Comparison of Hardness, FRF, Compressibility, and Ultra-sonic Modulus Measurements

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Friction Material Design

Friction Quality Measurements

Pass/Light Truck Brake Pad Quality

- There are diverse opinions within the brake community for determining ongoing production quality of a finished brake pad

- This presentation compares several industry methods

- There are two underlying common characteristics assessed across all manufacturers
  - **Dimensions**
    - » Overall thickness, abutment height/length, friction/plate flatness, parallelism, and topography/shape
  - **Friction Modulus**
    - » All use some type of measurement in attempt to assess raw materials and processing consistency for modulus

Friction Quality Measurements

Matrix of Main Quality Measurement Types

	Compressibility	FRF	Rockwell Hardness	Direct Modulus (Ultrasound)	Dimensions	Comment
Primary Characatersic Desired	Modulus	Modulus	Modulus	Modulus	Dimensions	--
What is it measuring	Approximation of friction modulus and dimensional effects	Primarily plate modulus & secondary friction modulus	Friction surface approximation of friction modulus	Approximation of friction modulus	Friction flatness, plate flatness, parallelism, abutments, etc.	--
Independent instrinsic quality/engineering measurement of friction materials	No	No	Yes	Yes	Yes	Can one compare quality independent of shape, friction formulation, chamfers/slots etc.?
In Process Correlation	No	No	Poor/Moderate	Excellent	--	Can I determine how a part was processed by correlating to previous process measurements?
Reference	SAE J2468	SAE J2598	SAE J2654	SAE Paper 2010-01-1701	--	--
Equipment Used for this presentation	Link 1620-H	Zonicbook 618E	Instron Wilson/Rockwell Series 600	Industrial Measurement Systems iETEK	--	--

Friction Quality Measurements

Compressibility

- Pad compressibility is made up of two primary components
  - **Friction Modulus**
    - » Reciprocal of compressibility without dimensional influence is an approximate measurement of Young's modulus.
  - **Dimensions**
    - » Any friction flatness, plate flatness, parallelism, and topography beyond being "zero" typically contribute to compressibility (i.e. will be part of the deflection in the compressibility). Typical friction flatness, plate flatness, parallelism specifications are in the 100-200 µm (0.10 mm – 0.20 mm) range.

Friction Quality Measurements

FRF, Hardness, Ultrasound

FRF is made up of two main components but in general is attempting to detect changes in friction modulus

- **Pressure Plate (primary)**
  - Material Properties (Modulus)
  - Plate thickness
- **Friction Material (secondary)**
  - Material Properties (Modulus)
  - Geometric Properties (slots, chamfers, variation within geometric properties)

Rockwell hardness

- Uses a small scale surface approximation of modulus which is then extrapolated to characterize the entire pad

Ultrasound

- Yields approximation of modulus based on the fundamental relationship between the ultrasonic velocity and the material elastic constants

Friction Quality Measurements

Assessing Friction Modulus

	Compressibility	FRF	Rockwell Hardness	Ultrasound
Acquiring Friction Modulus	Requires machining pads close to 'zero' for dimensions or using small coupon size pieces. Commonly referred to as "Specific" Compressibility	Need to account for other geometric variables (pressure plate thickness, friction thickness, slot depth, chamfer size, etc.)	Only rough relationship can be established to modulus	Direct measurement
Challenges	Lead time to make parts Still will have dimensional contributions	Sensitivity to changes to friction modulus lower than other factors (plate thickness, dimensions)	Have to know relationship to modulus and can be highly influenced if part is scorched Hardness measurement on a single pad is highly variable	Newer technology
Benefits	Yields combined measurement that gives insites into modulus and fluid displacement	Relatively quick measurement	Can correlate to previous measurements taken in the process (post hot press, post cure, post grind)	Can correlate to previous measurements taken in the process (post hot press, post cure, post grind)
Reference	SAE Presenation BC201-3 SAE Paper 2008-01-2572	----	-----	SAE Paper 2010-01-1701

Friction Quality Measurements

Repeatability/Environmental/Pressure Plate Sensitivity

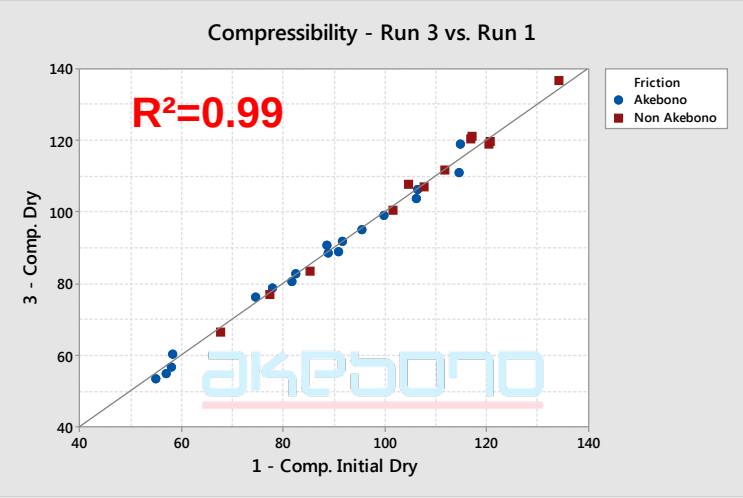
- N=10 different pad shapes all current OE production
- N=9 NAO's, N=1 Semi-Met
- N=6 Akebono, N=4 non Akebono
- Measurements:
  - Compressibility SAE J2468 T3/100 bar [microns]
  - FRF SAE J2598 [Hz] (1st bending mode)
  - Rockwell Hardness SAE J2654 [HRR or HRS]
  - Ultrasound Modulus [MPa] (note density = 1.00, reference SAE Paper
  - 2010-01-1701)

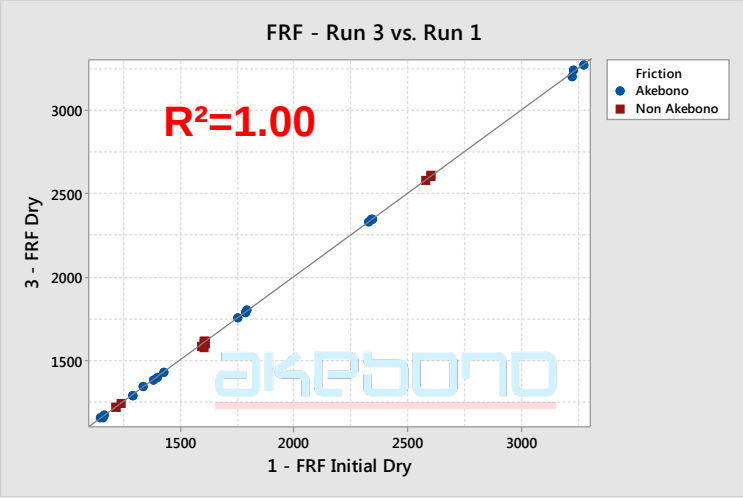
- Run 1 - Pads were dried out 2 hours @ 110^{O}C then measured
- Run 2 - Pads subjected to 25^{O}C @ 80% RH for 24 hours then measured
- Run 3 - Pads were dried out again 2 hours @ 110^{O}C then measured
- Run 4 - 0.40 mm ground off pressure plate, dried 2 hours @ 110^{O}C then measured (simulation of typical min to max plate thickness tolerance and pressure plate flatness almost zero)

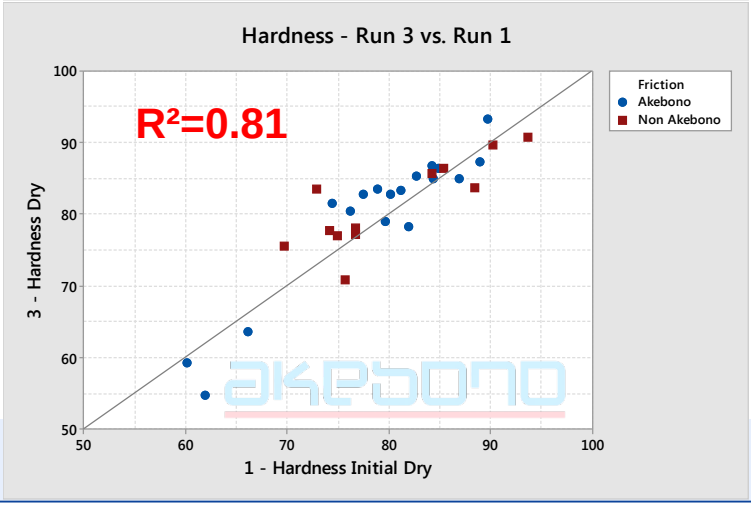
Friction Quality Measurements

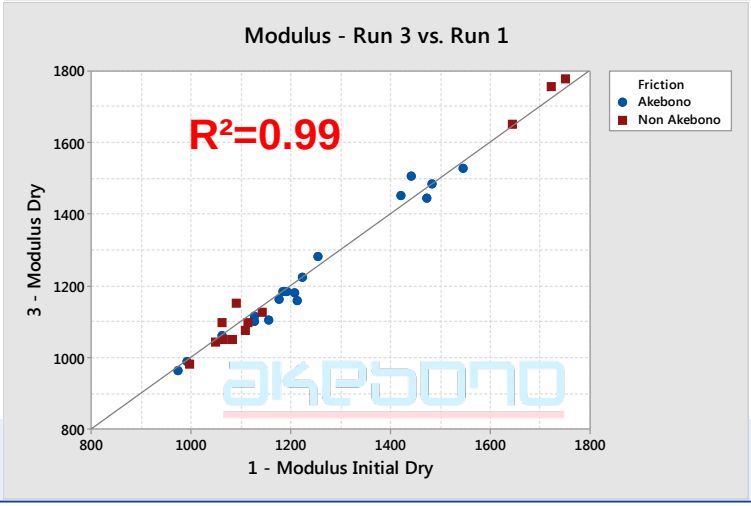
Repeatability - Run 3 vs. Run 1

- **Run 1 - Pads were dried out 2 hours @ 110^{O}C then measured**
- **Run 3 - Pads were dried out again 2 hours @ 110^{O}C then measured**





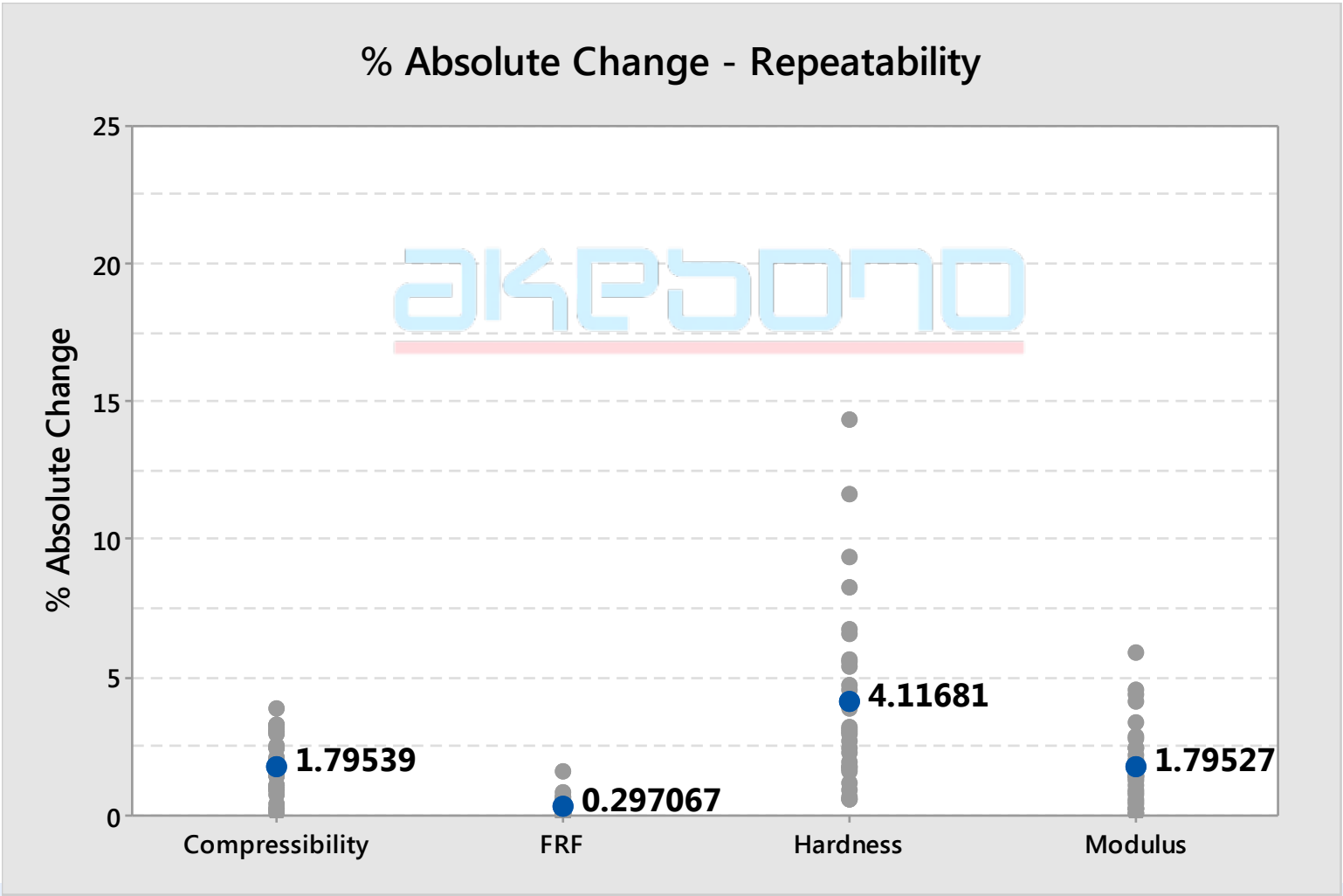




Note: X &Y scales are same on each respective plot

Friction Quality Measurements

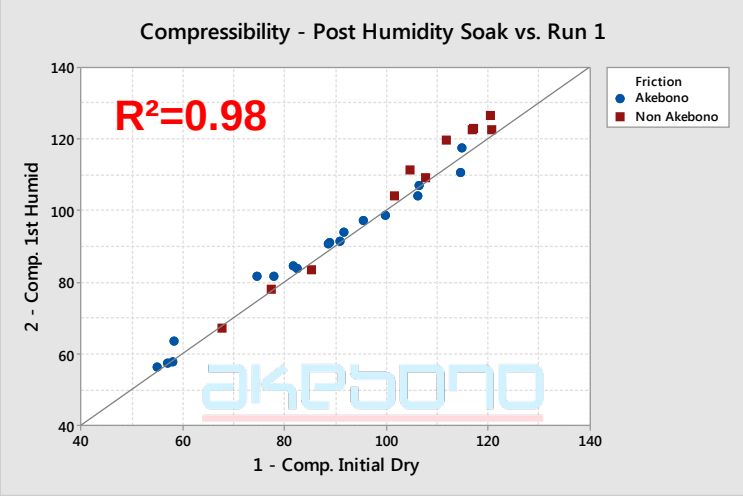
Absolute % Change - Repeatability

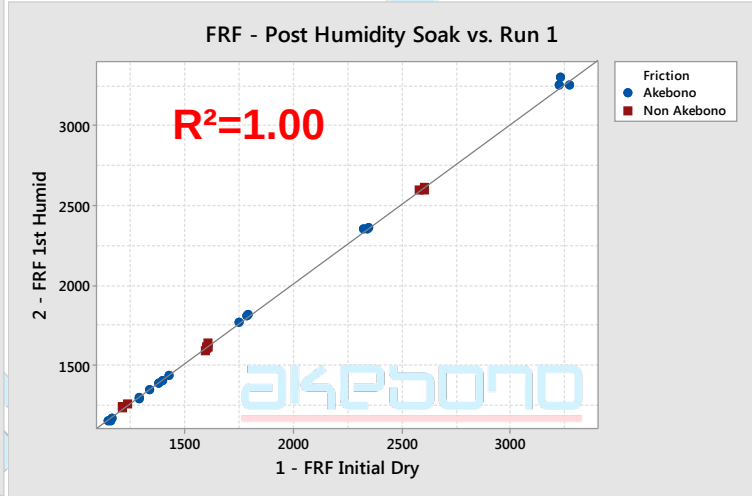


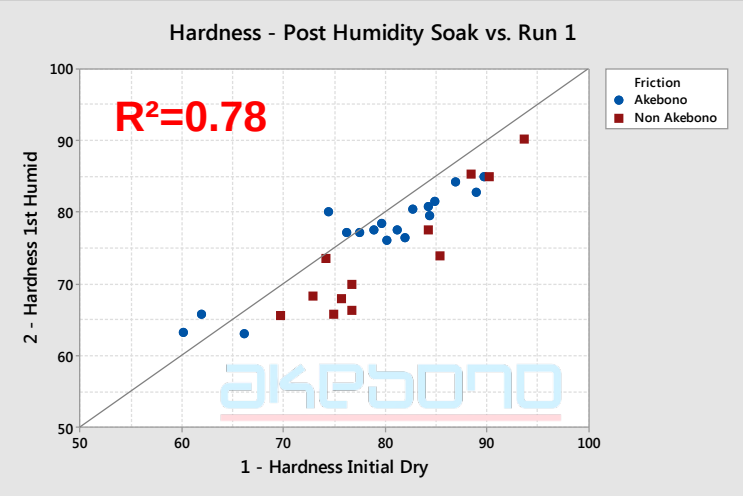
Friction Quality Measurements

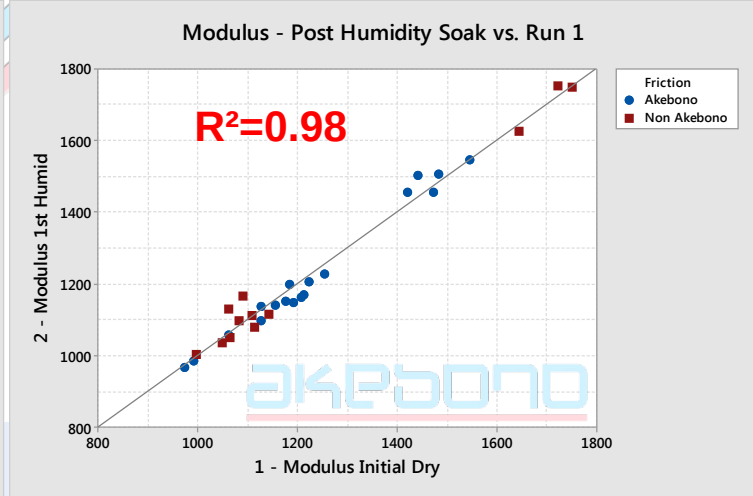
Environmental Sensitivity - Run 2 vs. Run 1

- **Run 1 - Pads were dried out 2 hours @ 110°C then measured**
- **Run 2 - Pads subjected to 25°C @ 80% RH for 24 hours then measured**









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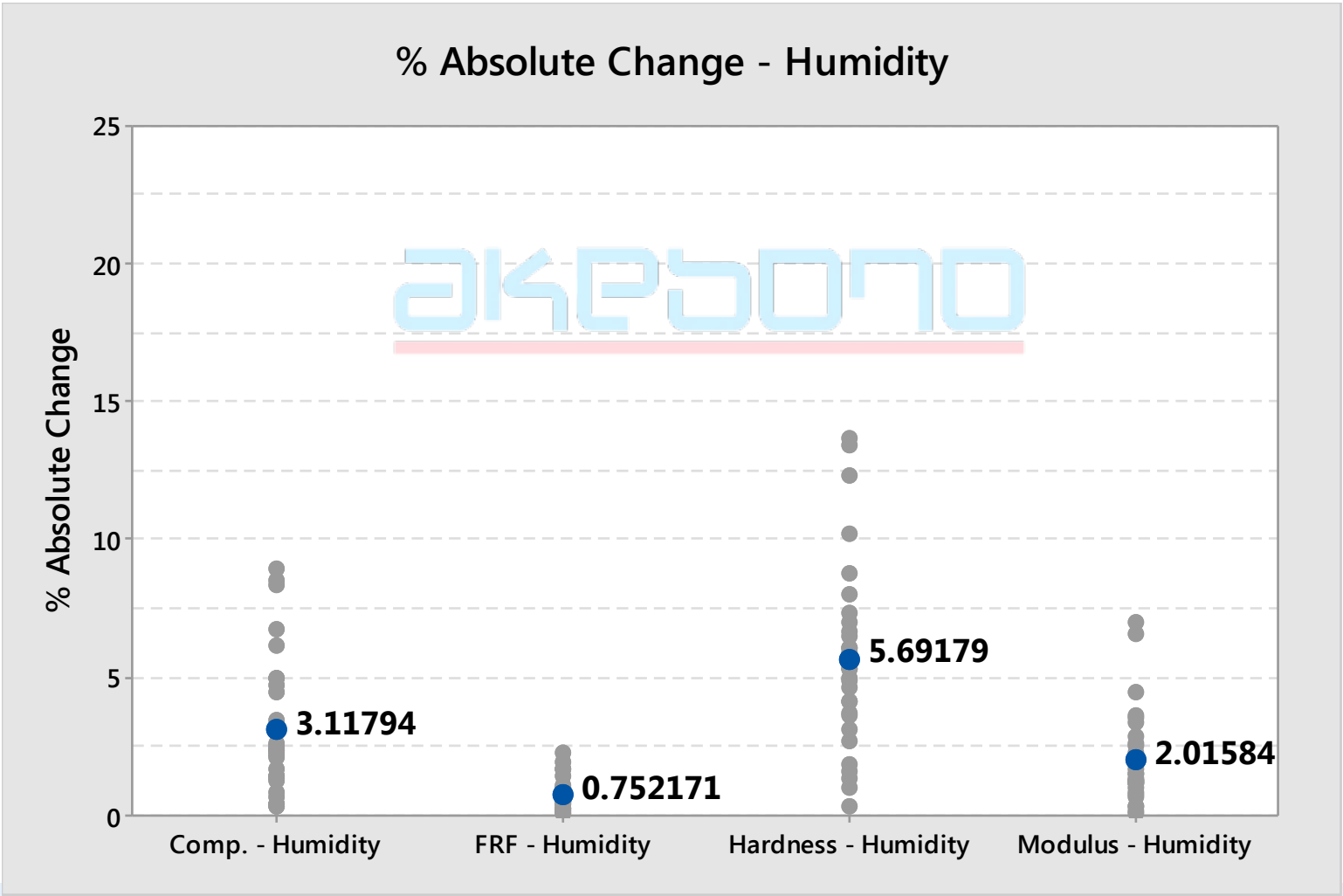
Friction Quality Measurements

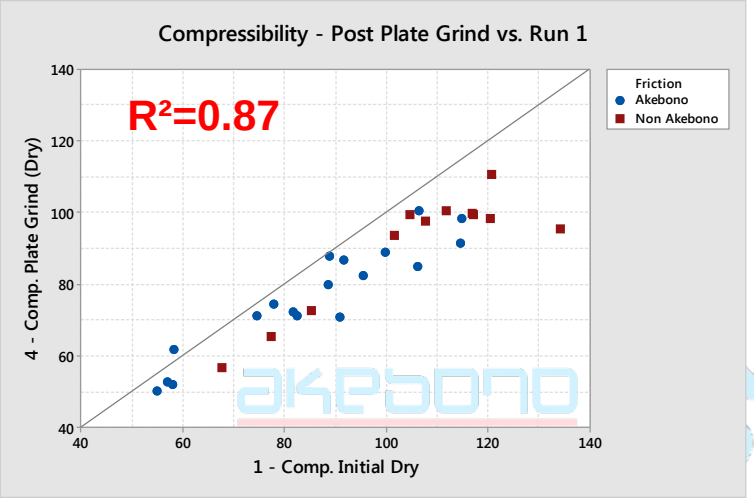
Absolute % Change - Humidity

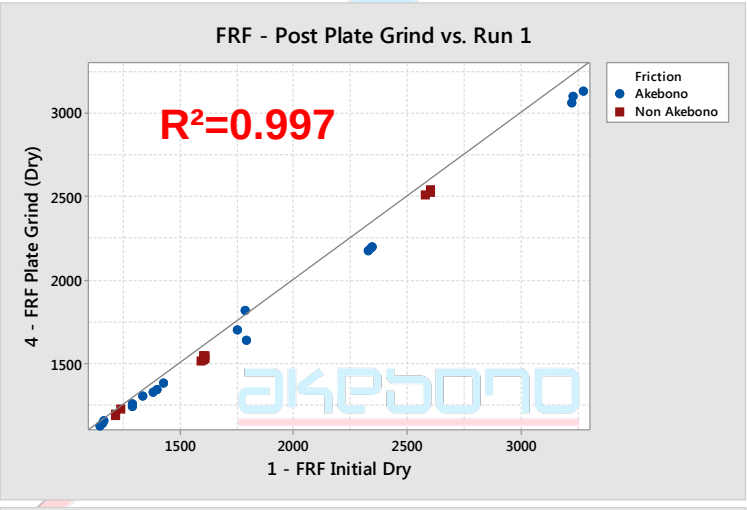


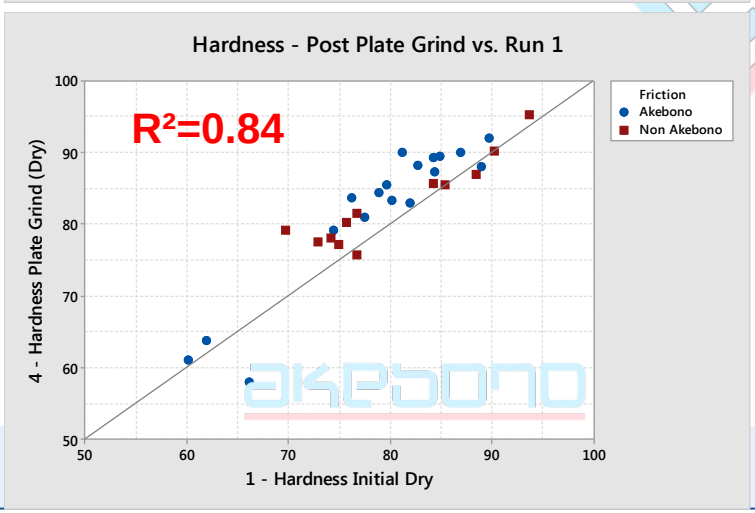
Friction Quality Measurements

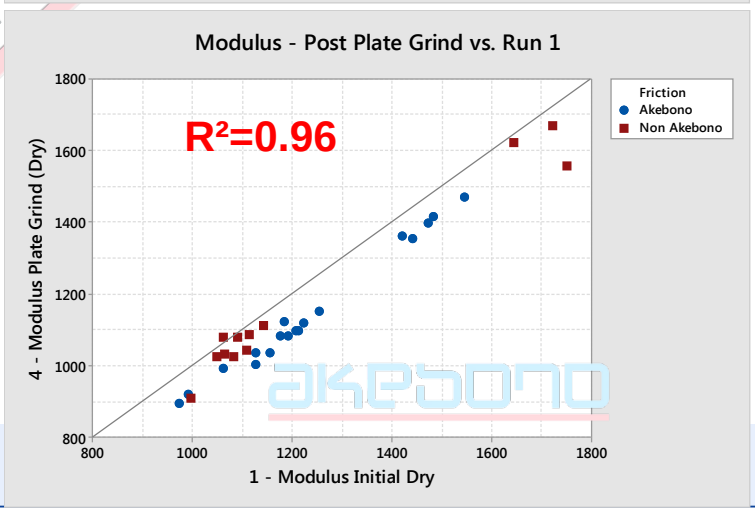
Pressure Plate Thickness/Flatness Sensitivity - Run 4 vs. Run 1

- **Run 1 - Pads were dried out 2 hours @ 110°C then measured**
- **Run 4 - 0.40 mm ground off pressure plate, dried 2 hours @ 110°C then measured**





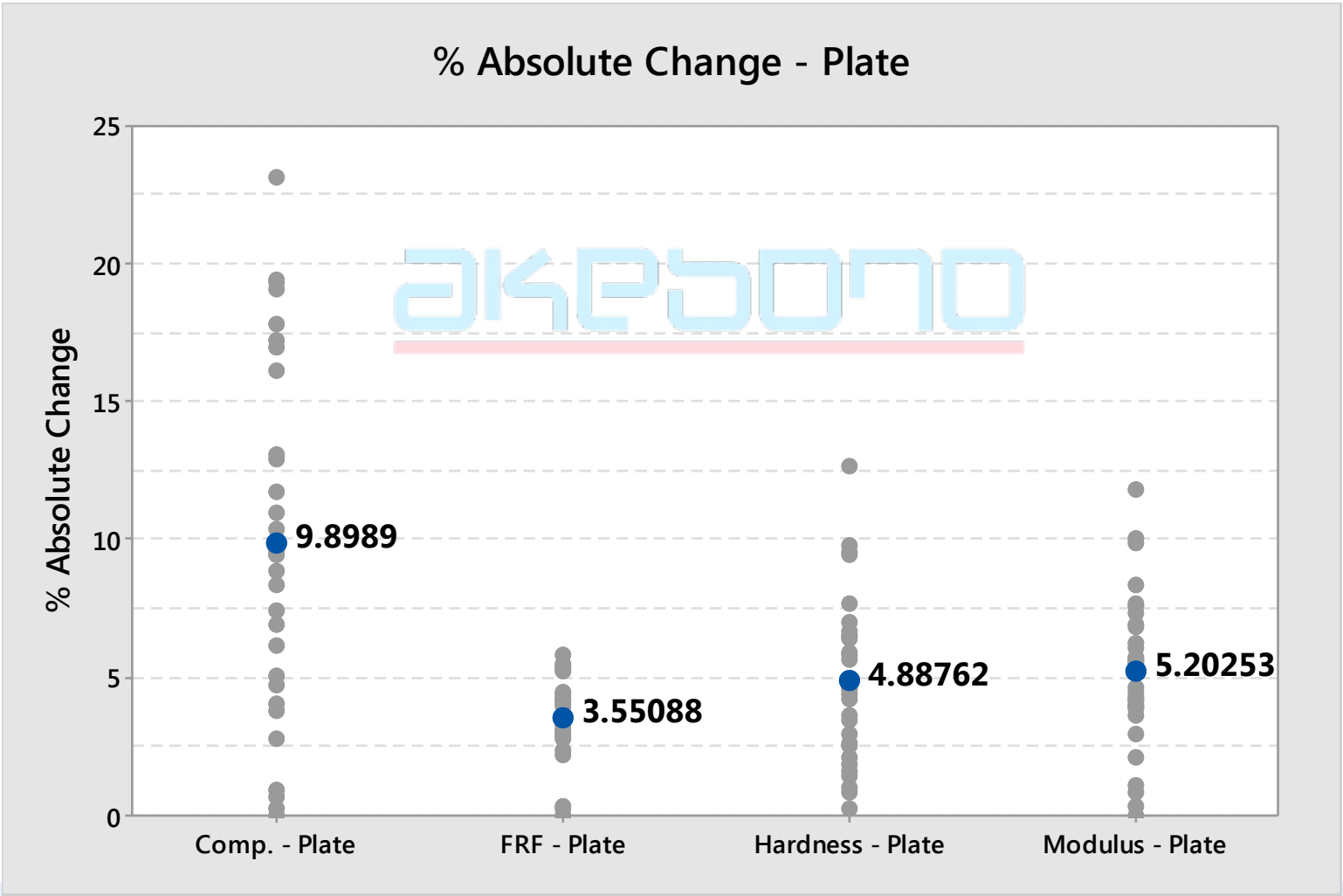




Note: X &Y scales are same on each respective plot

Friction Quality Measurements

Absolute % Change – Pressure Plate Thickness Sensitivity



Friction Quality Measurements

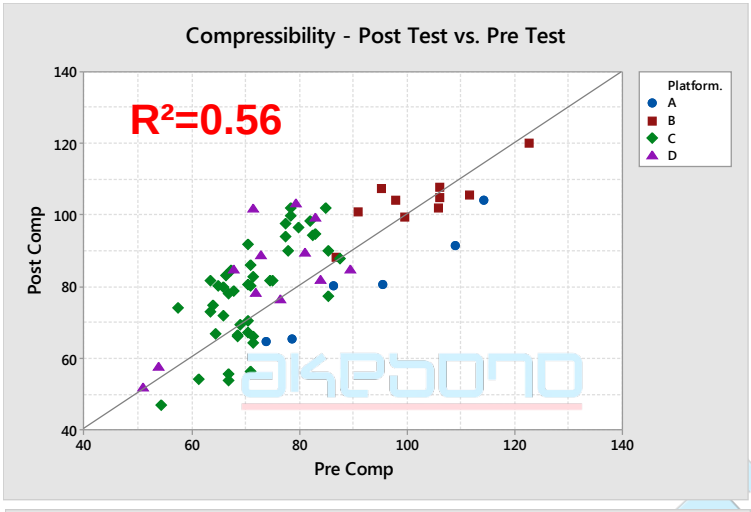
With “Use” Sensitivity

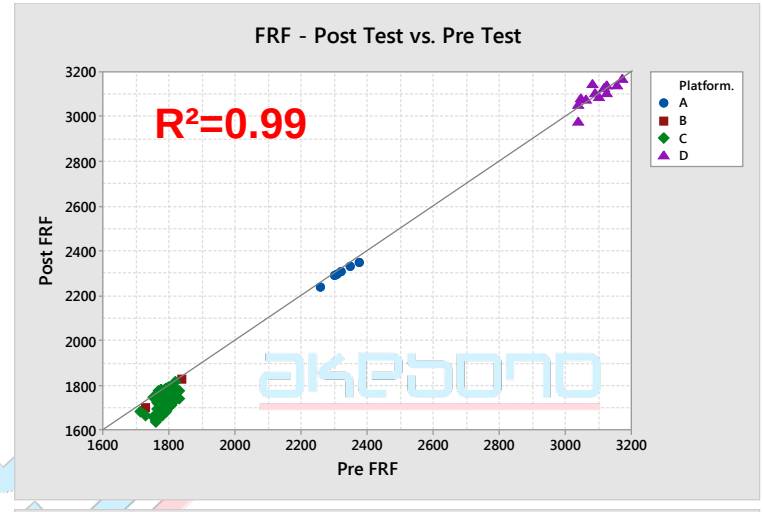
- N=4 vehicle platforms
- All NAO materials
- Various typical OE dynamometer development tests conducted (Performance, FMVSS, Noise, Wear, Thermal Abuse etc.)
- Measurements of Compressibility, FRF, Hardness, Modulus conducted pre and post test
  - Compressibility SAE J2468 T3/100 bar [microns]
  - FRF SAE J2598 [Hz] (1st bending mode)
  - Rockwell Hardness SAE J2654 [HRR or HRS]
  - Ultrasound Modulus [MPa] (note actual density used, reference SAE Paper 2010-01-1701)

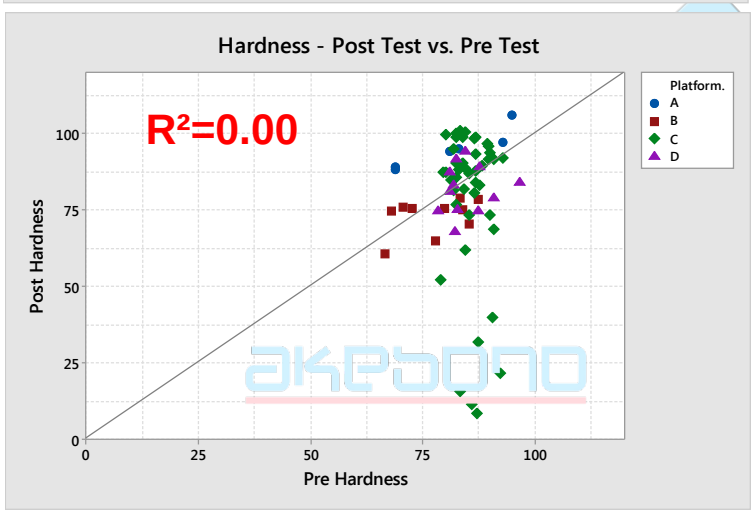
•Can one assess a field returned part for it’s initial quality metric?

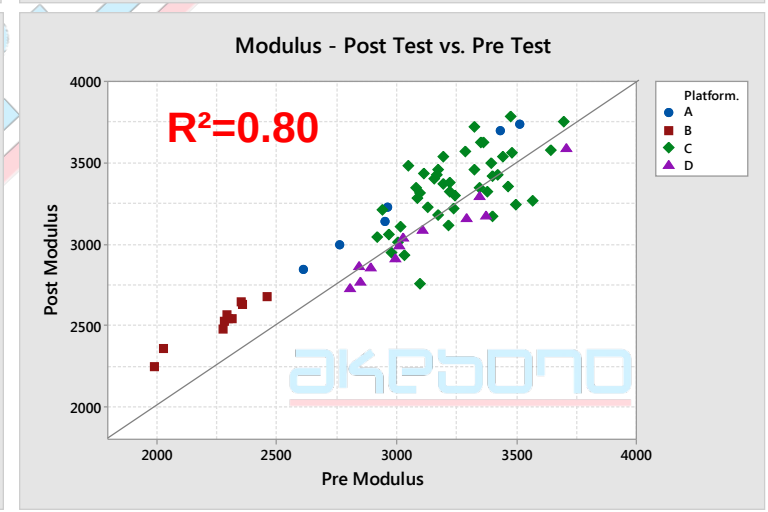
Friction Quality Measurements

Post Dynamometer Test vs. Initial Measurements









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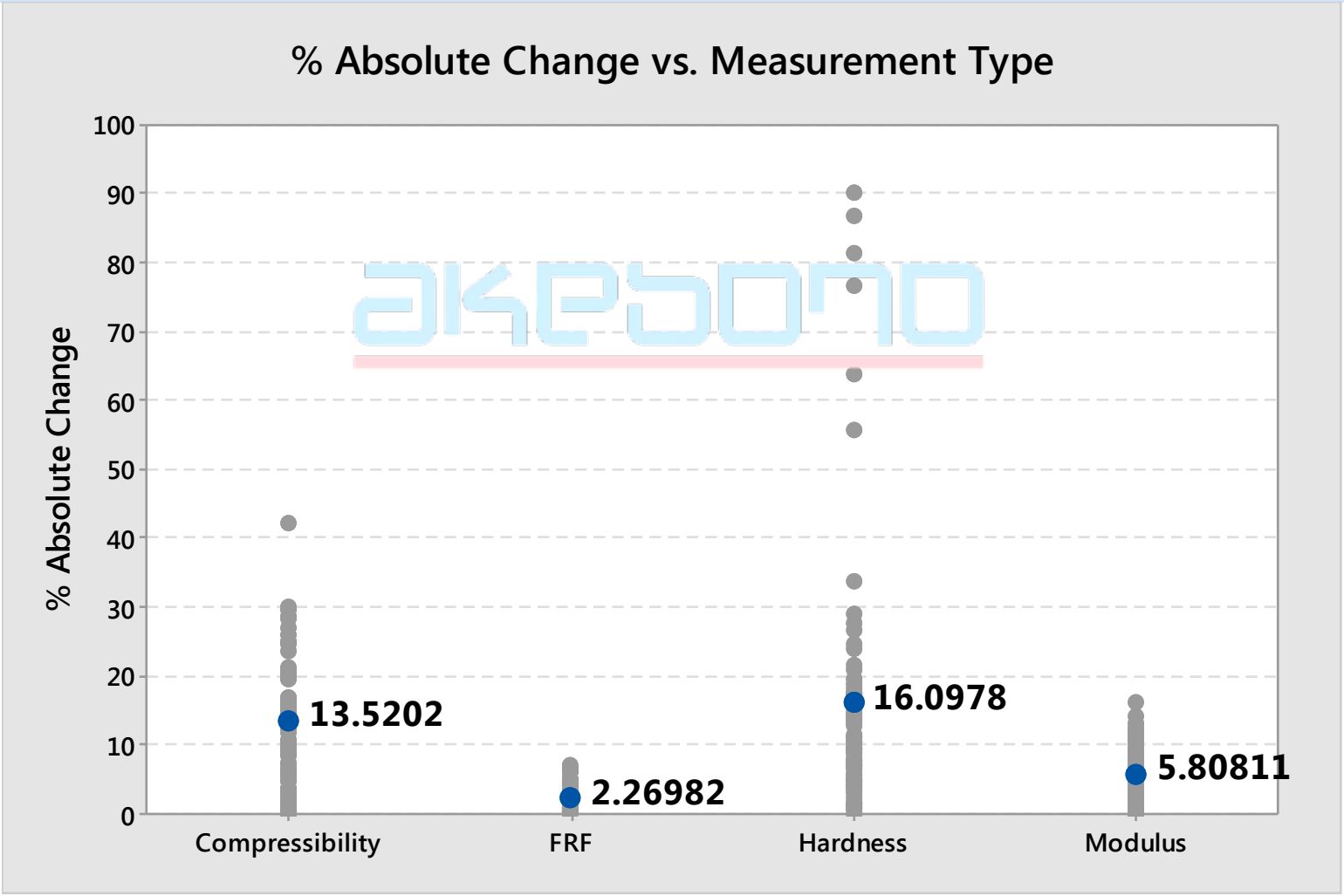
Friction Quality Measurements

Absolute % Change – Post Dynamometer vs Initial



Friction Quality Measurements

Detecting Small Changes Raw Material Properties

•Study was conducted to assess measurement types ability to discriminate between small changes in raw material physical properties

- Passenger car NAO
- A baseline mix and derivatives were made by replacing 1 raw material at a time
- The replacement raw material only differed by a small change in physical properties

- Measurements conducted on finished pad assemblies
  - Compressibility T3/100 bar [microns]
  - FRF [Hz] (1st bending mode)
  - Rockwell Hardness [HRR or HRS]
  - Ultrasound Modulus [MPa] (note actual density used, reference SAE Paper 2010-01-1701)

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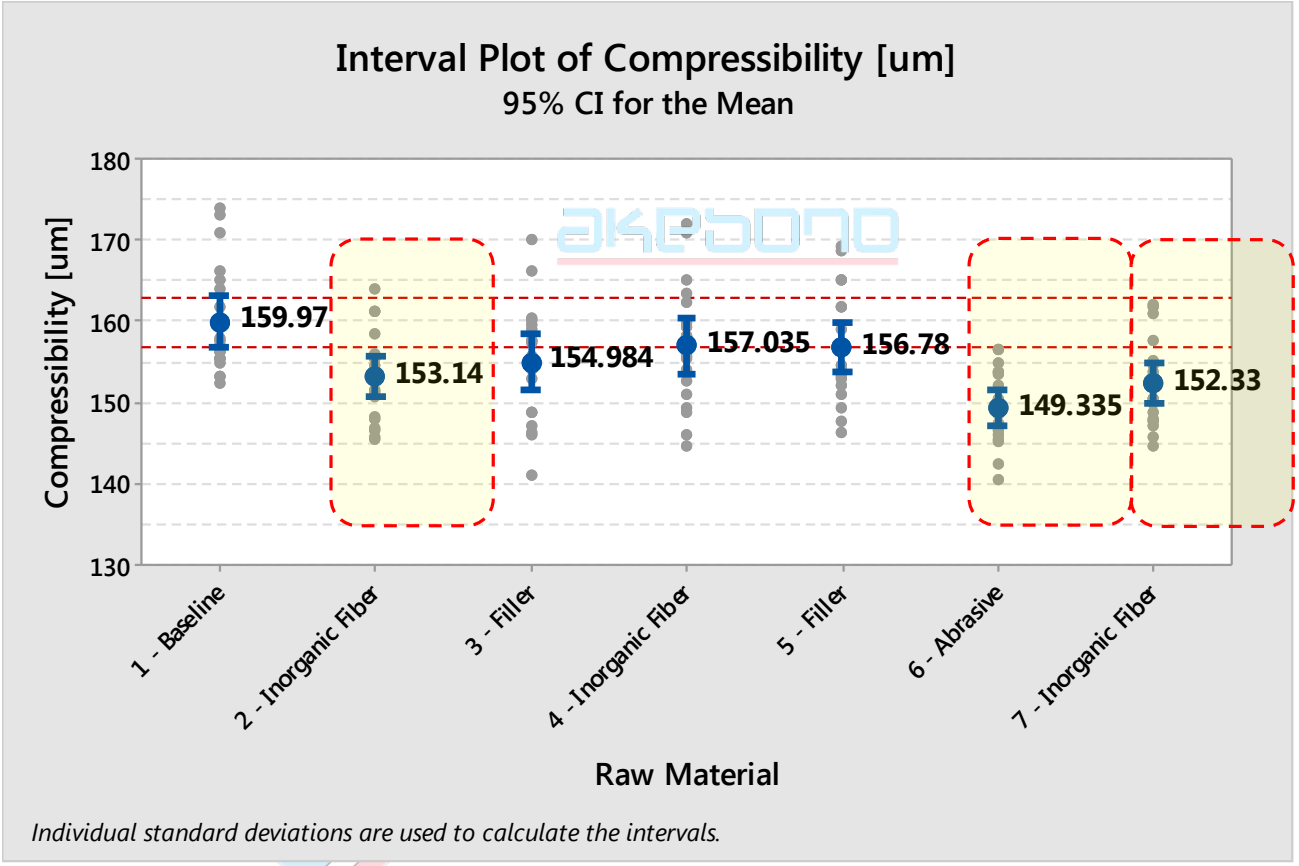
Friction Quality Measurements

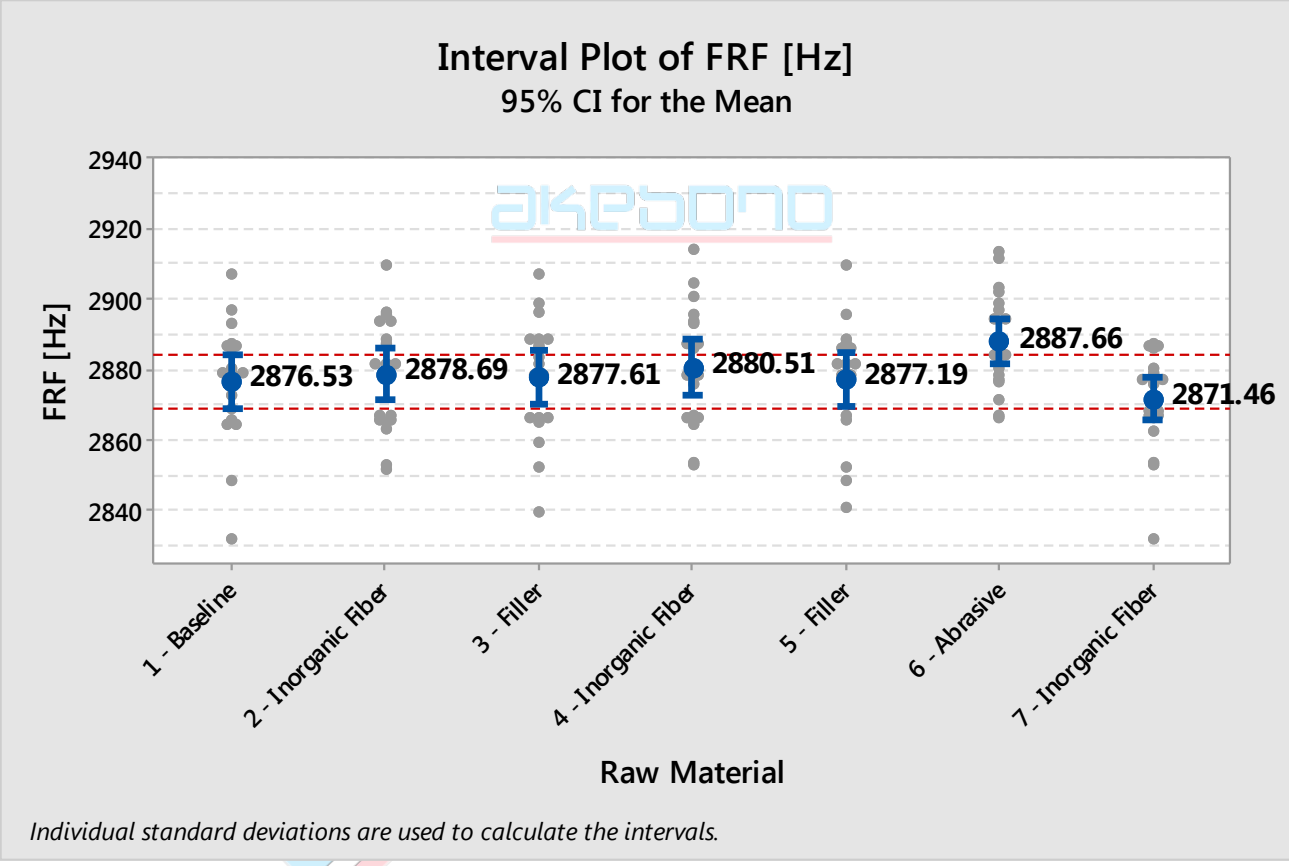
Detecting Small Changes Raw Material Properties



Statistically different mean (95% Confidence)

Friction Quality Measurements

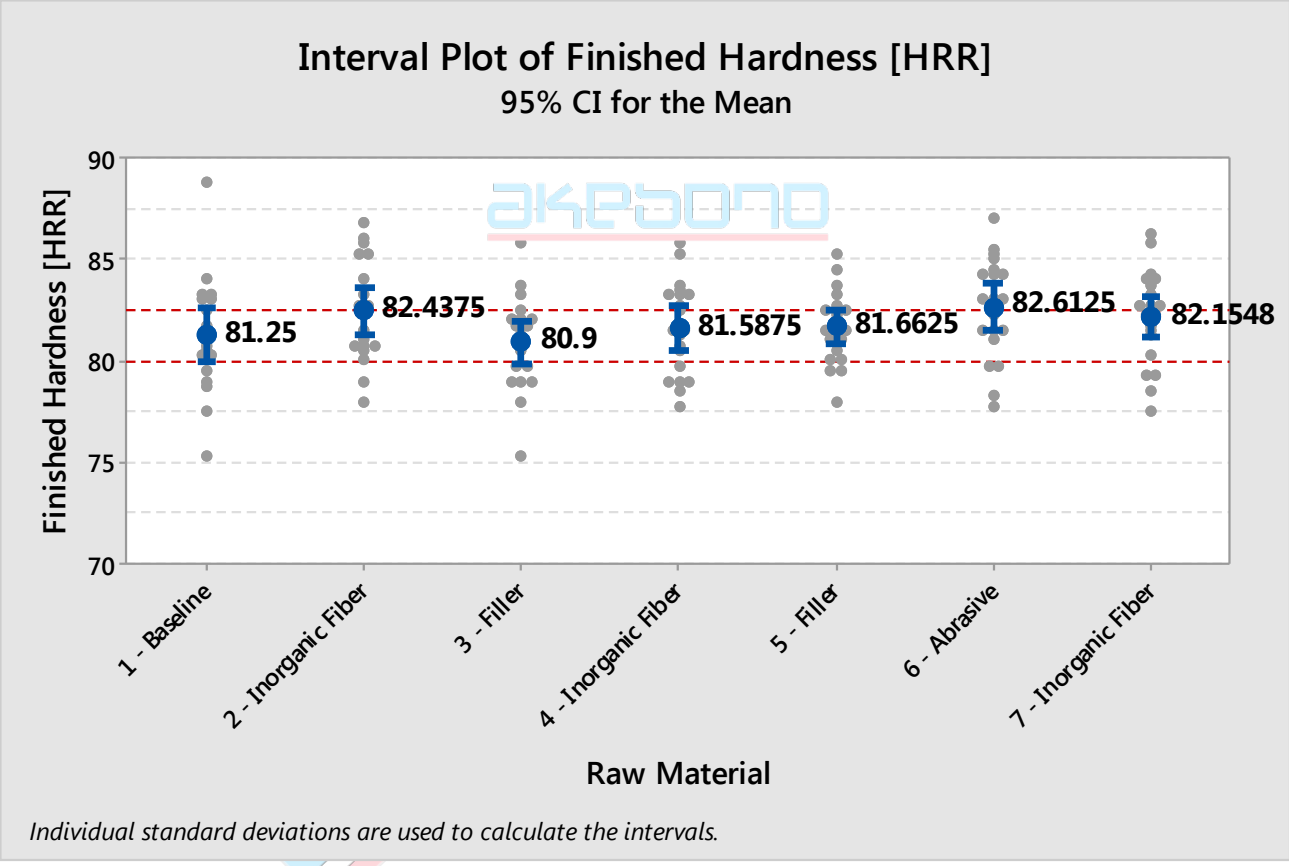
Detecting Small Changes Raw Material Properties



No statistical difference in means

Friction Quality Measurements

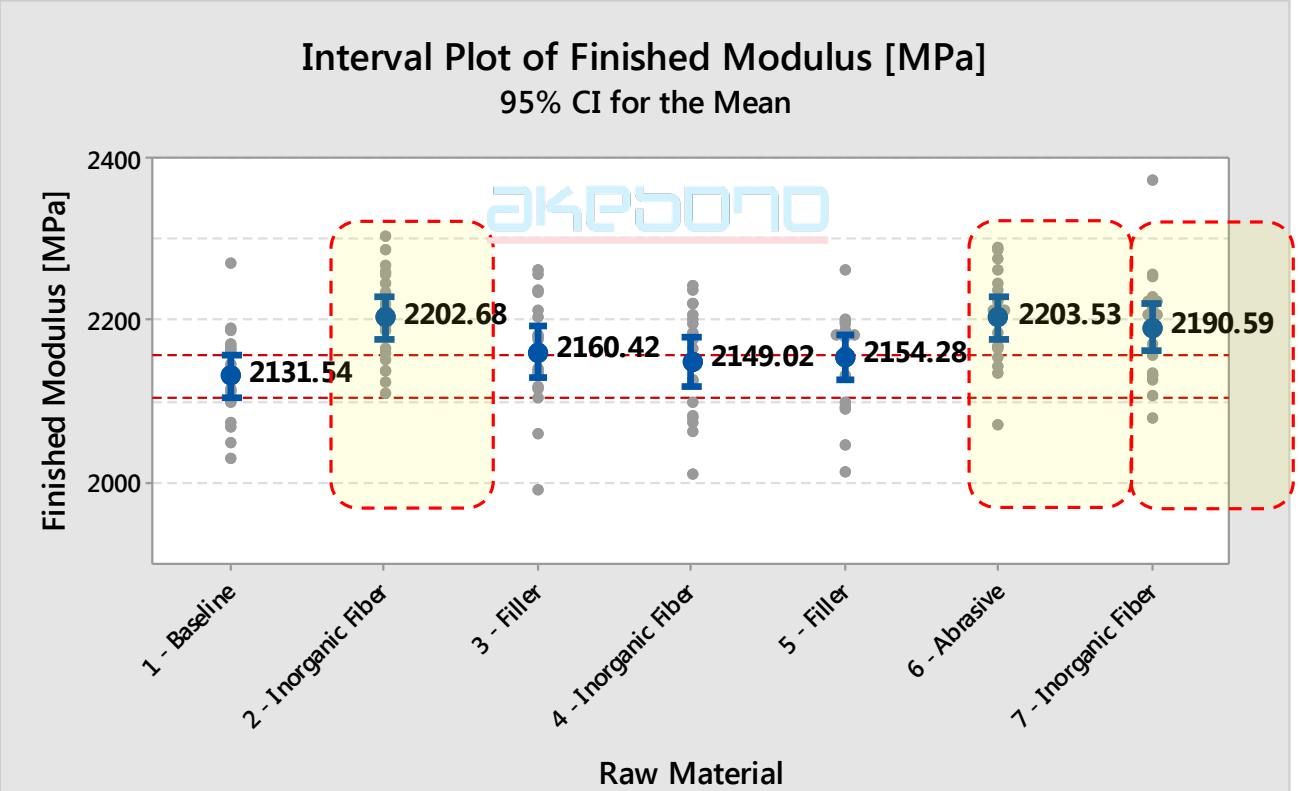
Detecting Small Changes Raw Material Properties



No statistical difference in means

Friction Quality Measurements

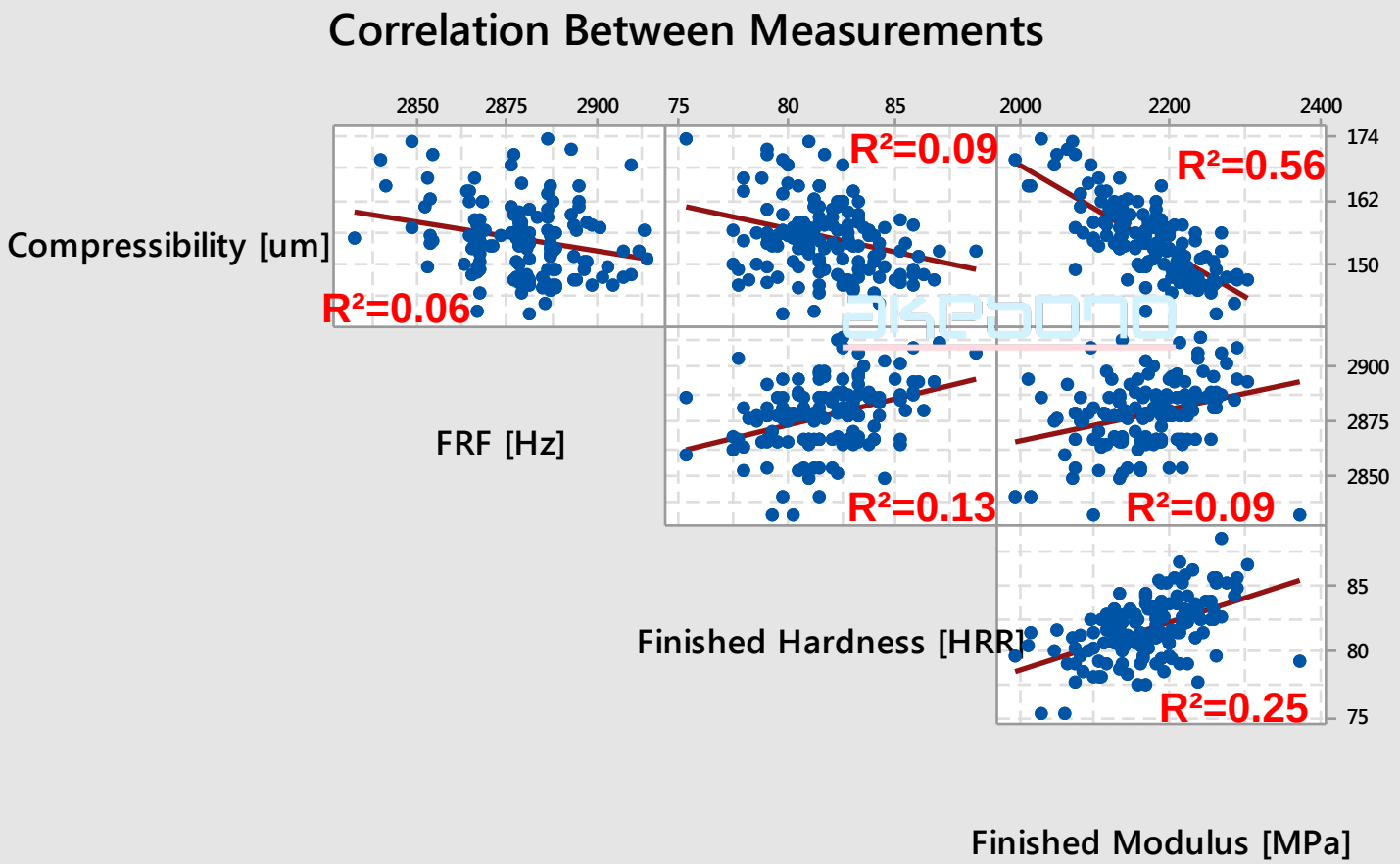
Detecting Small Changes Raw Material Properties



Statistically different mean (95% Confidence)

Friction Quality Measurements

Detecting Small Changes Raw Material Properties



Friction Quality Measurements

Summary Matrix

	Compressibility	FRF	Rockwell Hardness	Direct Modulus (Ultrasound)
Repeatability	1.80%	0.30%	4.11%	1.80%
Sensitivity to Humidity	3.11%	0.75%	5.69%	2.02%
Sensitivity to Plate Tolerance/Plate Flatness	9.90%	3.55%	4.89%	5.20%
Changes "with use"	13.52%	2.27%	16.10%	5.81%
Sensitivity to friction modulus	Excellent w/o dimensional component	Poor	Poor	Excellent
Independent instrinsic quality/engineering measurement	No (shape dependent)	No (shape dependent)	Yes	Yes
In Process Correlation	No	No	Poor/Moderate	Excellent

- **Direct modulus measurements on finished brake pad needs a formal testing procedure**
- **Direct modulus on finished brake pads should be considered as a primary assessment of friction quality along with dimensional measurements**

Friction Quality Measurements

Acknowledgments

- **Friction Team at Akebono Engineering Center**
- **Friction Team at Akebono Brake Glasgow**

Friction Quality Measurements

End

Thank you

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