2721
LabStand[A3]	1.6393806	6.329126	0.26	0.7964
LabStand[A4]	-5.12289	5.929081	-0.86	0.3907
LabStand[A5]	2.2434259	15.8709	0.14	0.8880
LabStand[B1]	13.907045	6.740858	2.06	0.0431*
LabStand[B2]	21.279087	10.55577	2.02	0.0480*
LabStand[B3]	10.600467	6.96107	1.52	0.1327
LabStand[B4]	1.2801609	9.35206	0.14	0.8915
LabStand[F1]	3.8571888	12.97022	0.30	0.7671
LabStand[G1]	4.0200602	5.040401	0.80	0.4280
LabStand[G2]	11.055134	8.566105	1.29	0.2014
LabStand[G3]	-14.24213	7.310393	-1.95	0.0557
LabStand[G4]	-34.15657	15.8709	-2.15	0.0351*
LabStand[G5]	-29.5665	12.0041	-2.46	0.0164*
LabStand[G6]	12.623572	18.23723	0.69	0.4913
Crosshead.Batch[A]	-28.52983	8.731678	-3.27	0.0017*
Crosshead.Batch[B]	9.7554305	5.940196	1.64	0.1054
Crosshead.Batch[C]	13.117651	7.89009	1.66	0.1012
Crosshead.Batch[D]	-14.27487	5.369417	-2.66	0.0099*
Crosshead.Batch[E]	19.931627	10.94978	1.82	0.0733
IND[PC10B]	1.929899	6.103819	0.32	0.7529
IND[831]	18.120113	12.23287	1.48	0.1434
IND[831-1]	21.084705	5.984075	3.52	0.0008*
IND[831-2]	4.5622024	8.044867	0.57	0.5726
IND[831-3]	-7.724446	9.403515	-0.82	0.4144
IND[PC10E]	-33.26006	8.129938	-4.09	0.0001*
IND[830-2]	-4.712419	7.801627	-0.60	0.5479

Level				Least Sq Mean
831-1	A			130.15395
831	A	B		127.18936
831-2	A	B	C	113.63145
PC10B	A	B		110.99915
830-2	A	B	C	104.35683
831-3		B	C	101.34480
PC10E			C	75.80919

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
E	A			129.00087
C	A	B		122.18690
B	A			118.82468
D		B	C	94.79437
A			C	80.53941

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
B2	A	130.34833
B1	A	122.97629
G6	A	121.69282
G2	A	120.12438
B3	A	119.66971
A2	A	115.47862
G1	A	113.08931
F1	A	112.92644
A5	A	111.31267
A3	A	110.70863
B4	A	110.34941
A4	A	103.94636
A1	A	103.24245
G3	A	94.82711
G5	A	79.50275
G4	A	74.91267

Levels not connected by same letter are significantly different.

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ATWLorig

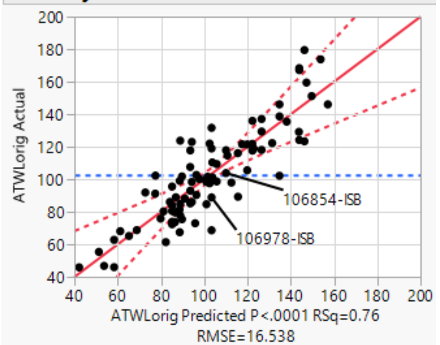
N=89 (Chart = Y + 2)

SUCCESS TOGETHER

Chart = Y plus the following tests:

TESTKEY	LTMSLAB	IND	LTMSAPP	ENGINE	ENHOURS	VAL	LTMSDATE	CHART	ENKIT	COM1	COM2	COM3	COM4	TAPBID	CRHBID	CAMBID
106978-ISB	G	831-2	1	46560896	7910	AG	20150308	N	ISB-826	K CAM	D TAP		HARDWARE	D	D	K
106854-ISB	B	831-2	3	46562869	5280	AG	20150313	N	ISB-821	NEW CAM	NEW TAP			D	D	K

Actual by Predicted Plot



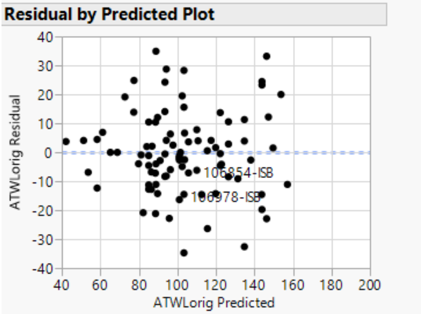
Summary of Fit

RSquare	0.761081
RSquare Adj	0.671487
Root Mean Square Error	16.53764
Mean of Response	102.7
Observations (or Sum Wgts)	89

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LabStand	14	14	5944.831	1.5526	0.1183
Crosshead.Batch	4	4	7479.958	6.8374	0.0001*
IND	6	6	10397.909	6.3365	<.0001*

Residual by Predicted Plot



Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	108.07491	5.64065	19.16	<.0001*
LabStand[A1]	-4.937461	8.523992	-0.58	0.5645
LabStand[A2]	7.2957473	5.641897	1.29	0.2006
LabStand[A3]	2.5363149	6.271627	0.40	0.6873
LabStand[A4]	-4.239369	5.801465	-0.73	0.4676
LabStand[A5]	3.1059489	15.88166	0.20	0.8456
LabStand[B1]	14.795088	6.591037	2.24	0.0282*
LabStand[B2]	22.167585	10.48572	2.11	0.0384*
LabStand[B3]	11.583097	7.202754	1.61	0.1127
LabStand[B4]	2.4504312	10.27853	0.24	0.8123
LabStand[F1]	4.7442917	12.92463	0.37	0.7148
LabStand[G1]	4.9094428	4.901595	1.00	0.3203
LabStand[G2]	11.943172	8.46782	1.41	0.1633
LabStand[G3]	-13.36619	7.268655	-1.84	0.0706
LabStand[G4]	-33.29405	15.88166	-2.10	0.0400*
LabStand[G5]	-29.69405	15.88166	-1.87	0.0661
Crosshead.Batch[A]	-28.41795	8.875551	-3.20	0.0021*
Crosshead.Batch[B]	9.870075	6.103515	1.62	0.1108
Crosshead.Batch[C]	13.231942	8.039225	1.65	0.1047
Crosshead.Batch[D]	-14.19794	5.469619	-2.60	0.0117*
Crosshead.Batch[E]	19.513877	11.85827	1.65	0.1048
IND[PC10B]	1.9242259	6.151158	0.31	0.7554
IND[831]	18.115151	12.32728	1.47	0.1466
IND[831-1]	21.077919	6.030621	3.50	0.0009*
IND[831-2]	4.6170791	8.126941	0.57	0.5719
IND[831-3]	-7.750108	9.479766	-0.82	0.4167
IND[PC10E]	-33.26483	8.192765	-4.06	0.0001*
IND[830-2]	-4.719434	7.862111	-0.60	0.5504

Level			Least Sq Mean
E	A	B	127.58879
C	A		121.30685
B	A		117.94499
D	A	B	93.87697
A		B	79.65696

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
831-1	A			129.15283
831	A	B		126.19006
831-2	A	B	C	112.69199
PC10B	A	B		109.99914
830-2	A	B	C	103.35548
831-3		B	C	100.32480
PC10E			C	74.81008

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
B2	A	130.24250
B1	A	122.87000
G2	A	120.01808
B3	A	119.65801
A2	A	115.37066
G1	A	112.98435
F1	A	112.81920
A5	A	111.18086
A3	A	110.61123
B4	A	110.52534
A4	A	103.83554
A1	A	103.13745
G3	A	94.70873
G5	A	78.38086
G4	A	74.78086

Levels not connected by same letter are significantly different.

Lubrizol

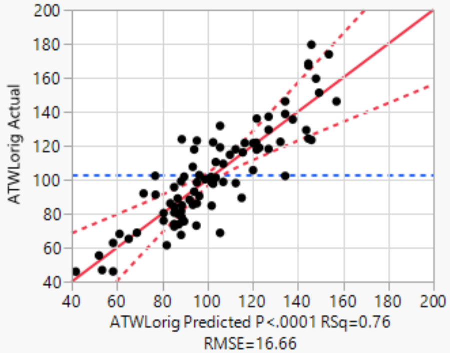
ATWLorig

N=87 (Chart = Y)

SUCCESS TOGETHER

Chart = Y only

Actual by Predicted Plot



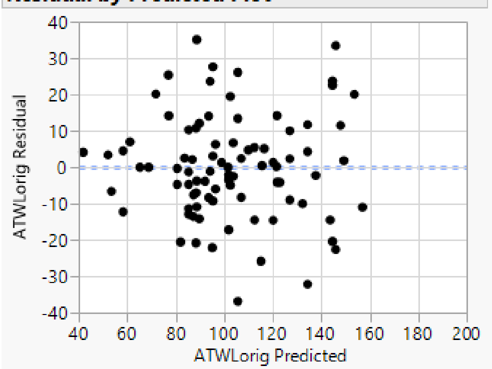
Summary of Fit

RSquare	0.764491
RSquare Adj	0.673326
Root Mean Square Error	16.65985
Mean of Response	102.8448
Observations (or Sum Wgts)	87

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LabStand	14	14	6124.744	1.5762	0.1117
Crosshead.Batch	4	4	7465.531	6.7245	0.0001*
IND	6	6	10243.796	6.1513	<.0001*

Residual by Predicted Plot



Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	107.71796	5.694256	18.92	<.0001*
LabStand[A1]	-5.344186	8.597415	-0.62	0.5365
LabStand[A2]	7.4882073	5.690449	1.32	0.1930
LabStand[A3]	2.3915839	6.319533	0.38	0.7064
LabStand[A4]	-4.150168	5.849296	-0.71	0.4807
LabStand[A5]	2.084346	16.03371	0.13	0.8970
LabStand[B1]	15.195262	6.65801	2.28	0.0259*
LabStand[B2]	22.496804	10.57187	2.13	0.0373*
LabStand[B3]	12.962724	7.949918	1.63	0.1081
LabStand[B4]	2.4694558	10.38171	0.24	0.8128
LabStand[F1]	5.1800321	13.03105	0.40	0.6924
LabStand[G1]	6.1009696	5.105977	1.19	0.2367
LabStand[G2]	12.348369	8.544684	1.45	0.1535
LabStand[G3]	-14.19209	7.369775	-1.93	0.0587
LabStand[G4]	-34.31565	16.03371	-2.14	0.0363*
LabStand[G5]	-30.71565	16.03371	-1.92	0.0600
Crosshead.Batch[A]	-28.04643	8.97392	-3.13	0.0027*
Crosshead.Batch[B]	10.045864	6.194167	1.62	0.1099
Crosshead.Batch[C]	13.398843	8.132539	1.65	0.1045
Crosshead.Batch[D]	-14.39506	5.537522	-2.60	0.0117*
Crosshead.Batch[E]	18.996785	12.06482	1.57	0.1204
IND[PC10B]	1.5476924	6.213039	0.25	0.8041
IND[831]	17.676701	12.42782	1.42	0.1599
IND[831-1]	20.799632	6.086929	3.42	0.0011*
IND[831-2]	6.1927528	8.388552	0.74	0.4632
IND[831-3]	-7.348621	9.561079	-0.77	0.4451
IND[PC10E]	-33.72669	8.268595	-4.08	0.0001*
IND[830-2]	-5.141466	7.935221	-0.65	0.5194

Level			Least Sq Mean
E	A	B	126.71474
C	A		121.11680
B	A		117.76382
D	A	B	93.32290
A		B	79.67152

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
831-1	A		128.51759
831	A		125.39466
831-2	A	B	113.91071
PC10B	A		109.26565
830-2	A	B	102.57649
831-3	A	B	100.36934
PC10E		B	73.99127

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
B2	A	130.21476
B1	A	122.91322
B3	A	120.68068
G2	A	120.06633
A2	A	115.20617
G1	A	113.81893
F1	A	112.89799
B4	A	110.18741
A3	A	110.10954
A5	A	109.80230
A4	A	103.56779
A1	A	102.37377
G3	A	93.52587
G5	A	77.00230
G4	A	73.40230

Levels not connected by same letter are significantly different.

Lubrizol