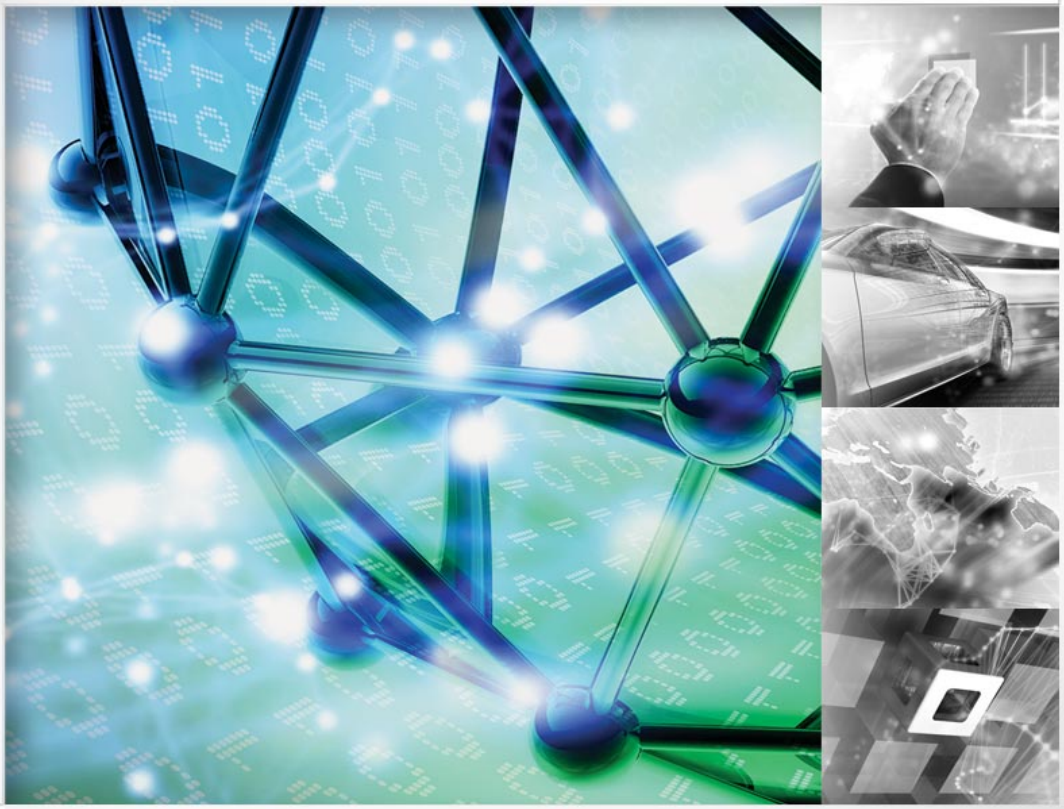


DD13 Scuffing Test Stylus Comparison

Kevin O'Malley
The Lubrizol Corporation
March 2017

Summary

SUCCESS TOGETHER

Objective: Determine if a correlation exists between stylus measurements which can be utilized to finalize liner specs, if needed.

Current Situation:

- Initial liner spec guidelines were set using 0.0002" radius stylus and are based on average measurements per liner:
  - Rvk: 0.5 to 1.8
  - Rk: 0.2 to 0.8
  - Rpk: 0.2 max
- DD13 reference tests have liners measured using 0.0001" radius stylus.
  - The average measurement per liner is provided in the ltms.csv file.
- TEI has measured 120 liners from the recent liner batch using both styluses; 4 measurements are provided for each liner using each stylus.

Findings:

- Liner measurements taken using the different styluses correlate with one another
- The correlation is not as strong for Rmr1 and Rpk as the other measurements.
- If needed, if is feasible to utilize the correlation between styluses when finalizing liner specs. The data used to establish the correlations does not cover the entire spec range. This means we'd have to assume the correlation holds across the range to which it would be applied.

Lubrizol

Path Forward

SUCCESS TOGETHER

Some options for finalizing specs:

1. Use 0.0002" Radius Stylus to measure liners and utilize Daimler specs
    1. May require translating prior measurements using 0.0001" radius stylus using stylus correlations
2. Translate Daimler specs (based on 0.0002" Radius Stylus) to 0.0001" Radius Stylus and continue measuring liners with 0.0001" Radius Stylus

	Current Daimler Spec using 0.0002" stylus	Proposed Daimler Spec for 0.0001" stylus using correlations	Proposed Daimler Spec for 0.0001" stylus assuming constant offset or no change
Rvk	0.5 to 1.8	0.6 to 1.83	0.59 to 1.89
Rk	0.2 to 0.8	0.26 to 0.93	0.29 to 0.89
Rpk	0.2 max	0.18 max	0.2 max

The upper limits of the Rvk and Rk specs are most susceptible to possible complications due to extrapolation

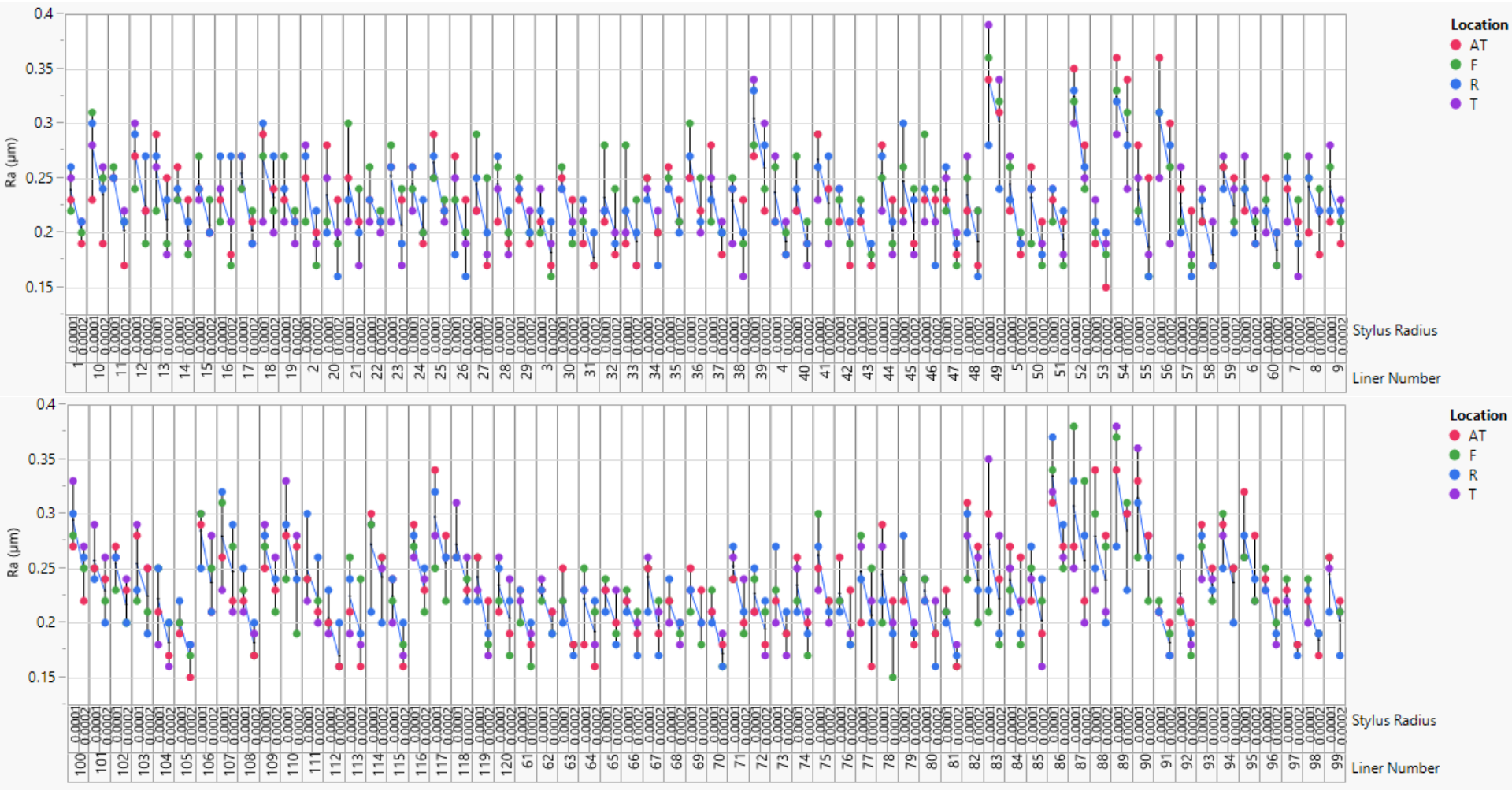
Lubrizol

APPENDIX A
Stylus Correlation
0.0001” Radius vs. 0.0002” Radius

Ra – Recent Liners

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

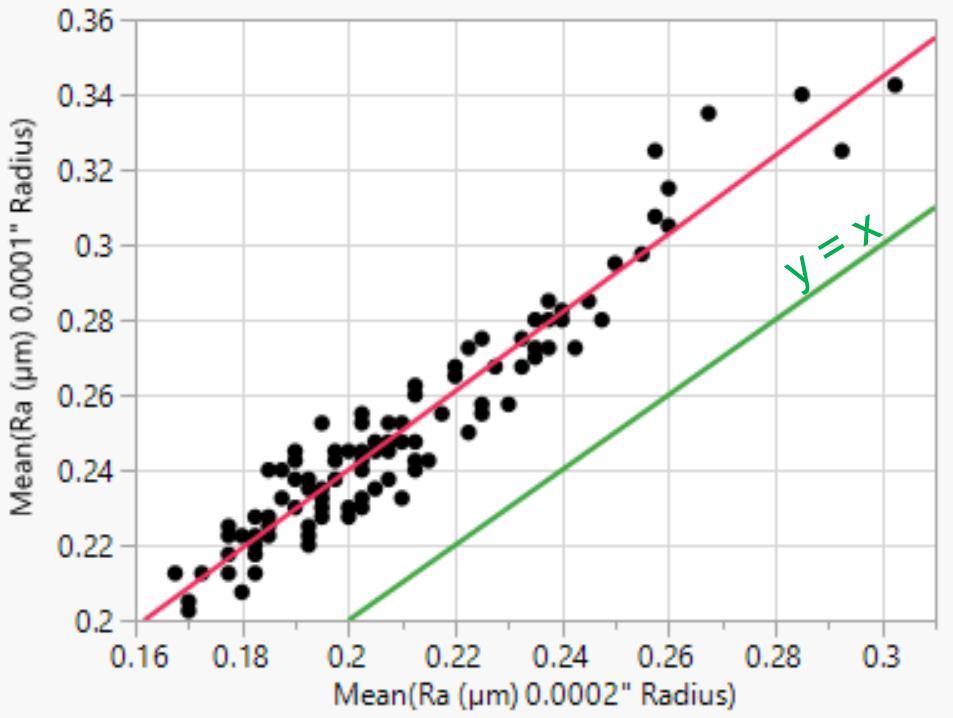


Lubrizol

Ra
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Ra (µm) 0.0001" Radius) = 0.030874 + 1.0459625*Mean(Ra (µm) 0.0002" Radius)

Summary of Fit

RSquare	0.913428
RSquare Adj	0.912694
Root Mean Square Error	0.008575
Mean of Response	0.249458
Observations (or Sum Wgts)	120

Lack Of Fit

Analysis of Variance

Parameter Estimates

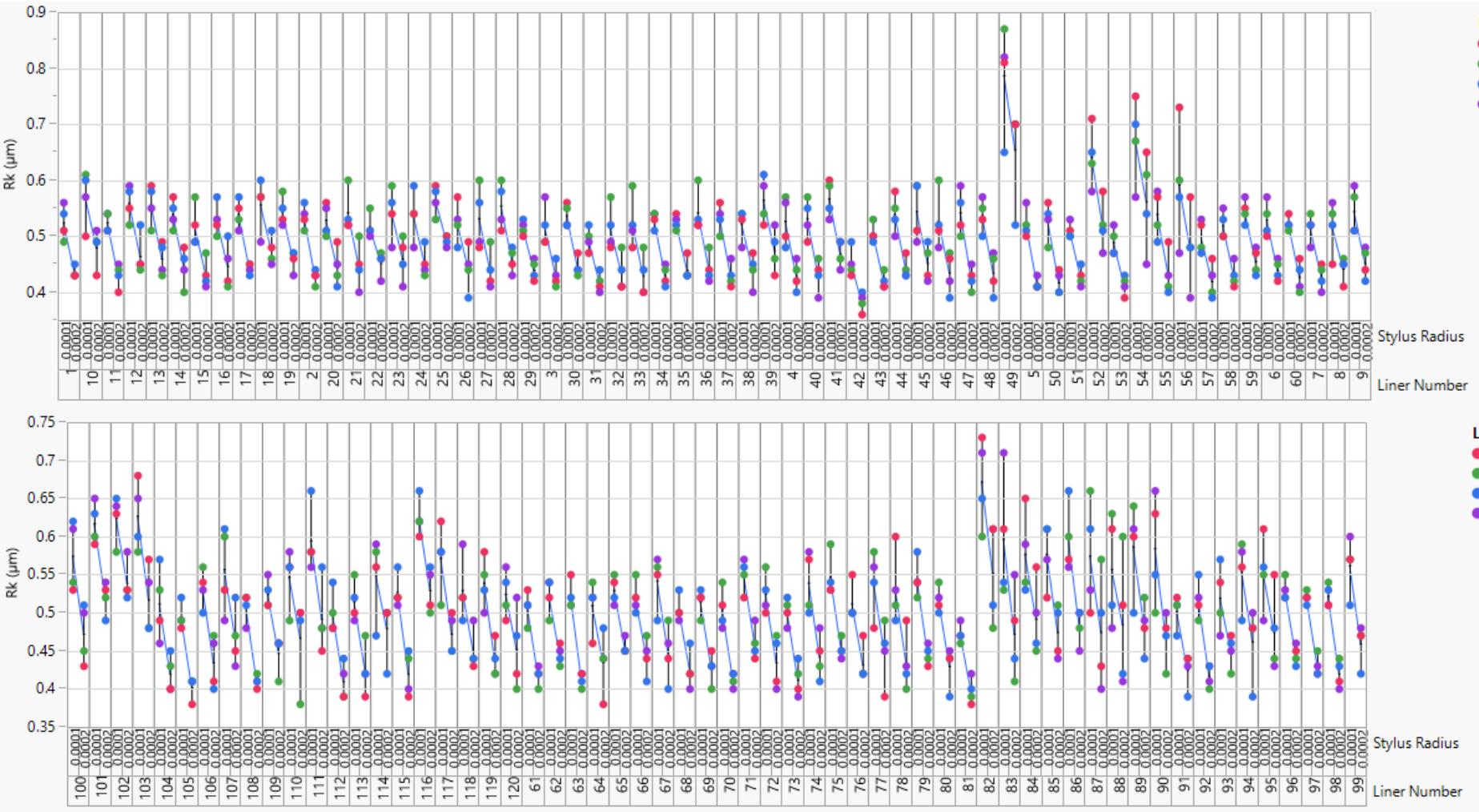
Term	Estimate	Prob>|t|
Intercept	0.030874	<.0001*
Mean(Ra (µm) 0.0002" Radius)	1.0459625	<.0001*

Lubrizol

Rk

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

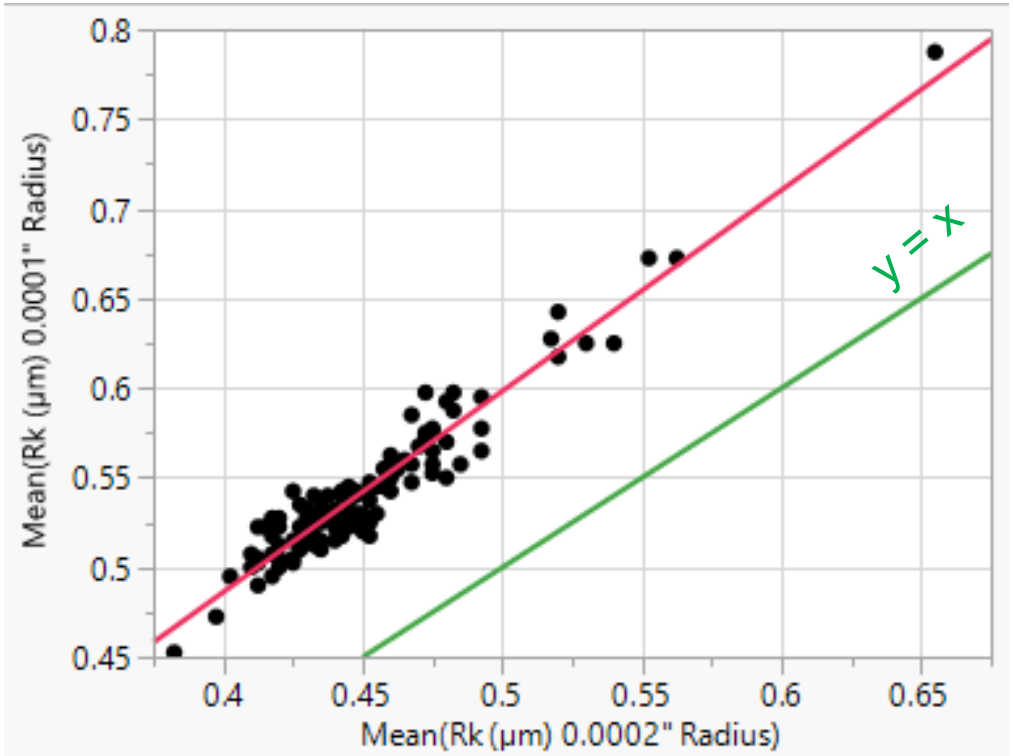


Lubrizol

Rk
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Rk (µm) 0.0001" Radius) = 0.0375656 + 1.1215402*Mean(Rk (µm) 0.0002" Radius)

Summary of Fit

RSquare	0.919976
RSquare Adj	0.919298
Root Mean Square Error	0.01194
Mean of Response	0.542563
Observations (or Sum Wgts)	120

Lack Of Fit

Analysis of Variance

Parameter Estimates

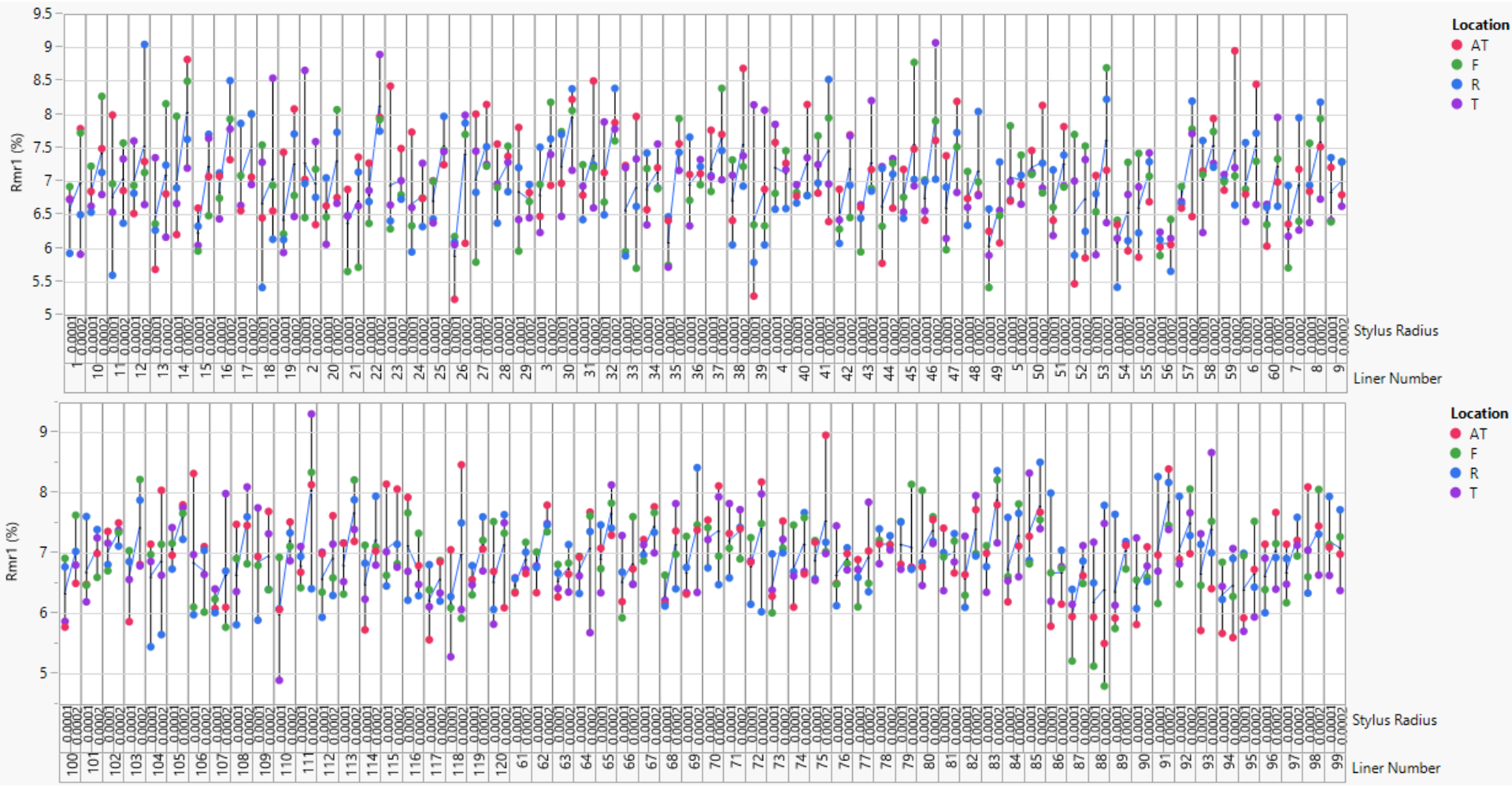
Term	Estimate	Prob>|t|
Intercept	0.0375656	0.0073*
Mean(Rk (µm) 0.0002" Radius)	1.1215402	<.0001*

Lubrizol

Rmr1

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

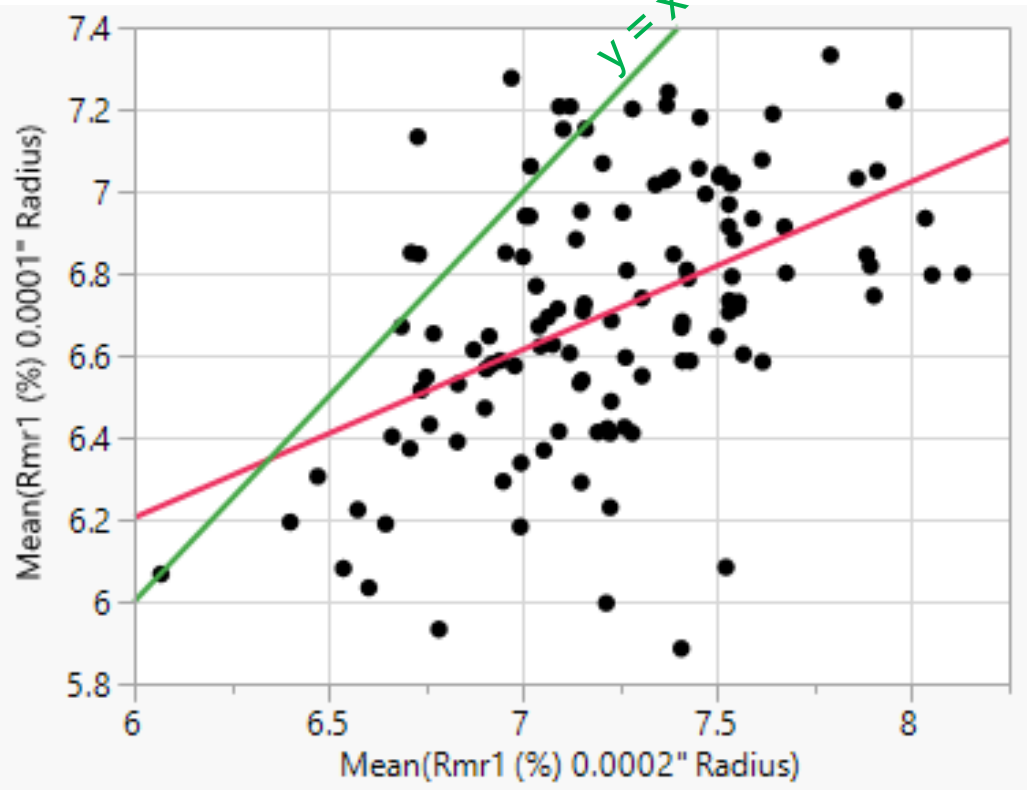


Lubrizol

Rmr1
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Rmr1 (%) 0.0001" Radius) = 3.74676 + 0.4096635*Mean(Rmr1 (%) 0.0002" Radius)

Summary of Fit

RSquare	0.23085
RSquare Adj	0.224332
Root Mean Square Error	0.284037
Mean of Response	6.70554
Observations (or Sum Wgts)	120

Analysis of Variance

Parameter Estimates

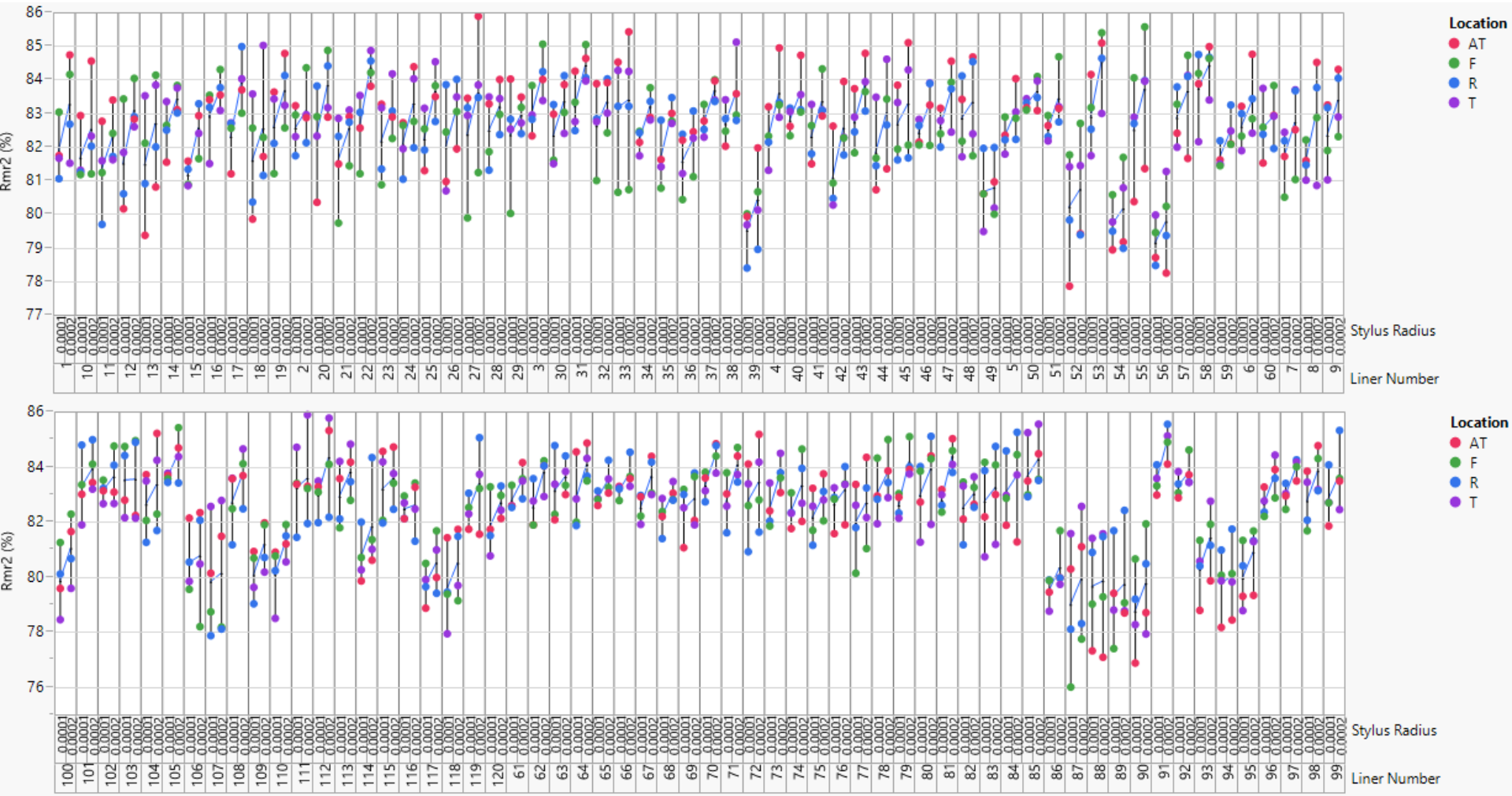
Term	Estimate	Prob>|t|
Intercept	3.74676	<.0001*
Mean(Rmr1 (%) 0.0002" Radius)	0.4096635	<.0001*

Lubrizol

Rmr2

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

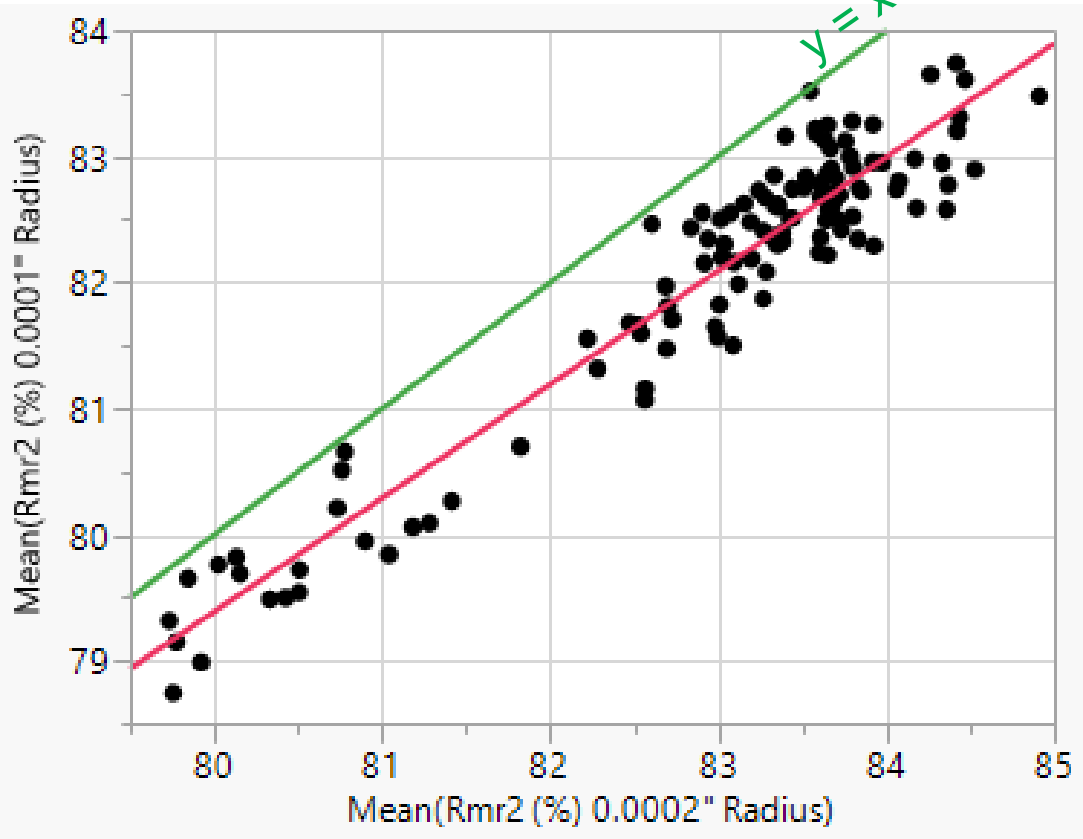


Lubrizol

Rmr2
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Rmr2 (%) 0.0001" Radius) = 7.2963177 + 0.9011709*Mean(Rmr2 (%) 0.0002" Radius)

Summary of Fit

RSquare	0.912356
RSquare Adj	0.911614
Root Mean Square Error	0.350912
Mean of Response	82.04866
Observations (or Sum Wgts)	120

Analysis of Variance

Parameter Estimates

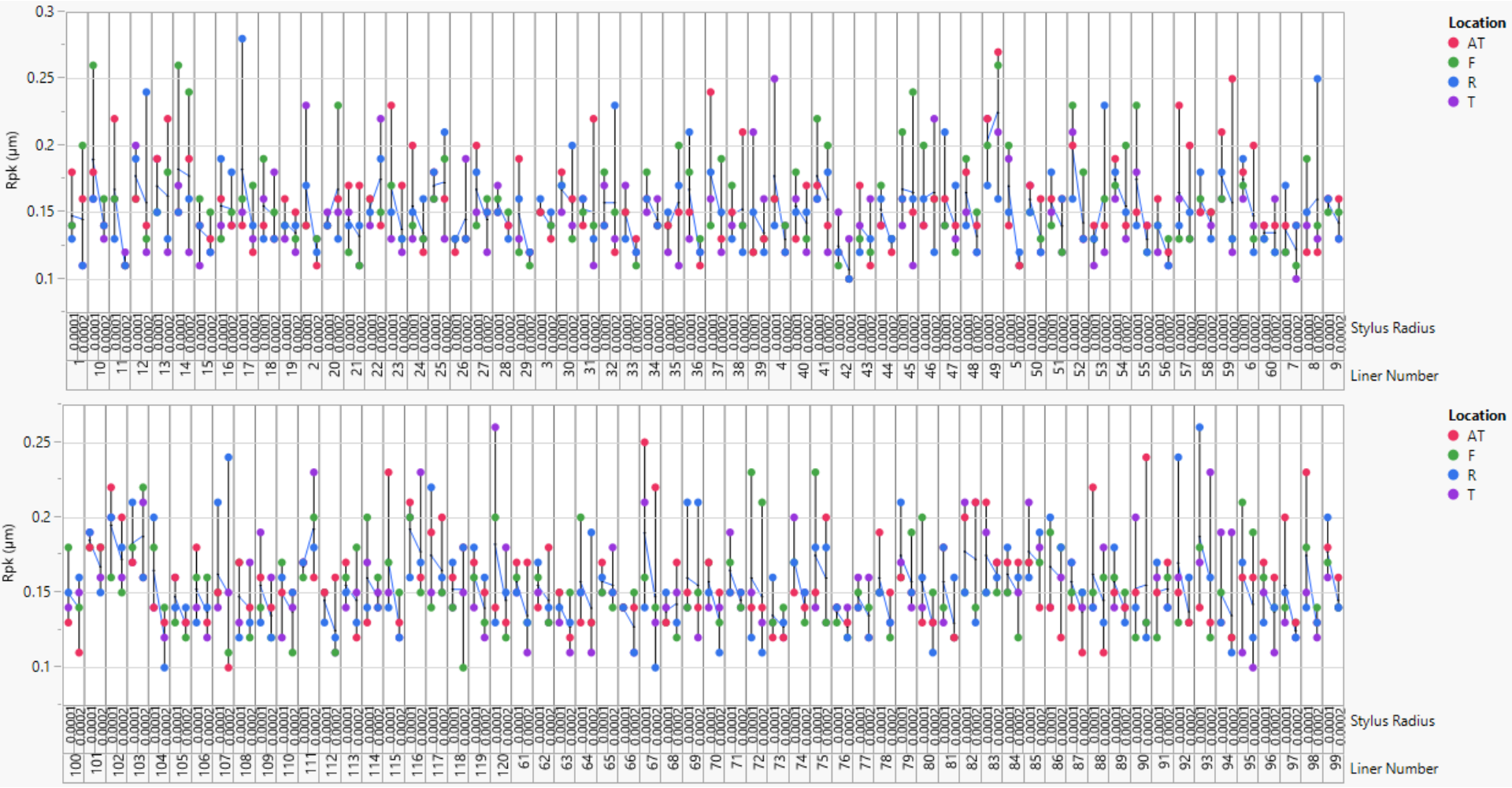
Term	Estimate	Prob>|t|
Intercept	7.2963177	0.0009*
Mean(Rmr2 (%) 0.0002" Radius)	0.9011709	<.0001*

Lubrizol

Rpk

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

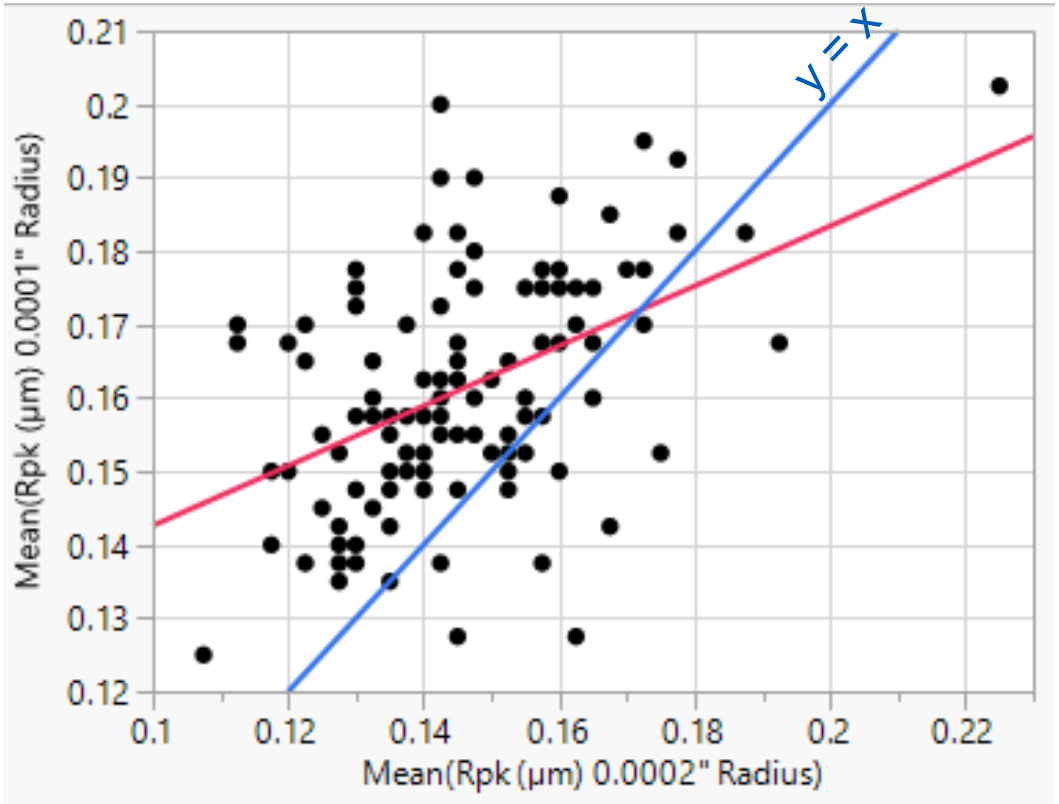


Lubrizol

Rpk
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Rpk (µm) 0.0001" Radius) = 0.1017946 + 0.4080578*Mean(Rpk (µm) 0.0002" Radius)

Summary of Fit

RSquare	0.21403
RSquare Adj	0.20737
Root Mean Square Error	0.013796
Mean of Response	0.160938
Observations (or Sum Wgts)	120

Lack Of Fit

Analysis of Variance

Parameter Estimates

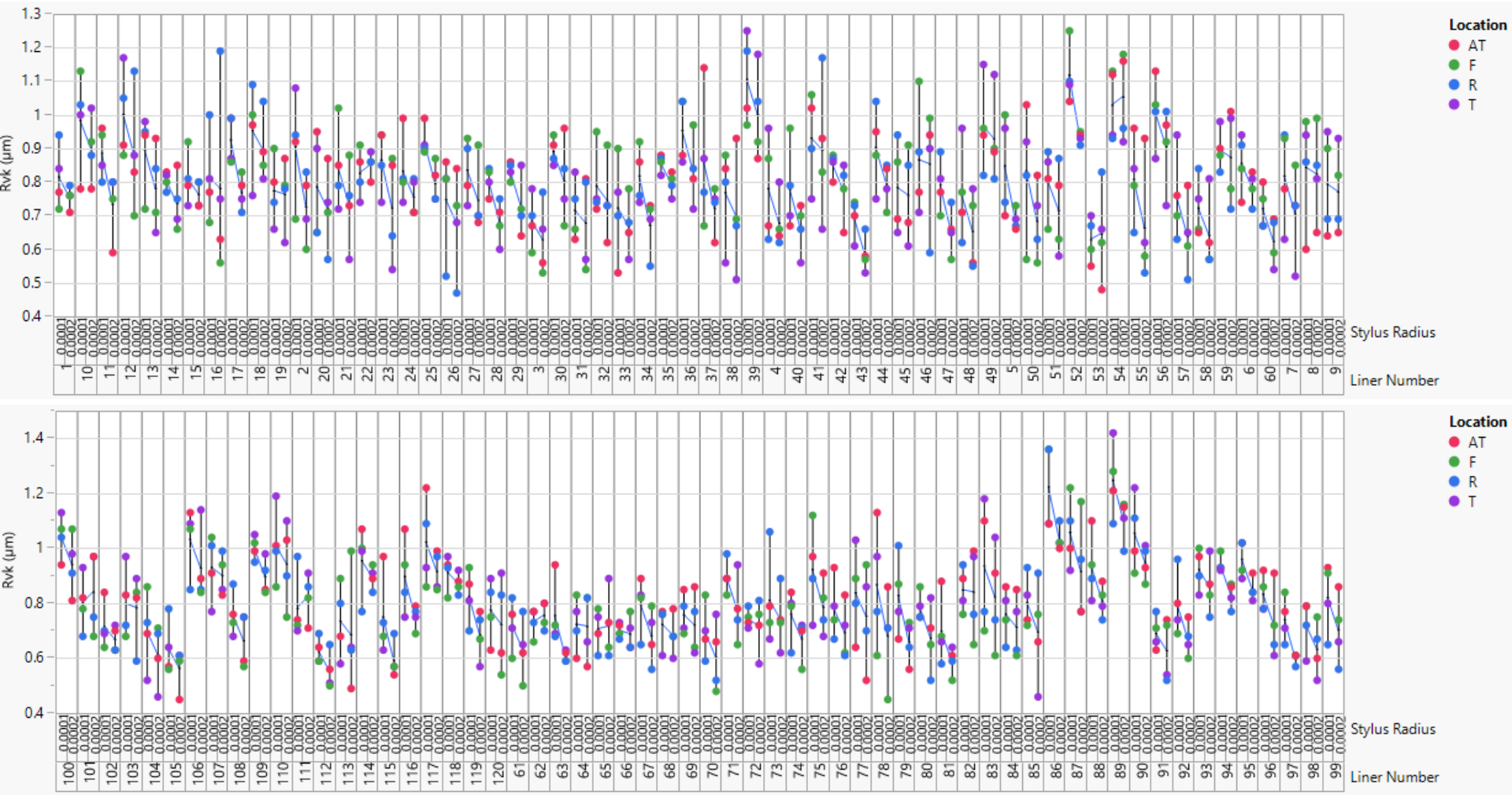
Term	Estimate	Prob>|t|
Intercept	0.1017946	<.0001*
Mean(Rpk (µm) 0.0002" Radius)	0.4080578	<.0001*

Lubrizol

Stylus Correlation Example
Rvk

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

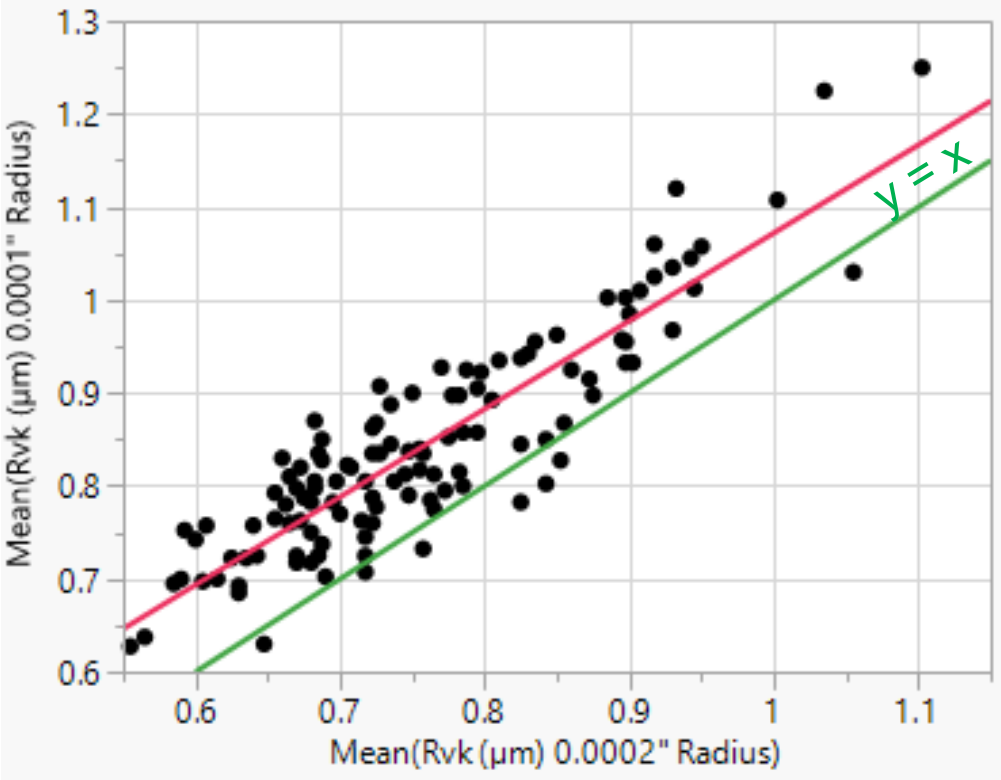


Lubrizol

Stylus Correlation Example
Rvk

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Rvk (µm) 0.0001" Radius) = 0.125808 + 0.9462665*Mean(Rvk (µm) 0.0002" Radius)

Summary of Fit

RSquare	0.805016
RSquare Adj	0.803364
Root Mean Square Error	0.051483
Mean of Response	0.84225
Observations (or Sum Wgts)	120

Lack Of Fit

Analysis of Variance

Parameter Estimates

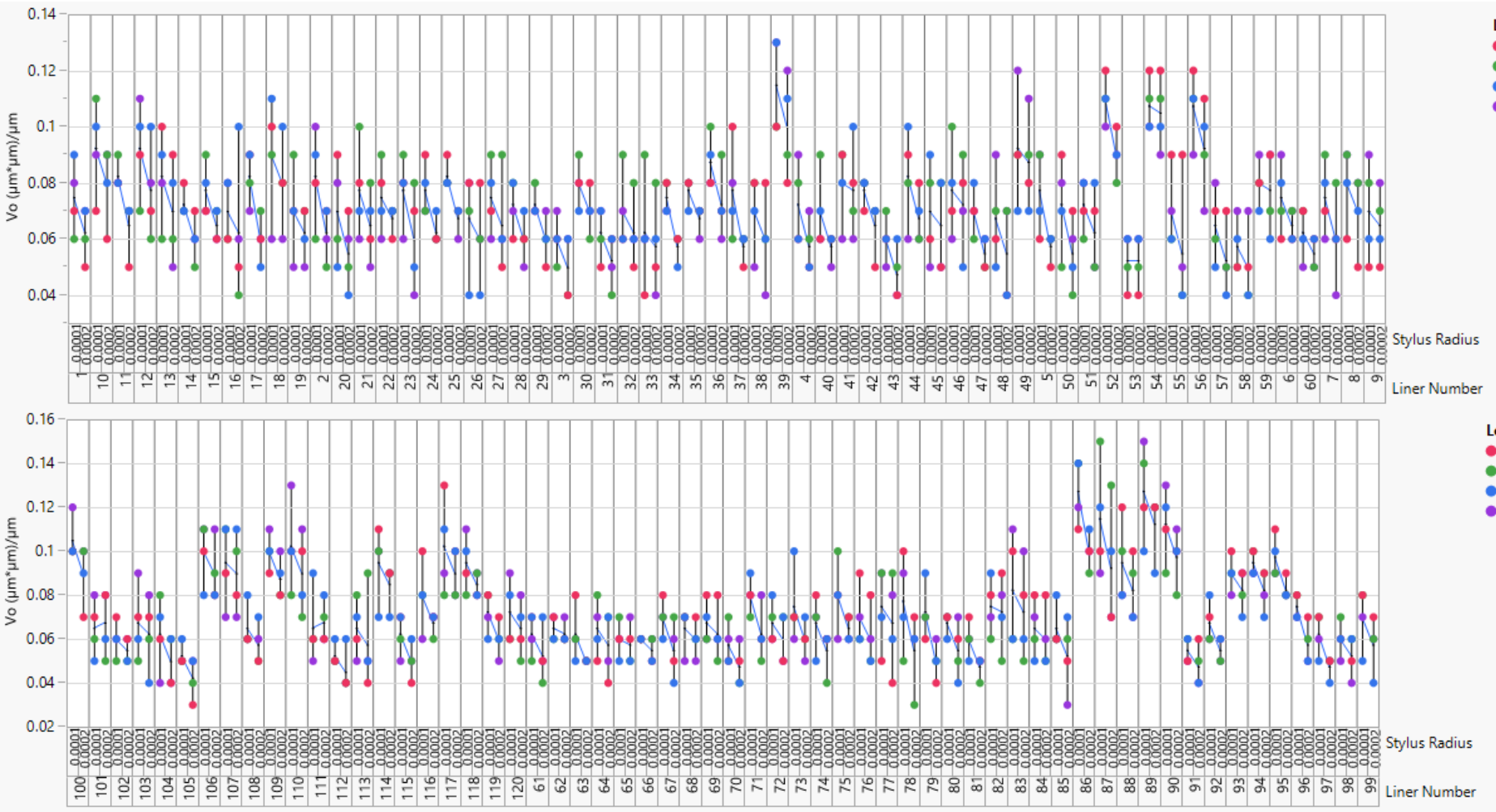
Term	Estimate	Prob>|t|
Intercept	0.125808	0.0002*
Mean(Rvk (µm) 0.0002" Radius)	0.9462665	<.0001*

Lubrizol

Vo

SUCCESS TOGETHER

Eight measurements were taken on each liner; four measurements per stylus

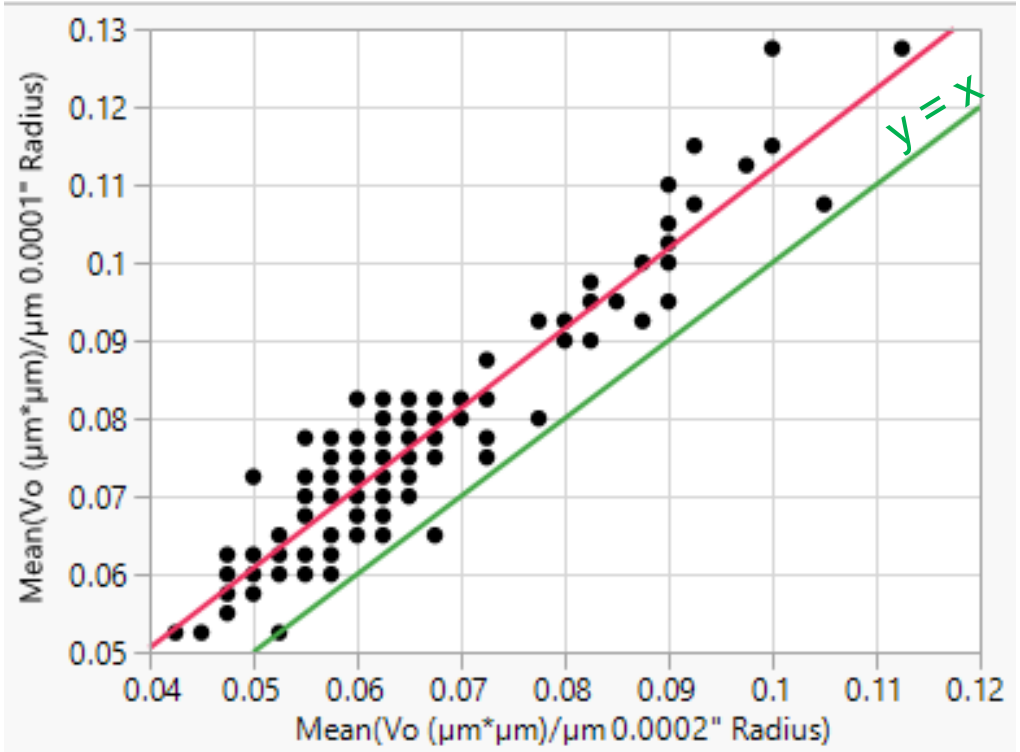


Lubrizol

Vo
Stylus Correlation

SUCCESS TOGETHER

- The four measurements per liner are averaged (an average per stylus)
- The averages are plotted versus one other to assess the correlation between the styluses
- Each point on the plot is associated with a single liner



Linear Fit

Mean(Vo (µm*µm)/µm 0.0001" Radius) = 0.0094854 + 1.0259536*Mean(Vo (µm*µm)/µm 0.0002" Radius)

Summary of Fit

RSquare	0.883855
RSquare Adj	0.882871
Root Mean Square Error	0.005305
Mean of Response	0.076771
Observations (or Sum Wgts)	120

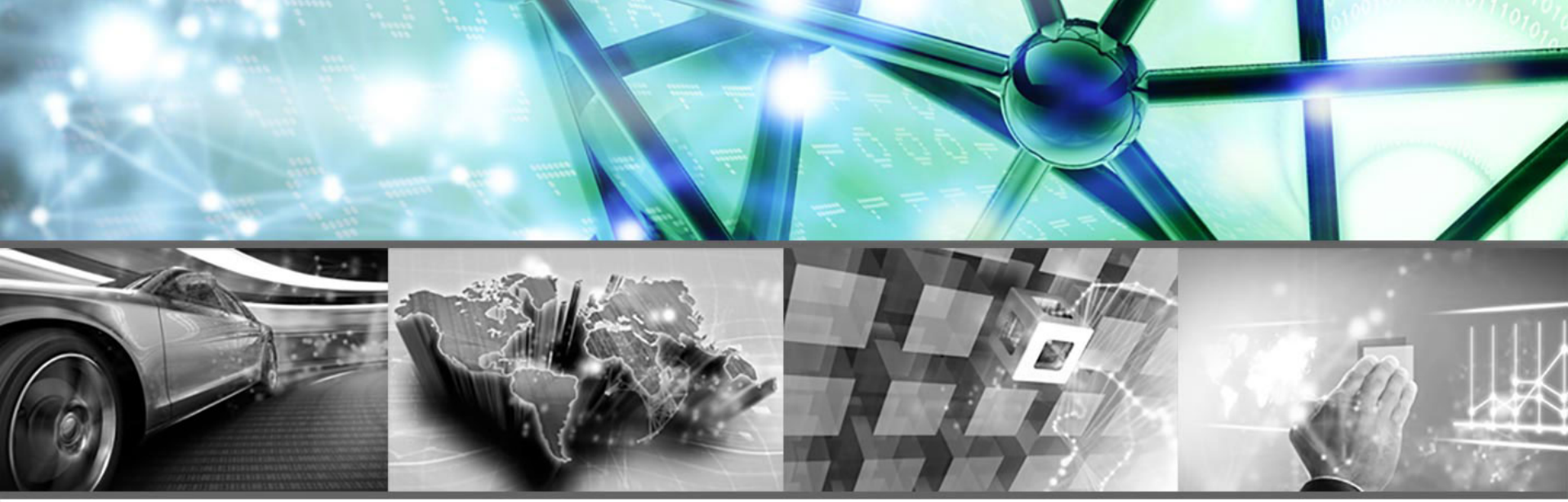
Lack Of Fit

Analysis of Variance

Parameter Estimates

Term	Estimate	Prob>|t|
Intercept	0.0094854	<.0001*
Mean(Vo (µm*µm)/µm 0.0002" Radius)	1.0259536	<.0001*

Lubrizol



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