ARC
Asphalt Research Consortium

Mixture Design to Enhance Safety and Reduce Noise of HMA (Task VP2-a)

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Modeling ETG , San Antonio, Texas, September, 2009

Progress Update for ARC Subtask VP2-a :
Noise and Friction

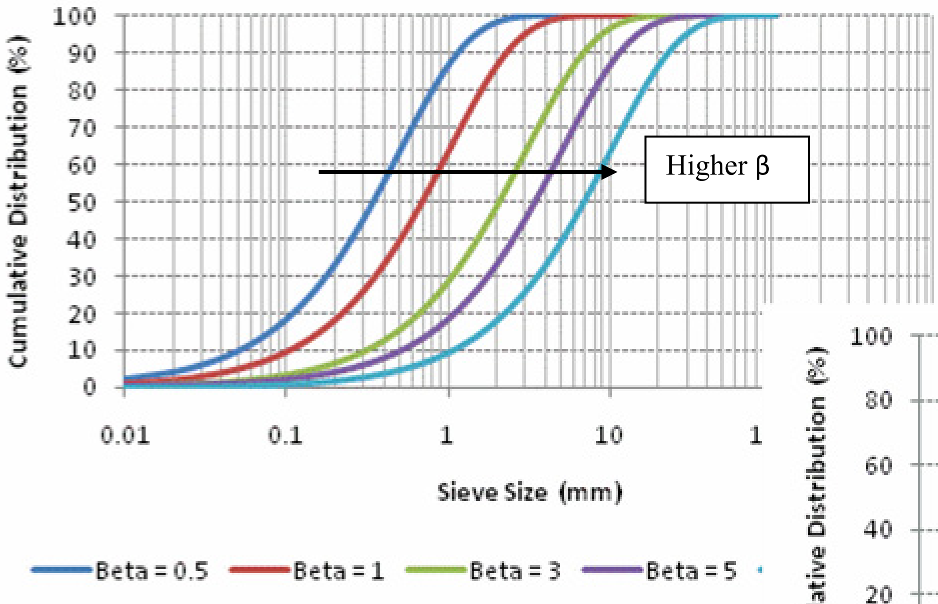
- Objective of Subtask: Functional Mixture Design
- Modifying current methods to measure and predicted functional characteristics of lab compacted samples:
  - Gradation
  - Macro-texture
  - Friction
- Developing a polishing procedure for gyratory compacted samples to simulate traffic effects.
- Macro-texture spectrum analysis for noise absorption
  - Work in collaboration with University of Pisa (Losa et al.)

Materials Tested

- Gyratory compacted samples tested in this study:
  - Three design equivalent single axle loads (ESALs):
    - E-1, E-2, and E-3.
  - Two nominal maximum aggregate sizes (NMAS):
    - 12.5, and 19 mm.
  - Two aggregate types: gravel and limestone.
  - Three compaction temperatures: 60, 90, and 120 C.
  - Two compaction pressures: 300 and 600 kPa.

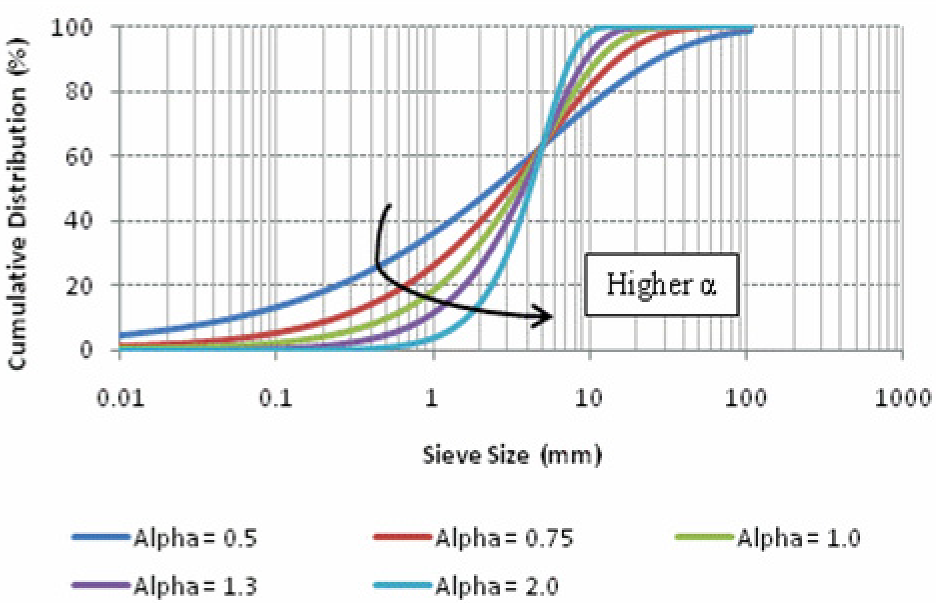
Gradation Analysis and Modeling

(Mahmoud and Masad)

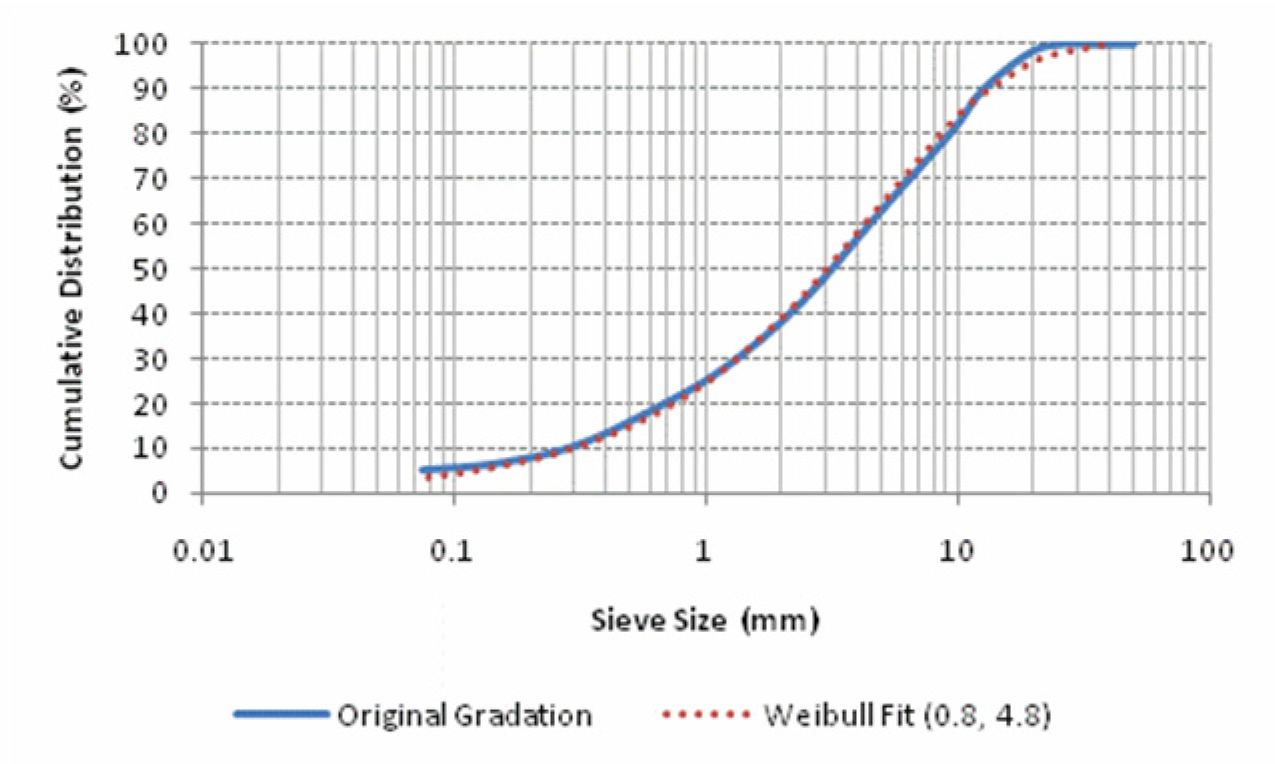


$$F(x,\alpha,\beta) = 1 - e^{-\left(x/\beta\right)^{\alpha}}$$

Weibull distribution



Example of Fitted Model (Gradation Analysis)



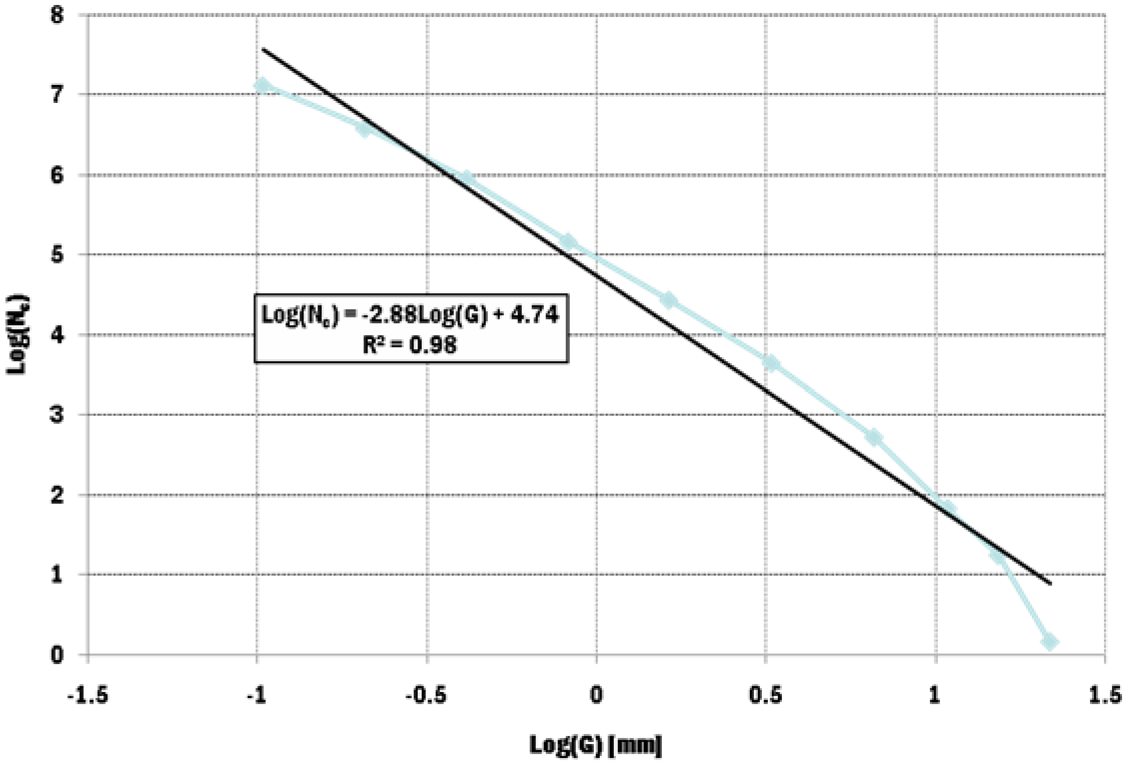
Gradation Analysis and Modeling Fractal Dimension (D)

- Fractal Dimension Analysis

$$G = \frac{\ln y - \ln x}{\frac{1}{x} - \frac{1}{y}} \qquad N = \frac{M}{\gamma \frac{\pi}{6} G^3}$$

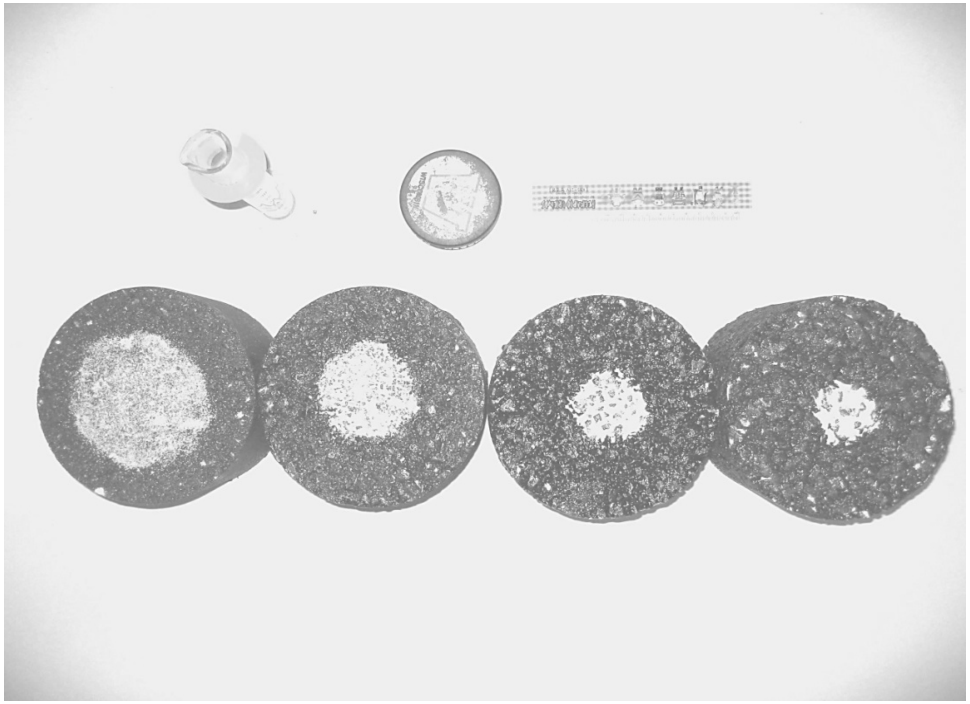
  - G: is the equivalent sphere diameter of aggregate particle passing sieve size x (mm) and retained on sieve y (mm)
  - N : The number of aggregate particles retained on sieve "y".

Example of Fitted Model (D)



- **Fractal Dimension D: absolute value of the slope (2.88 in this examples)**

Macrotexture Measurements

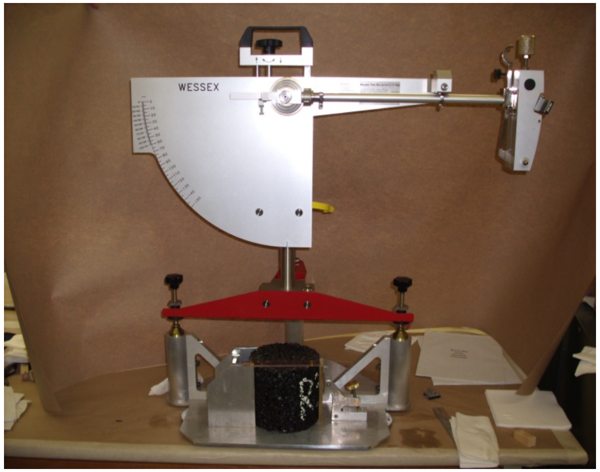


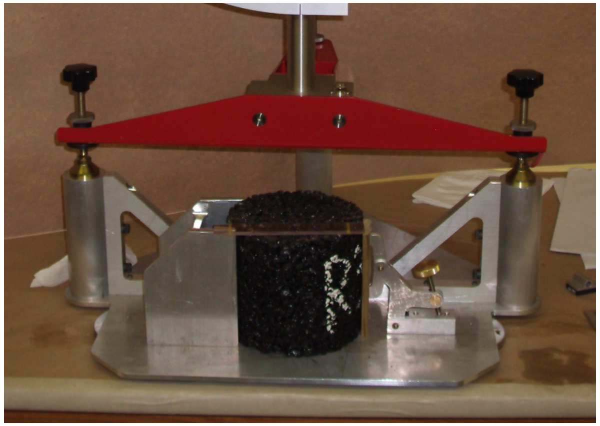
From left to right: Fine, Coarse, SMA, Porous Mixtures

- Sand patch method
- Spreading a known volume of material (sand).
- Measure the diameter of the area covered (at 4 equally spaced angles)
- Mean Texture Depth (MTD).
- The procedure is repeated three times for every sample.

$$MTD = \frac{4V}{\pi D^2}$$

Microtexture (Friction) Measurements





• British Pendulum Skid Resistance Tester
• Friction measured by swinging the pendulum.

•The loss of the kinetic energy as result of the interaction between the rubber and the sample surface is reported as the British Pendulum Number (BPN)

•Higher BPN values indicate higher surface microtexture and better skid resistance.

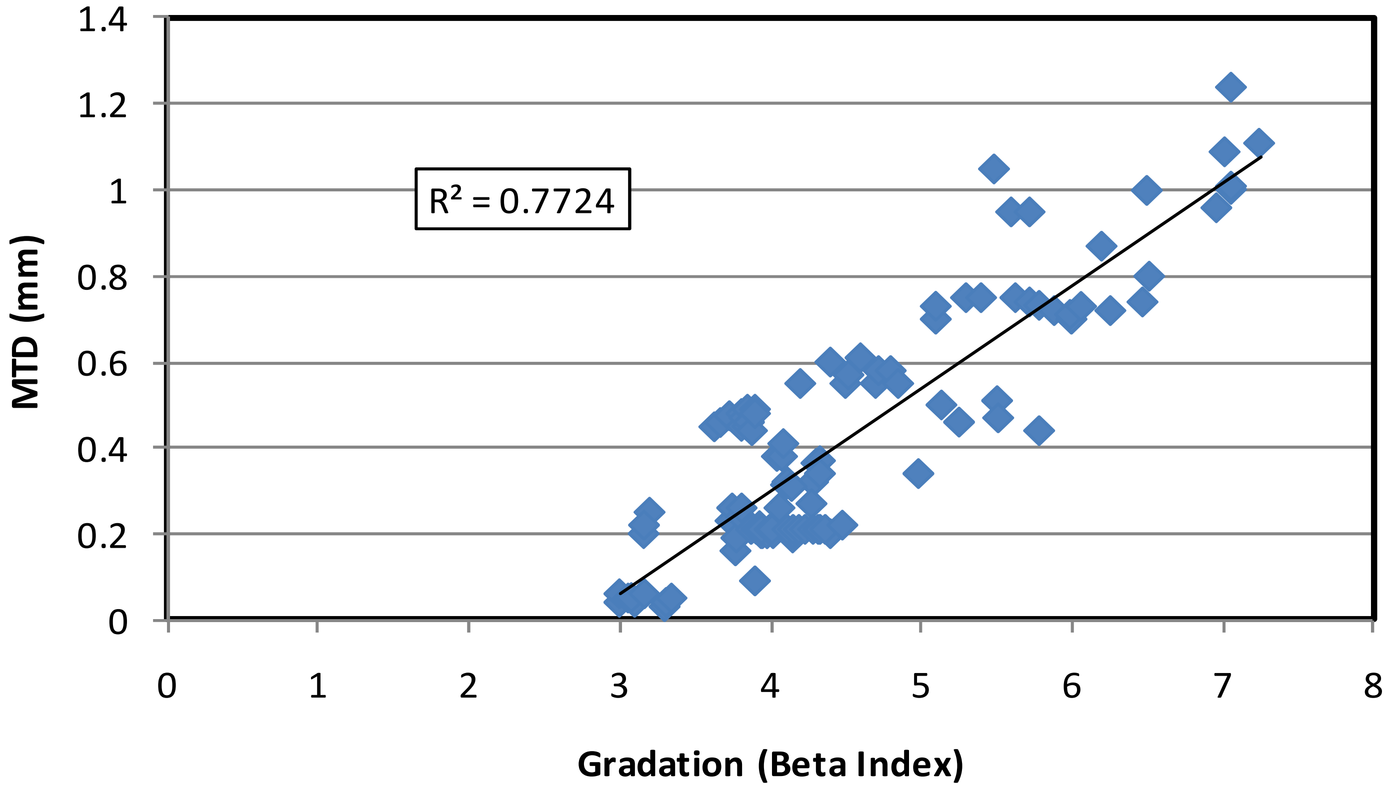
Analysis of Results

- The analysis was conducted for all the mix gradations in this study.
- The α values were very similar. All dense mixes.
- D values correlated with the β values:
  - Linear with R^2 value of 0.92.
  - This might change if different gradations were studied
- Correlations with β

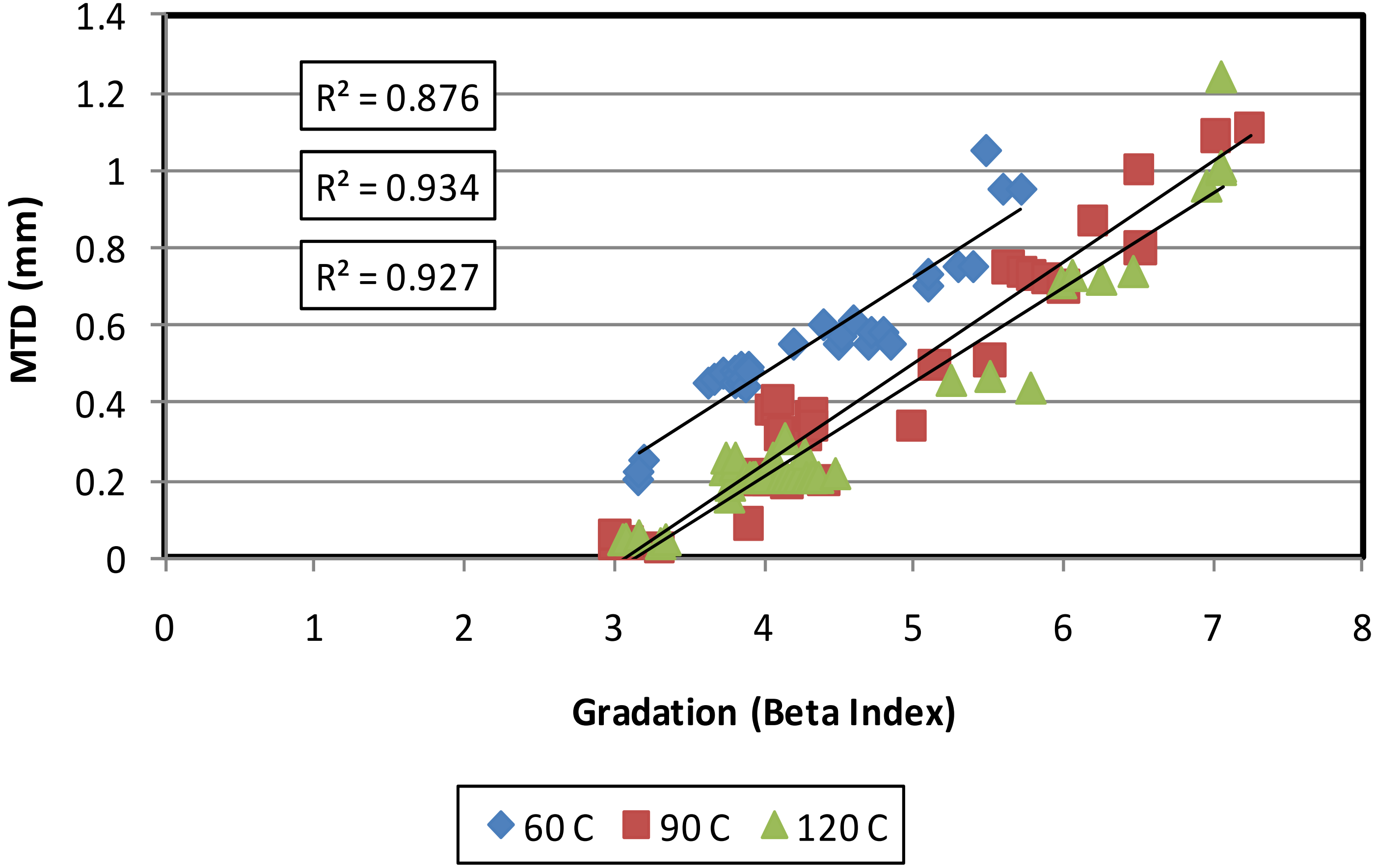
Results & Analysis

- About 140 samples were tested (BPN & MTD)
- Correlations with:
  - FAA, percent Crushed Aggregates, Flat to Elongated ratio, gradation index (Beta), Air voids, Compaction Temperature, and Compaction Pressure.

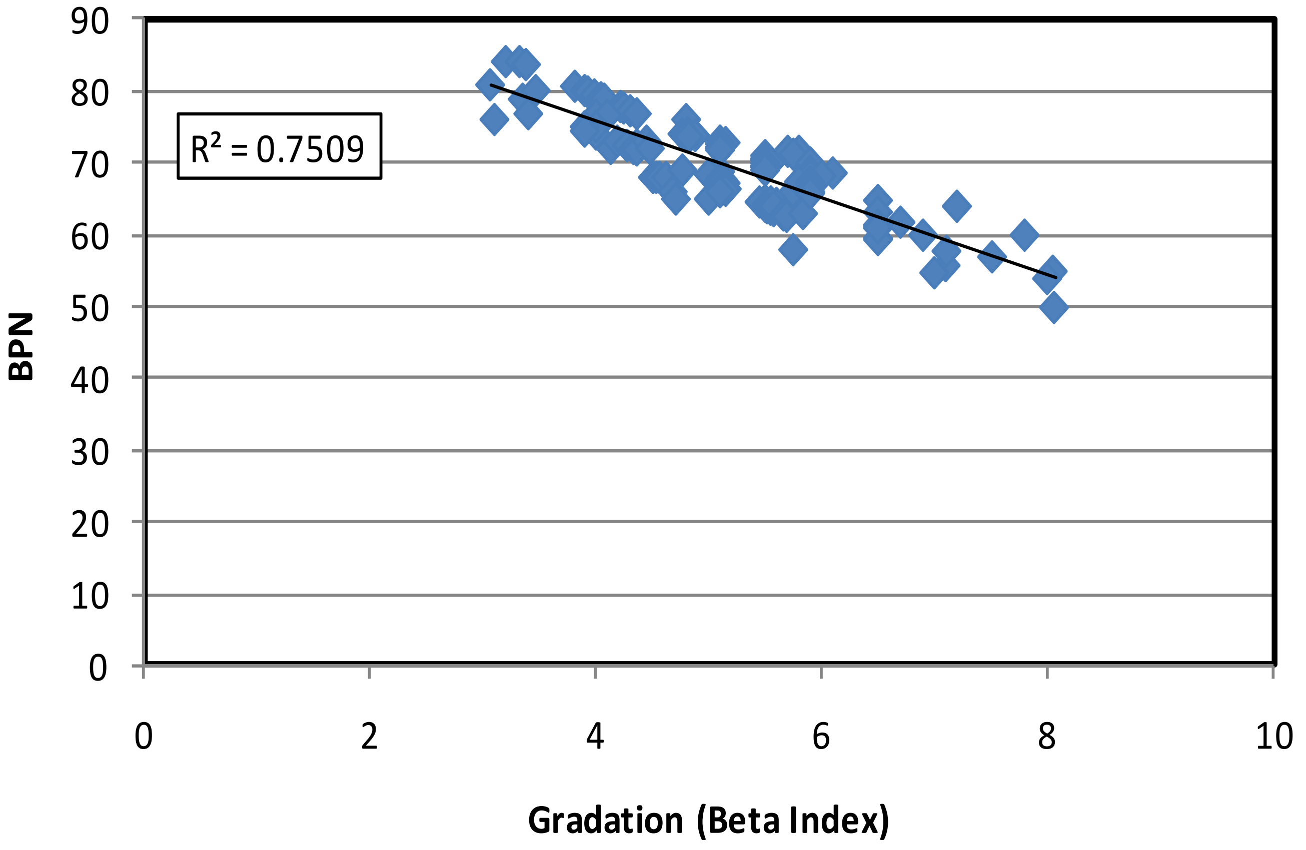
Results & Analysis- Macro Texture



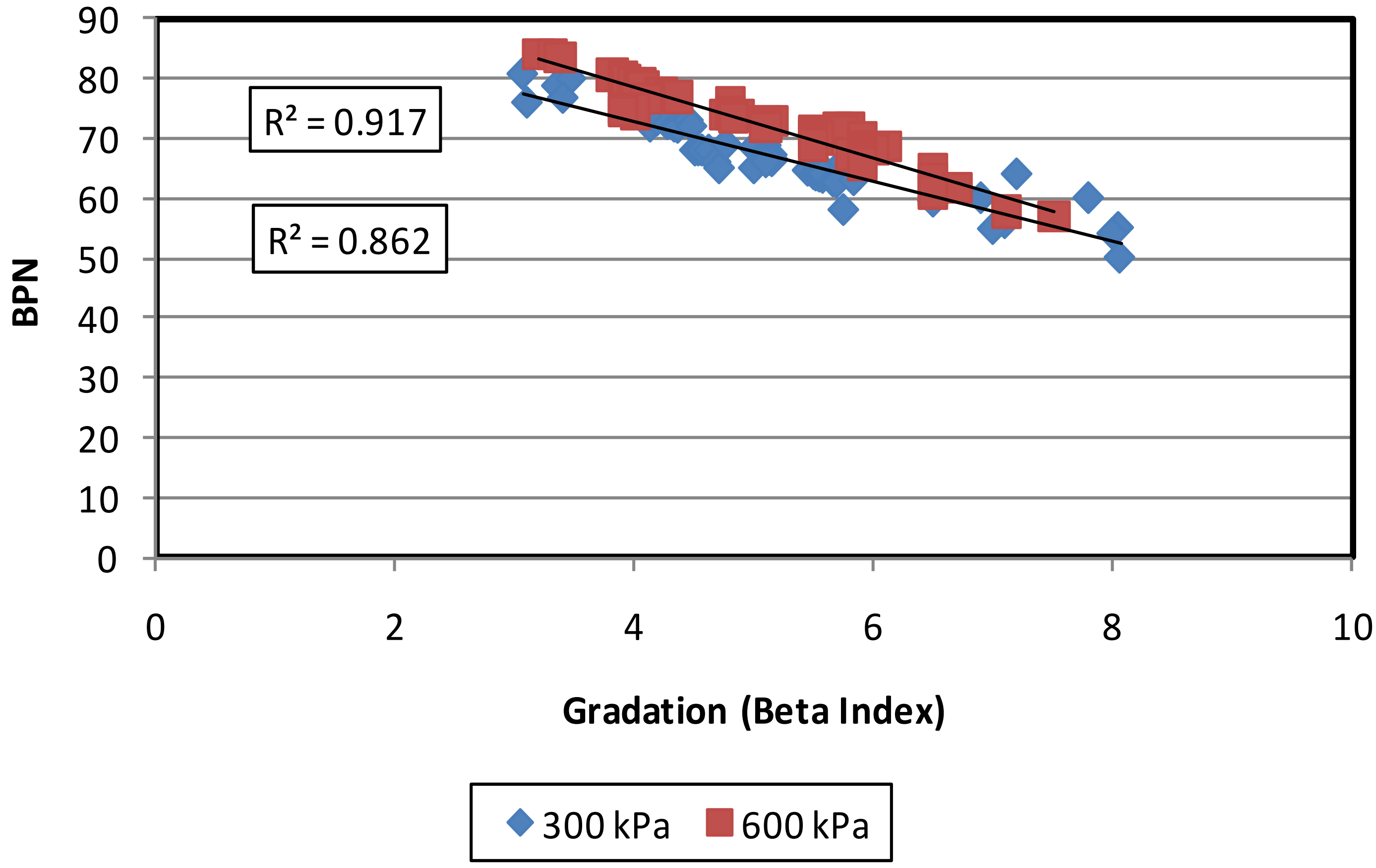
Results & Analysis- Macro Texture



BPN – Friction Number



BPN – Friction Number



Results & Analysis- All Dense Graded

Sorting Factor	Levels Included in Analysis	Correlations with BPN - (0-100)	Correlations with MTD-mm
Gradation (beta index)	Six Levels: 3, 4, 5, 6, 7, 8	None	Gradation Beta (0.72), Temperature (0.77),
FAA	Five Levels: 43, 44, 45, 46, and 47	Gradation Beta (0.83), and F/E (0.67)	Gradation Beta (0.95), Temperature (0.80),
% Crushed Faces	Five Levels: 75, 80, 85, 90, and 95	Gradation Beat (0.64), and Pressure (0.88)	Gradation Beta (0.85), Temperature (0.97), and Air Voids (0.61)
Flat/Elongated percent	Six Levels: 0.4, 1.1, 1.8, 2.5, 3.2, 3.9	Gradation Beta (0.84), Pressure (0.92), and Temperature (0.63)	Gradation Beta (0.93) and Temperature (0.77)

Interim Findings

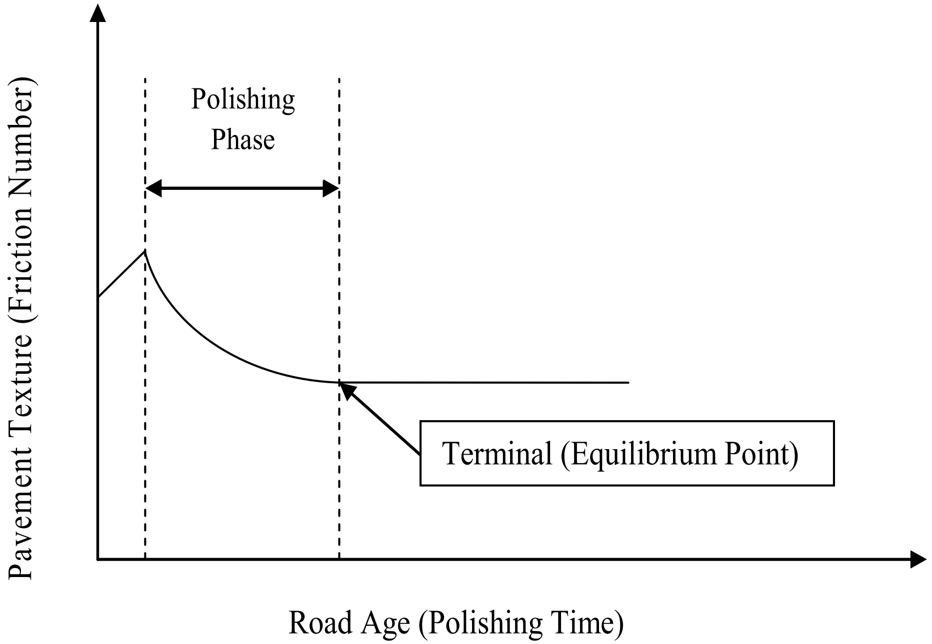
- MTD (Macrotexture):
  - Strongly correlated: gradation beta indices and compaction temperature
  - Angularity of fine and coarse aggregate (FAA, percent crushed faces, or flat and elongated) are not important factors.
- There is more to Macro-texture than only MTD.

Interim Findings

- BPN (Microtexture):
  - High correlation with gradation,
  - High correlation with the compaction pressure.
- The newly developed protocol for measuring MTD and BPN are sensitive to aggregate and mixture properties.

Polishing Effects

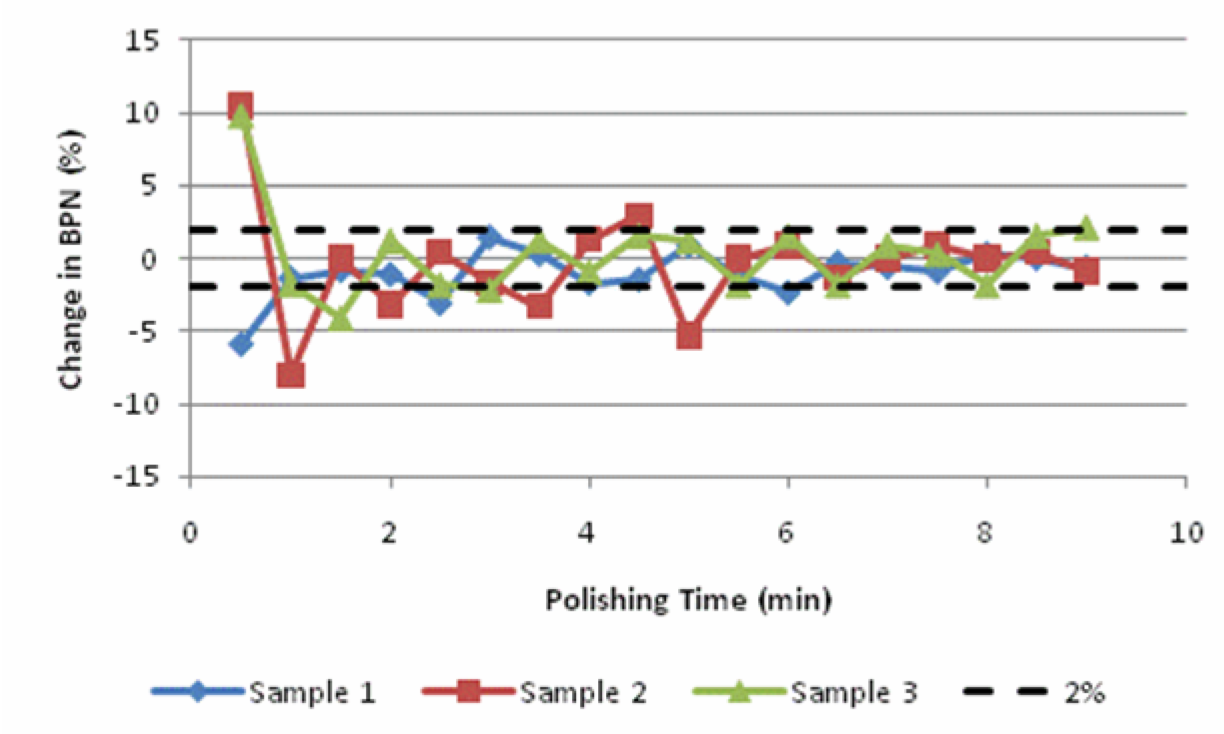
- Texture of pavement surfaces reduces with time:
  - Develop a methodology to capture this behavior (Polishing)



Polishing Procedure

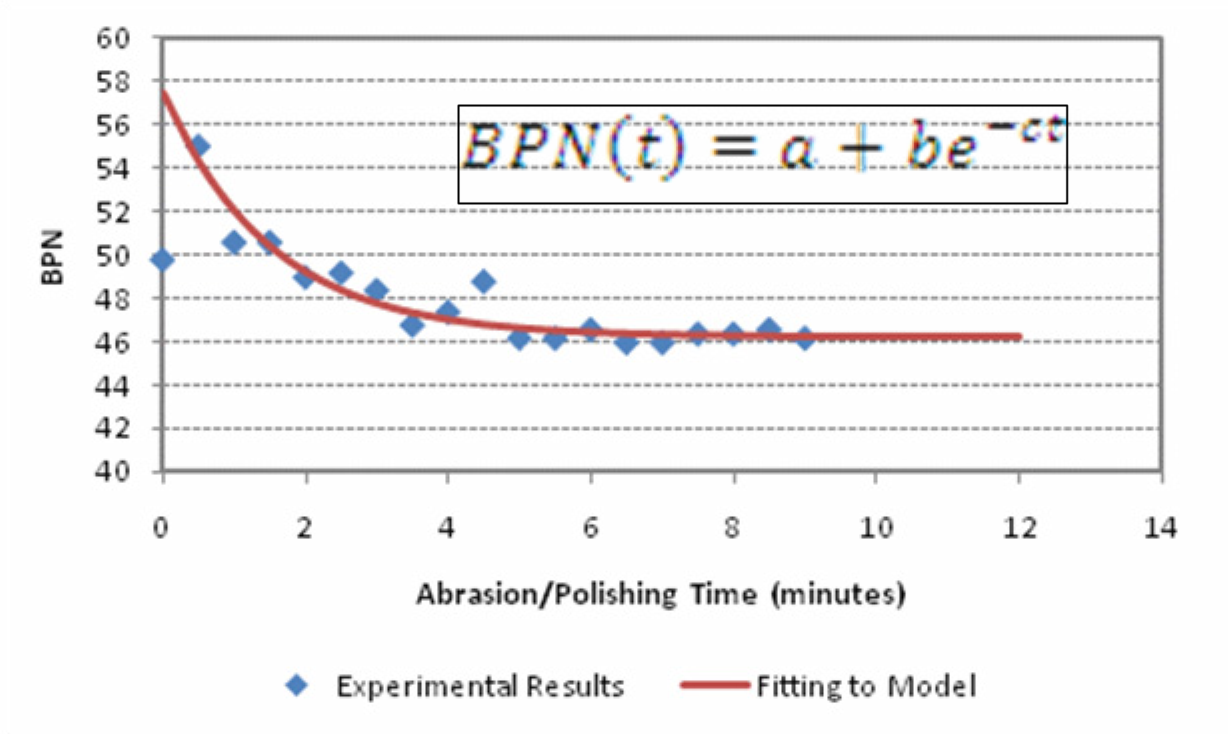
- Polishing was simulated using an abrasive rotating disk applied on the surface of the gyratory samples.
  - (3M Quick Change Disk No. 9140-9143)
  - Nominal constant rotation speed of 600 RPM using a "No. 7144 Type 3 Black Decker Drill".
- Measure the BPN before polishing and after polishing for various times.

Polishing Results Analysis

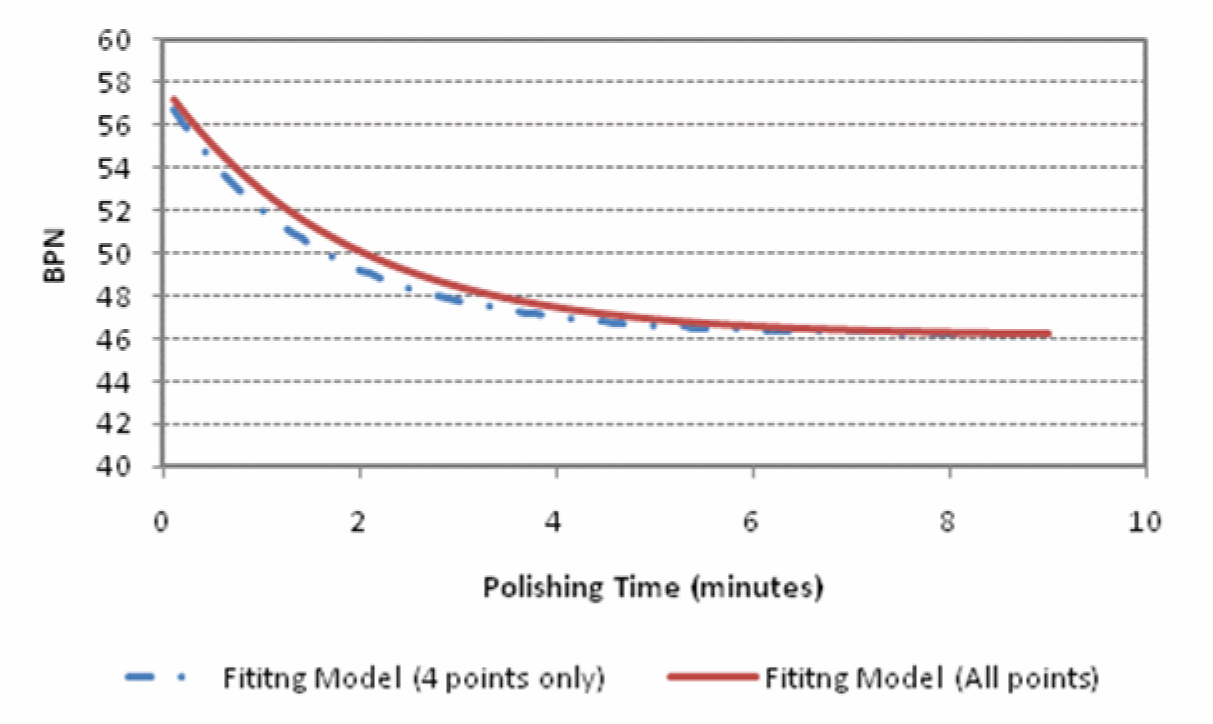


- After 6 minutes of polishing all the changes are less than 2%
- 9 minutes is proposed as a sufficient time of polishing to reach Terminal Condition

Polishing Trend Analysis



Polishing Analysis



- All points: 0.5,1,1.5,... 9 minutes (19points)
- 4 Points: 0.5, 3, 6, and 9 minutes

Design for Noise Reduction

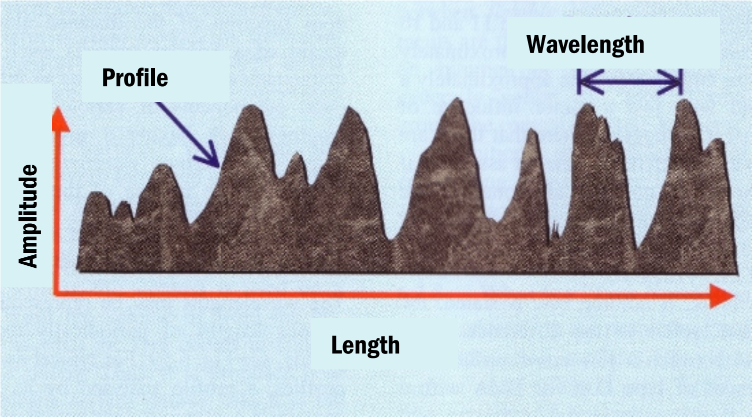
- Objective: Optimize Gradation
  - Develop a model to predict the coefficient of absorption based on the gradation of the mix and voids.
  - Find optimum gradation and voids content to reduce noise.
    - Reduce generation
    - Increase absorption

Noise Reduction Characteristics

- Noise Generation
  - Macro-texture: Investigation of new measuring method … Laser Profilometer.
- Noise Absorption:
  - Measurement of "absorption coefficient" of asphalt mixes using the impedance tube.
    - Modeling of noise absorption in terms of mixture characteristics.

Macro-texture/Laser Profilometer

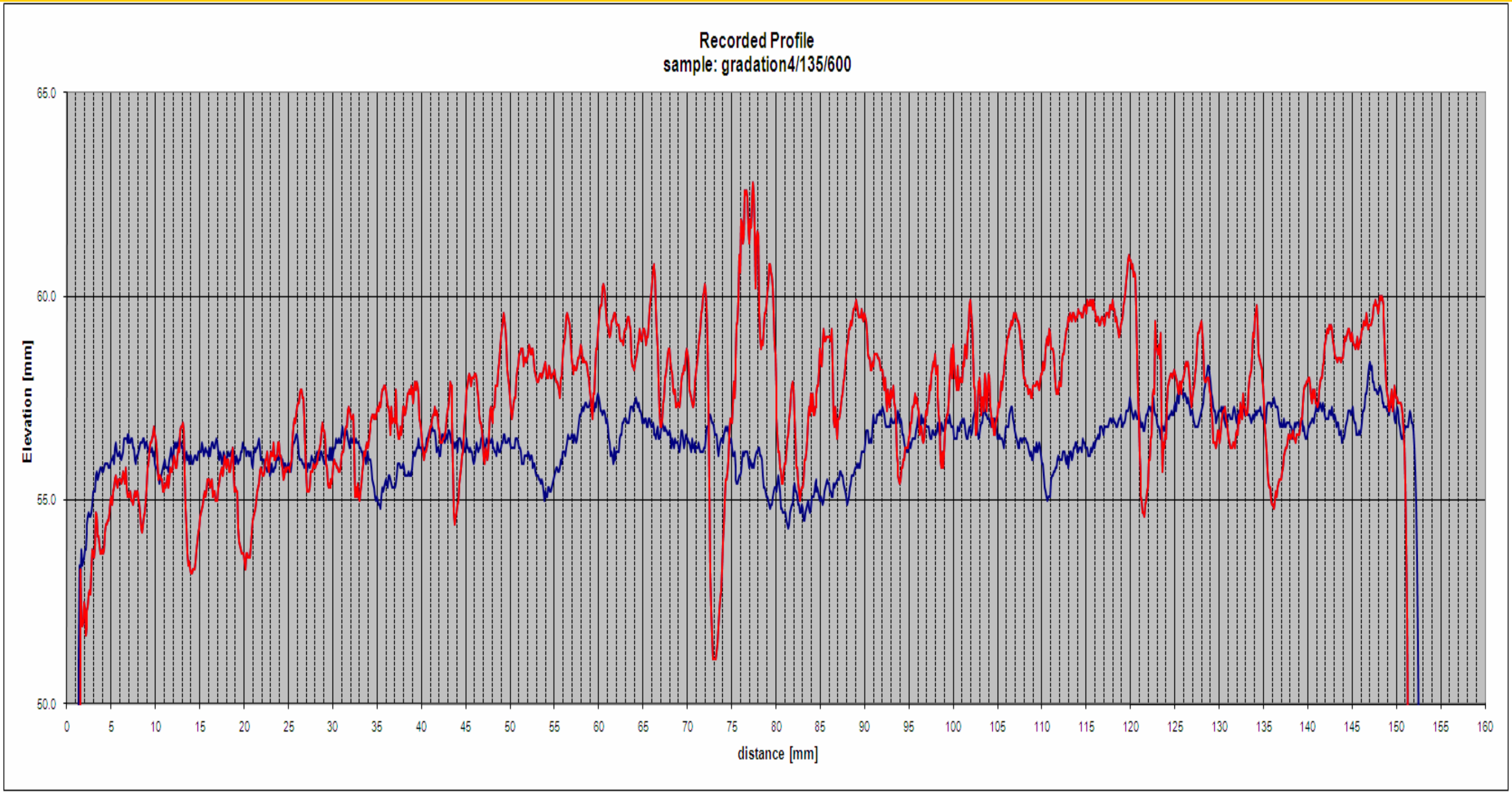
Work in collaboration w Professor Losa (University of Pisa)



•Device	•Sampling Rate	•Sampling Interval	•Vertical Resolution	•Measuring Speed	•Length of Profile
•Stationary Profilometer	•16 kHz	•0.1 mm	•0.05 mm	•Manual	•750 mm
•Mobile Profilometer	•16 kHz	•1 mm	•0.05 mm	•20 km/h	•unlimited

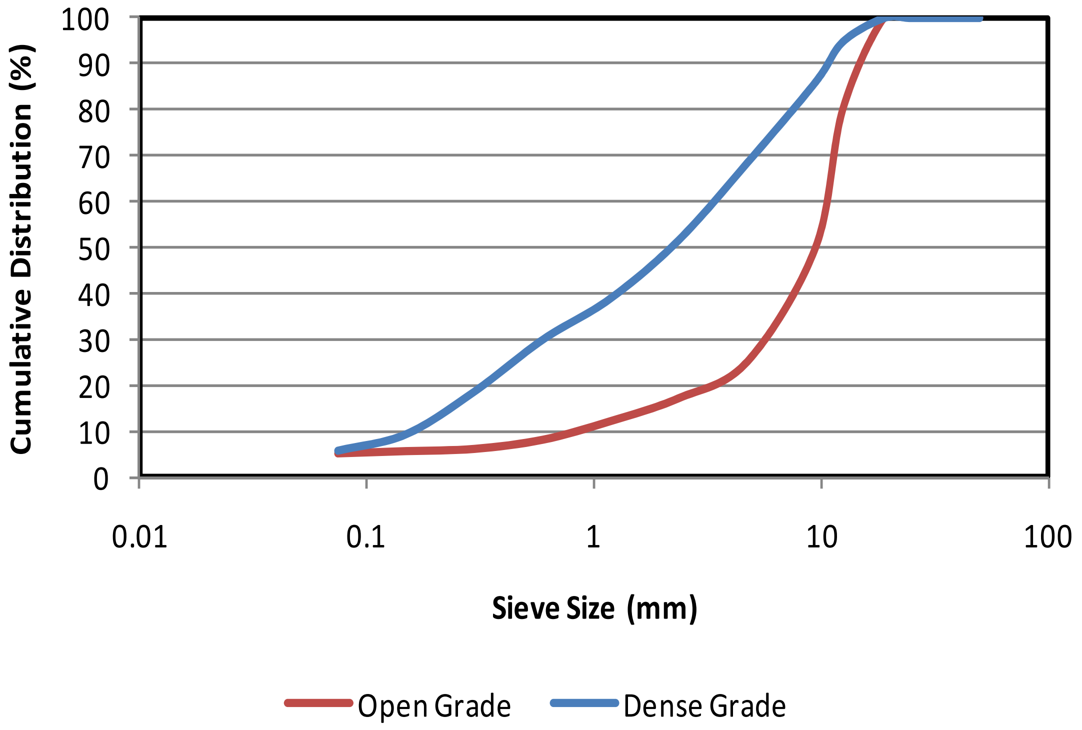
Example of Measurements UW Mixes

Data collected at University of Pisa Sep. 2009

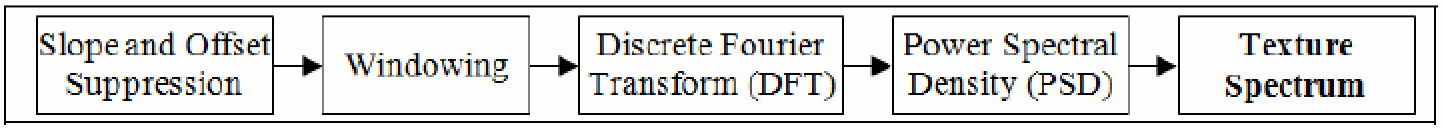


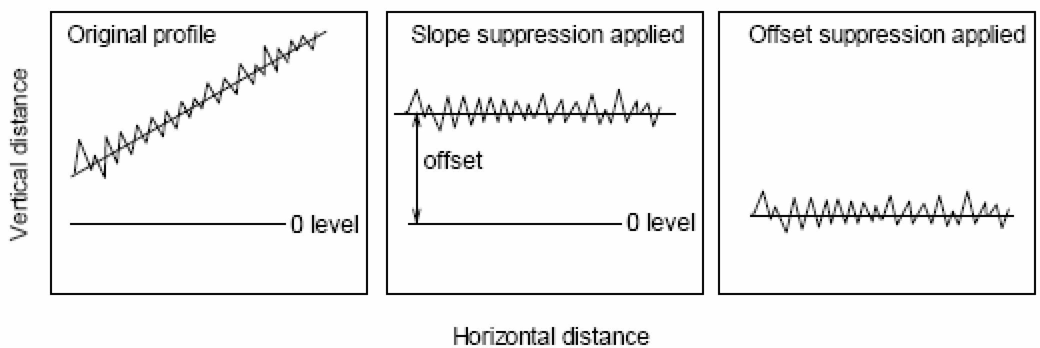
Gradation and Texture

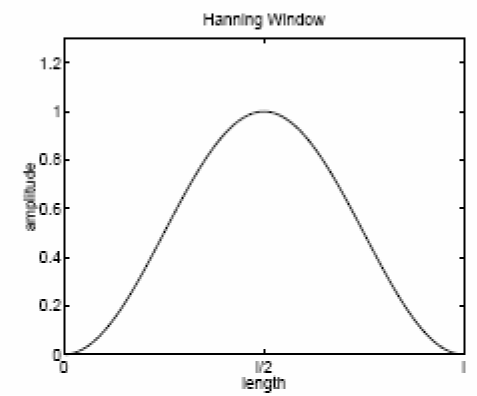
Gradation Indices	Open Graded	Dense Graded
Alpha	1.51	0.69
Beta	10.05	3.38



Noise Generation Characteristics
Texture Level / Spectrum (ISO 13473-4)



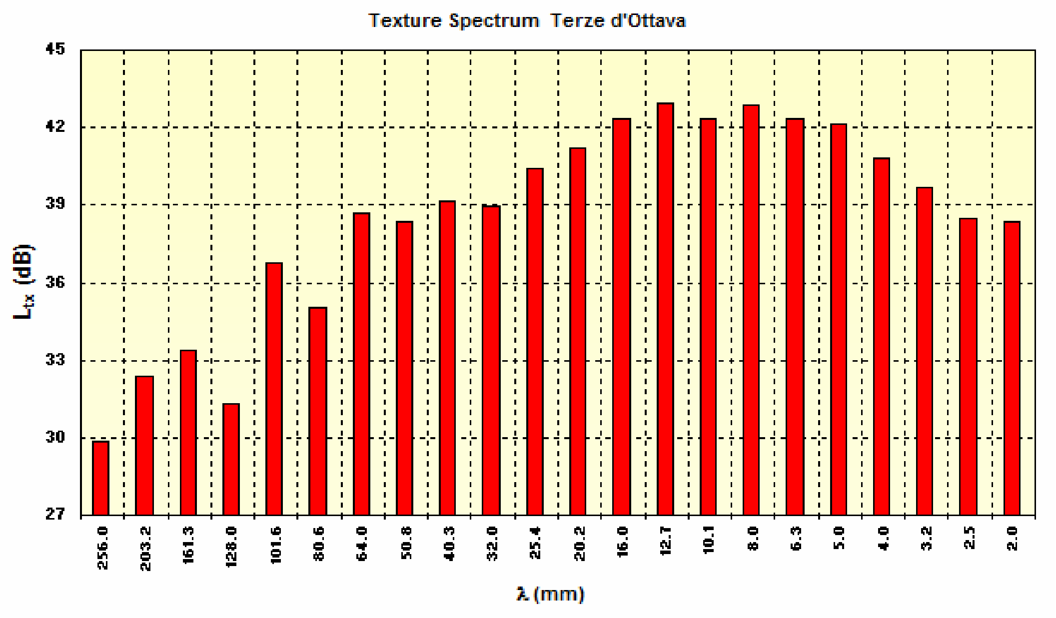




Noise Generation
Evaluation of texture Spectrum (ISO/CD 13473-4)

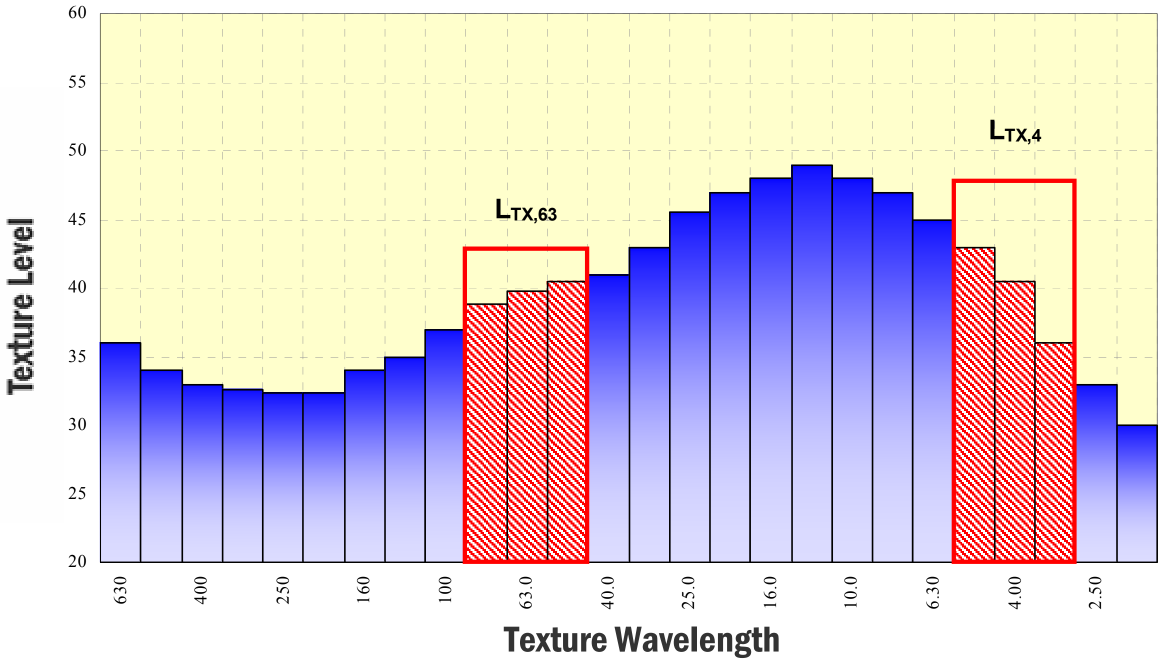
- MTD is not sufficient , texture "spectrum" is needed
- Discrete Fourier Transform (DFT)
- Power Spectral Density PSD
- Spectral Power Zp
- Texture Level Ltx

$$L_{tx,\lambda} = 10 \cdot \log \frac{Z_p}{a_{ref}^2}$$

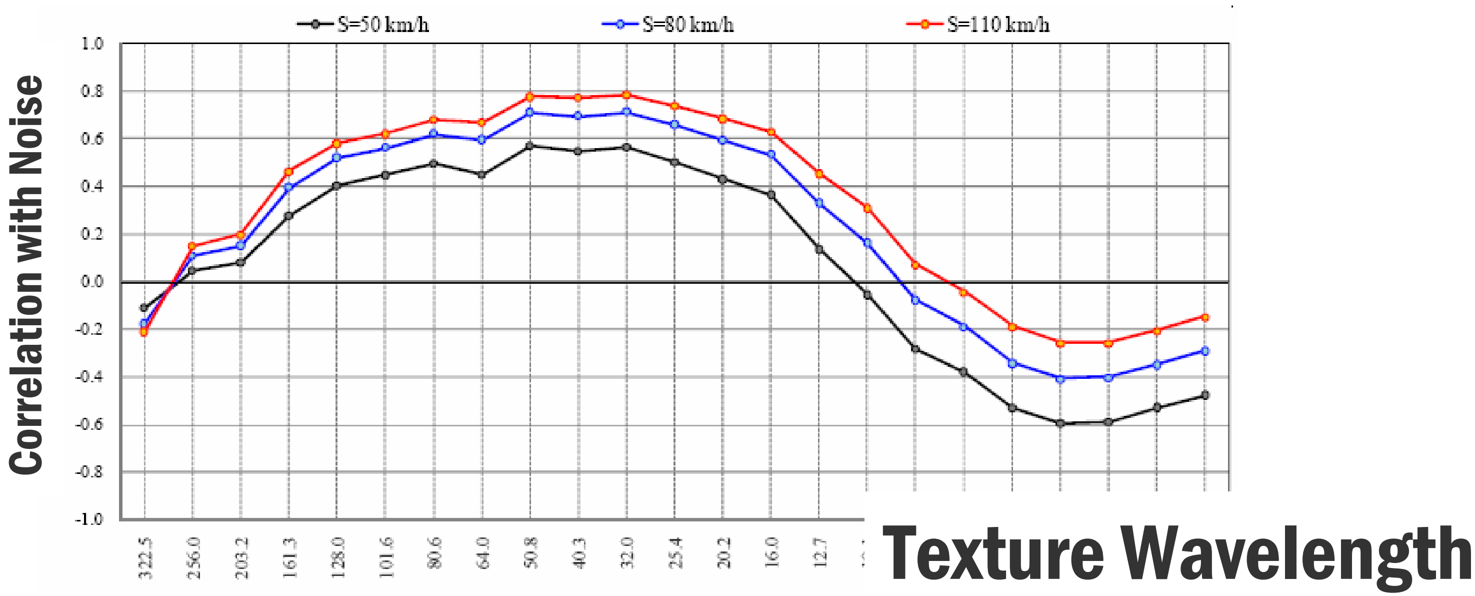


Noise Generation – Macrotexture versus tyre/road noise

- Sandberg and Ejsmont (2002), (Losa et al, 2008/09)
  - $L_{TX,4}$ is related to high frequencies noise (f>1000 Hz)
  - $L_{TX,63}$ is related to low frequencies noise (f<1000 Hz)



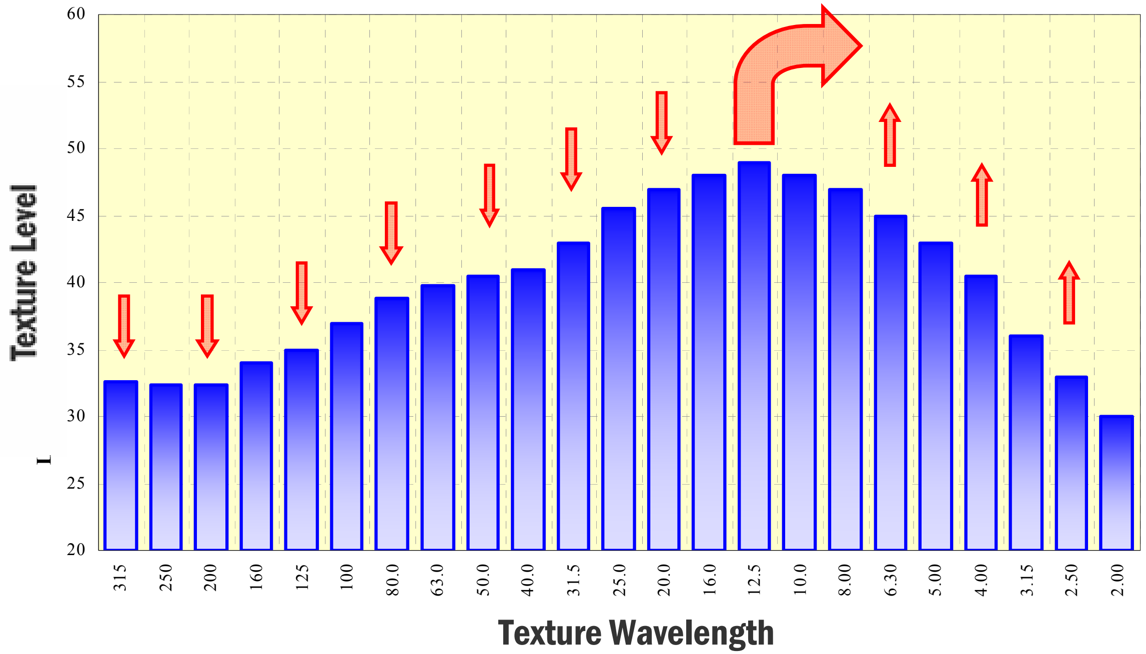
Noise Generation Modeling
(Losa et al. 2008/09)



- Correlation coefficients (r) between texture and noise levels.
- Negative r values: at this wavelength, higher texture will produce less noise
- Positive r values: at this wavelength, higher texture will produce more noise

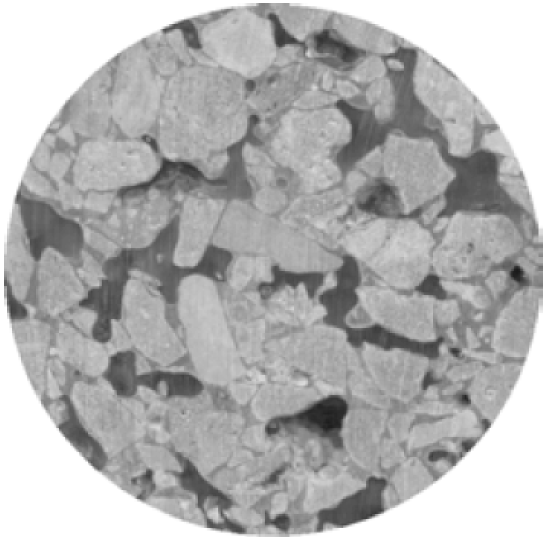
Macrotexture versus tyre/road noise

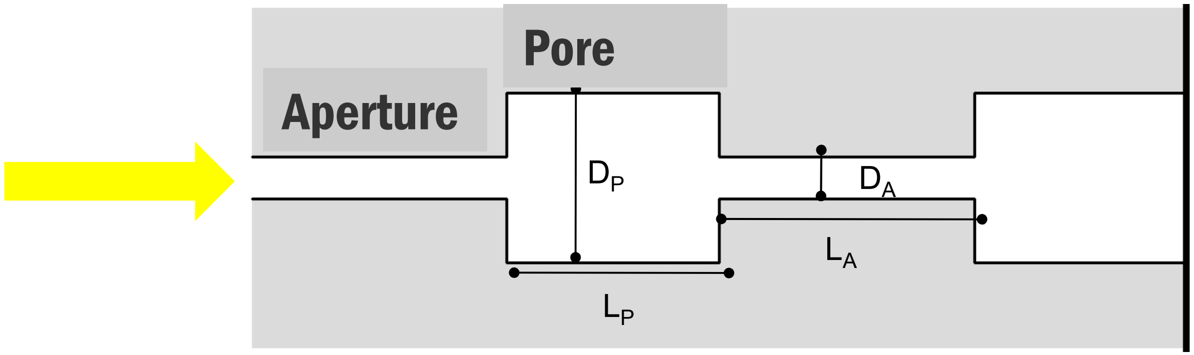
- **Optimize** "Texture level" to generate less noise



(After Losa et al. 2009)

Noise Absorption Modeling
Voids structure (Losa et al. 2008/09)





F = Microstructural Model $\alpha = F(D_P, L_P, D_A, L_A)$

G = Theoretical Model $(D_P, L_P, D_A, L_A) = G(\text{Composition Characteristics})$

Noise Absorption Measurements

Absorption Coefficient (Alpha)

Noise Absorption Modeling

Theoretical Model → D_P

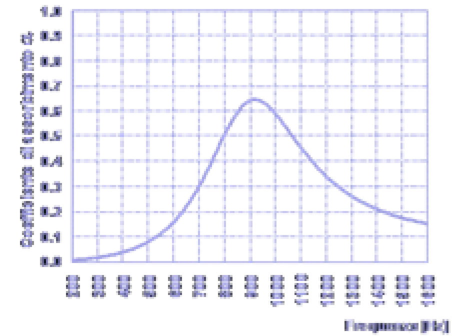
Relationships between D_P and L_A, D_A, L_P →

L_P

D_A

L_A

Microstructural Model →



$$D_P = F(V_V, D, P_{0.075}, N_{gyrations})$$

D: fractal dimension (gradation)

Summary of Progress – Functional Design

- Testing procedures are under development for measuring the following for mixture samples:
  - macro-texture, (sand patch and laser),
  - noise absorption, (Impedance Tube) and
  - friction (British Pendulum)
- A method for simulating traffic polishing effect was introduced. (BPN @ 0.5, 3, 6, and 9 min)

Summary of progress

- These developed procedures rely on already existing measuring procedures and/or equipments with minor modifications.
- The measurements are based on laboratory compacted asphalt mixes.
  - No large asphalt slabs
  - These characteristics can eventually be included within the mixture volumetric design procedures.

Thank You

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