Airport Pavement Friction & Texture: Conventional, Innovative, and Next Generation…

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Overview

- <u>Conventional</u>…
  - <u>Friction & Texture Refresher</u>
  - Measurement Devices & Requirements
  - Limitations of Dense-Graded HMA
- <u>Innovative</u>…
  - Prediction of texture and frictional properties at mix design stage
  - Laboratory evaluation of mix polishing
- <u>Next Generation</u>…
  - Stone Mastic Asphalt (SMA)
  - High Friction Surface Treatment (HFST)

Acknowledgements…

- Michelin Report "The Tyre Grip"

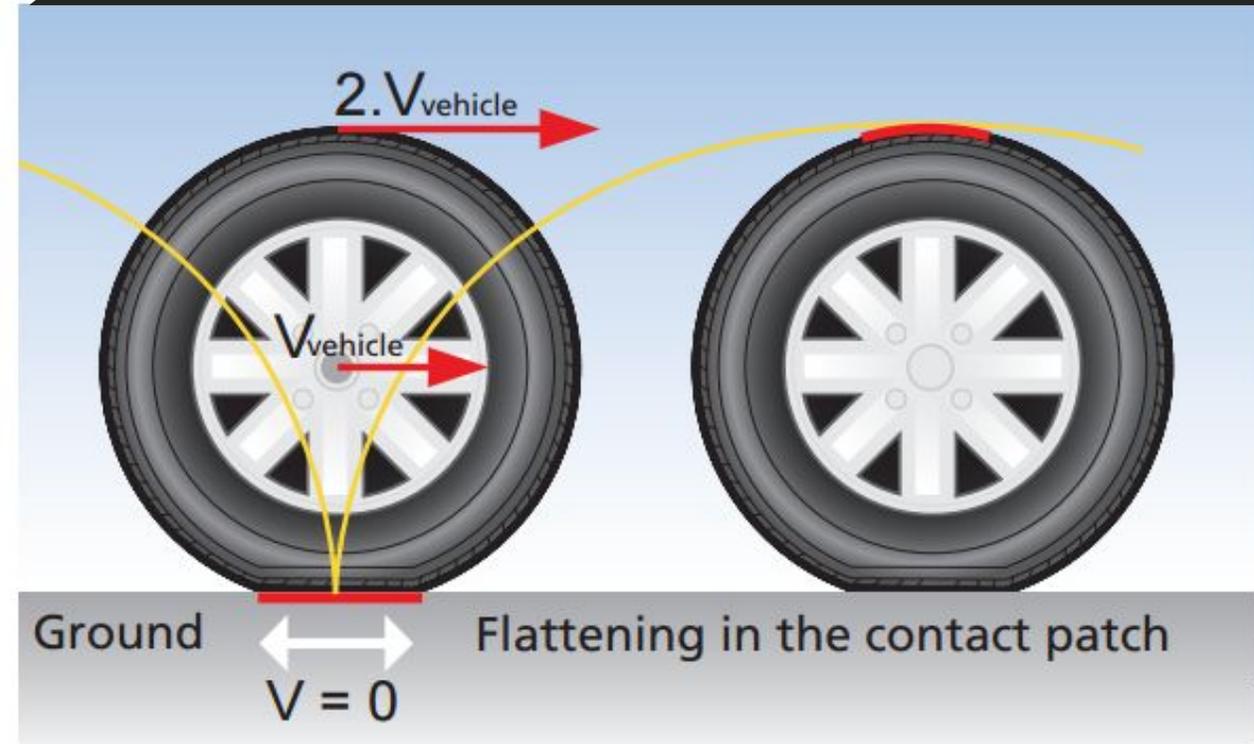**Bibendum**

(aka Michelin Man)

Mascot

Michelin SCA

So, What is Friction?

- Most basically, <u>forces</u> due to <u>energy loss</u> that resist the relative motion between two surfaces – in our case a tire and a pavement.
- Tire-Pavement Friction allows:
  - <u>Traction</u> - the ability to accelerate from a stationary position
  - <u>Steering</u> – a suitable side-force allowing change in direction
  - <u>Braking</u> – the ability to decelerate and stop the vehicle
  - <u>Maintain Position</u> – prevents sliding under external forces (wind, slope, etc.)

The Grip Double Paradox

- Paradox 1 – the contact patch of the tire does not move in relation to the pavement surface (at constant speed).
  - Relative speed (i.e. slip speed) between contact patch and surface is zero
  - Patch continuously replaced as tire rolls
  - Only resistance to movement is rolling resistance at flattened edges

$2.\ V_{vehicle}$

$V_{vehicle}$

Ground

$V = 0$

Flattening in the contact patch
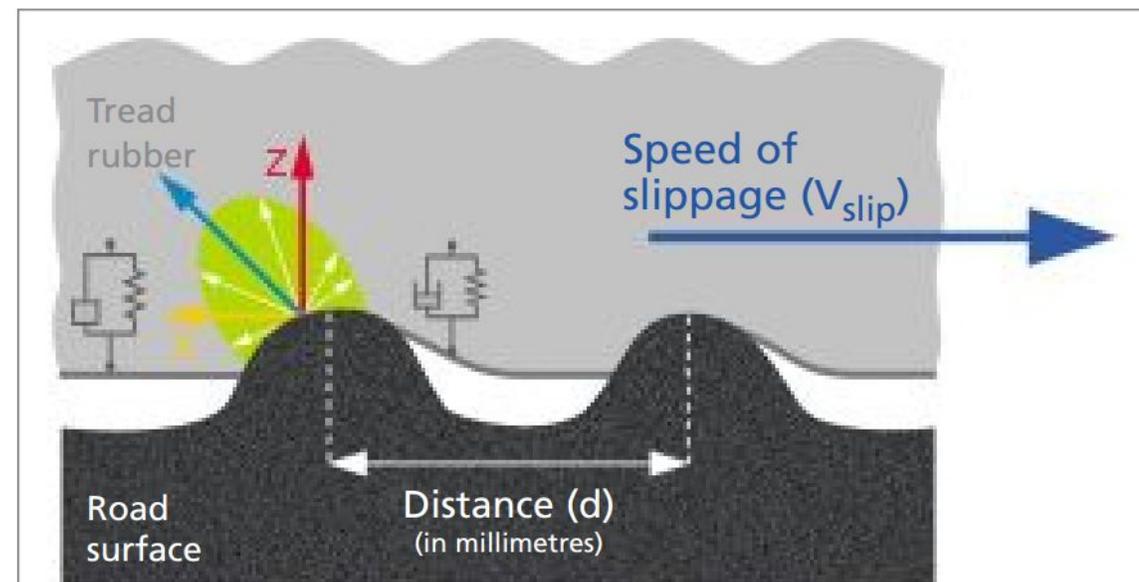
The Grip Double Paradox

- <u>Paradox 2</u> – Grip is generated from Slip!
  - Slippage within the patch occurs only during braking, accelerating or cornering
  - The relative speed of the tire decreases (during braking) with respect to the vehicle speed – generating slippage

$$\text{Slip Ratio} = \frac{V_{vehicle} - V_{tire}}{V_{vehicle}} * 100$$
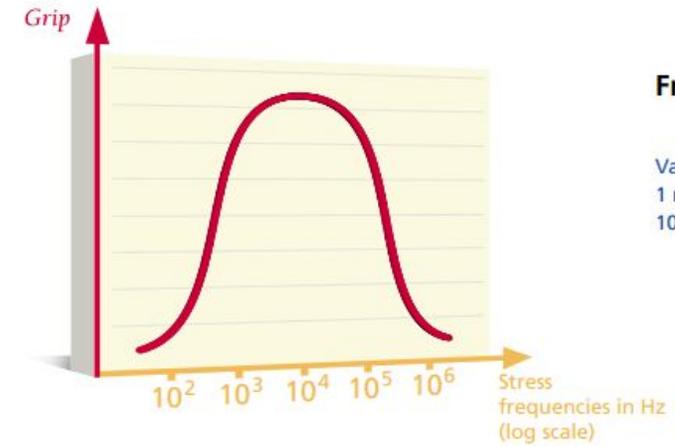
- Slippage results in 2 stress mechanisms

Grip Stress Mechanisms
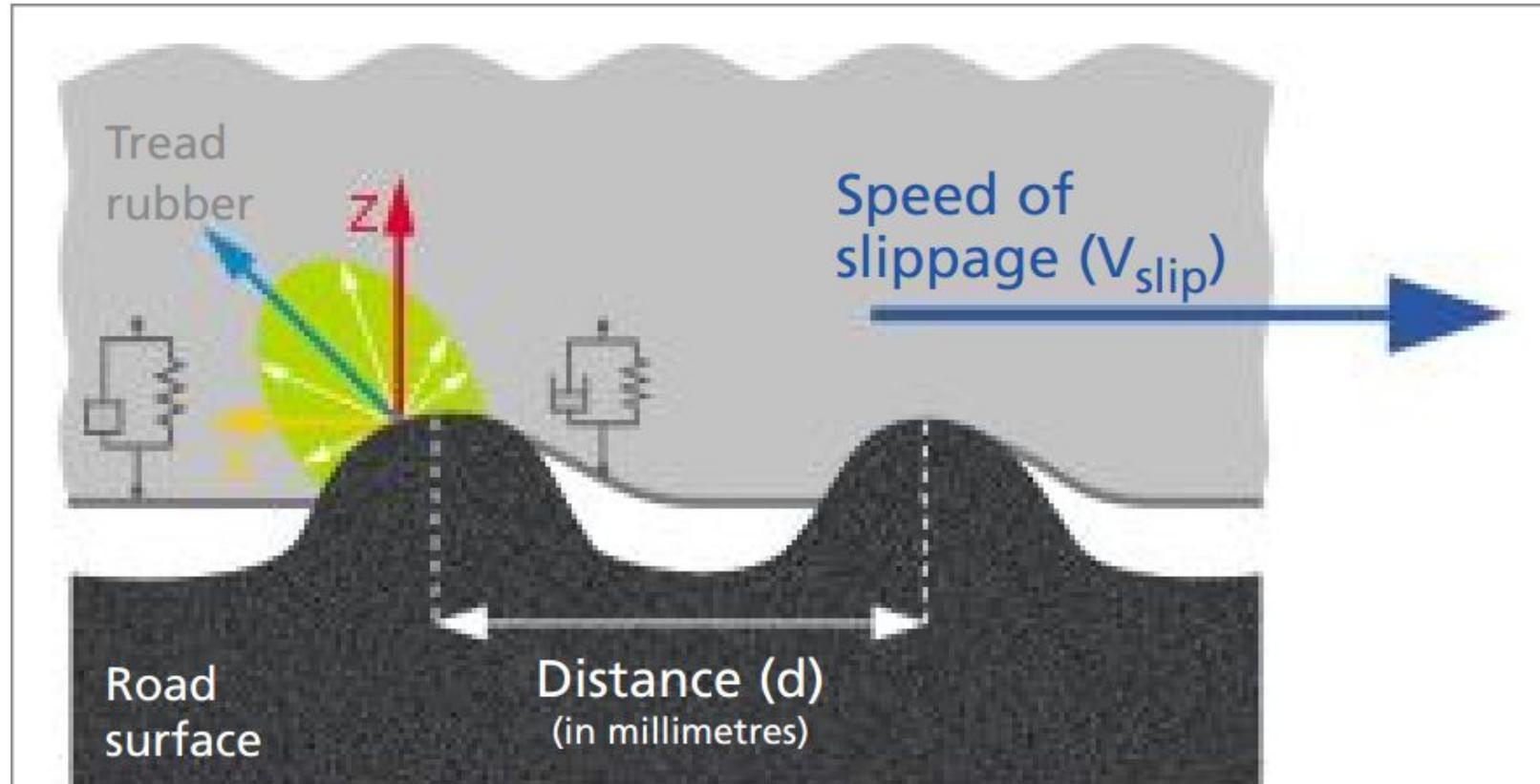
- Distortion / Indentation
  - Rubber distorts as it slips over pavement texture
  - Viscous nature of rubber does not immediately return to its original shape (hysteresis) leading to an energy loss
  - Occurs at micro- and macro-texture ranges (ie. 1 micron to 10 mm)

$$\text{Frequency} = \frac{V_{slip}}{d}$$

Values:
$1 \text{ m/s} < V_{slip} < 5 \text{ m/s}$
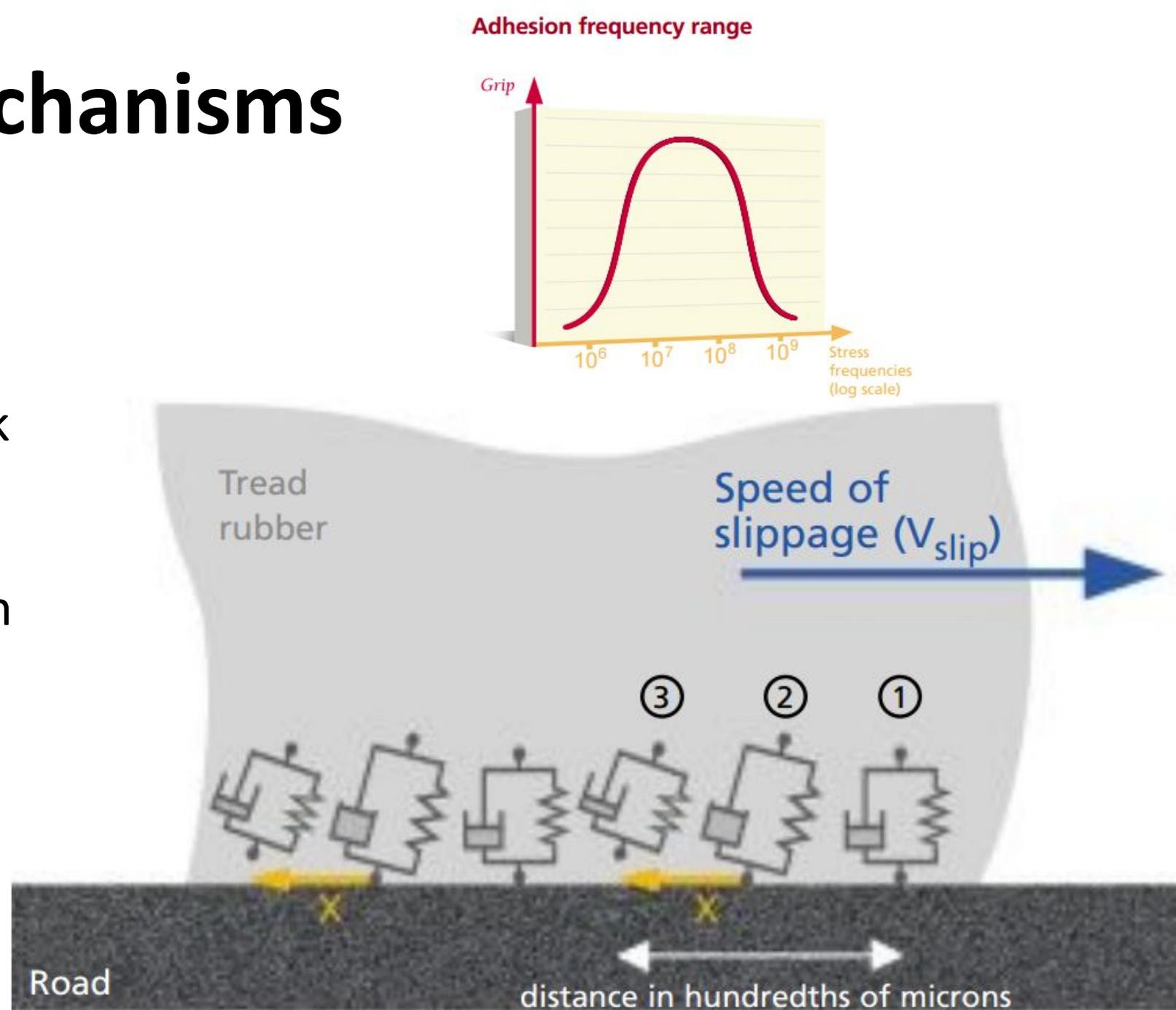$10^{-6} \text{ m} < d < 10^{-2} \text{ m}$

Grip

$10^2 \quad 10^3 \quad 10^4 \quad 10^5 \quad 10^6$ Stress frequencies in Hz (log scale)

Tread rubber

Z

Speed of slippage (V_{slip})

Road surface

Distance (d) (in millimetres)

Grip Stress Mechanisms

- <u>Molecular Adhesion</u>
  - Van der Waals bonds form, stretch, and break resulting in energy loss (visco-elastic work)
  - Work energy varies with speed and tire temperature
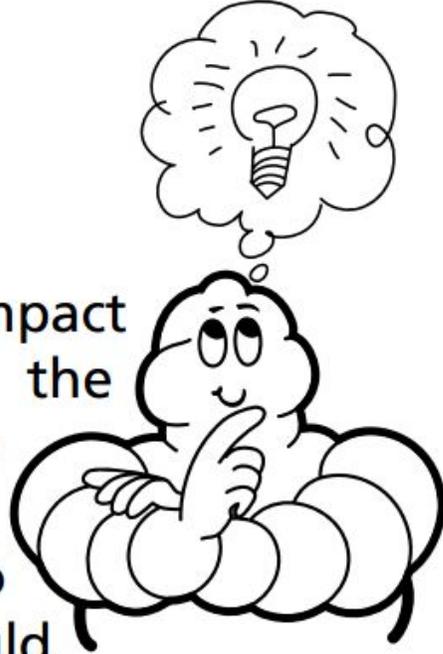 - Requires direct contact with road surface (i.e. no water!)

Adhesion frequency range

Grip

10^6 10^7 10^8 10^9 Stress frequencies (log scale)

Tread rubber

Speed of slippage (V_{slip})

③ ② ①

Road

distance in hundredths of microns

Grip Stress Mechanisms

- Aren't these stress mechanisms occurring at constant speed as well?
- Yes, but…

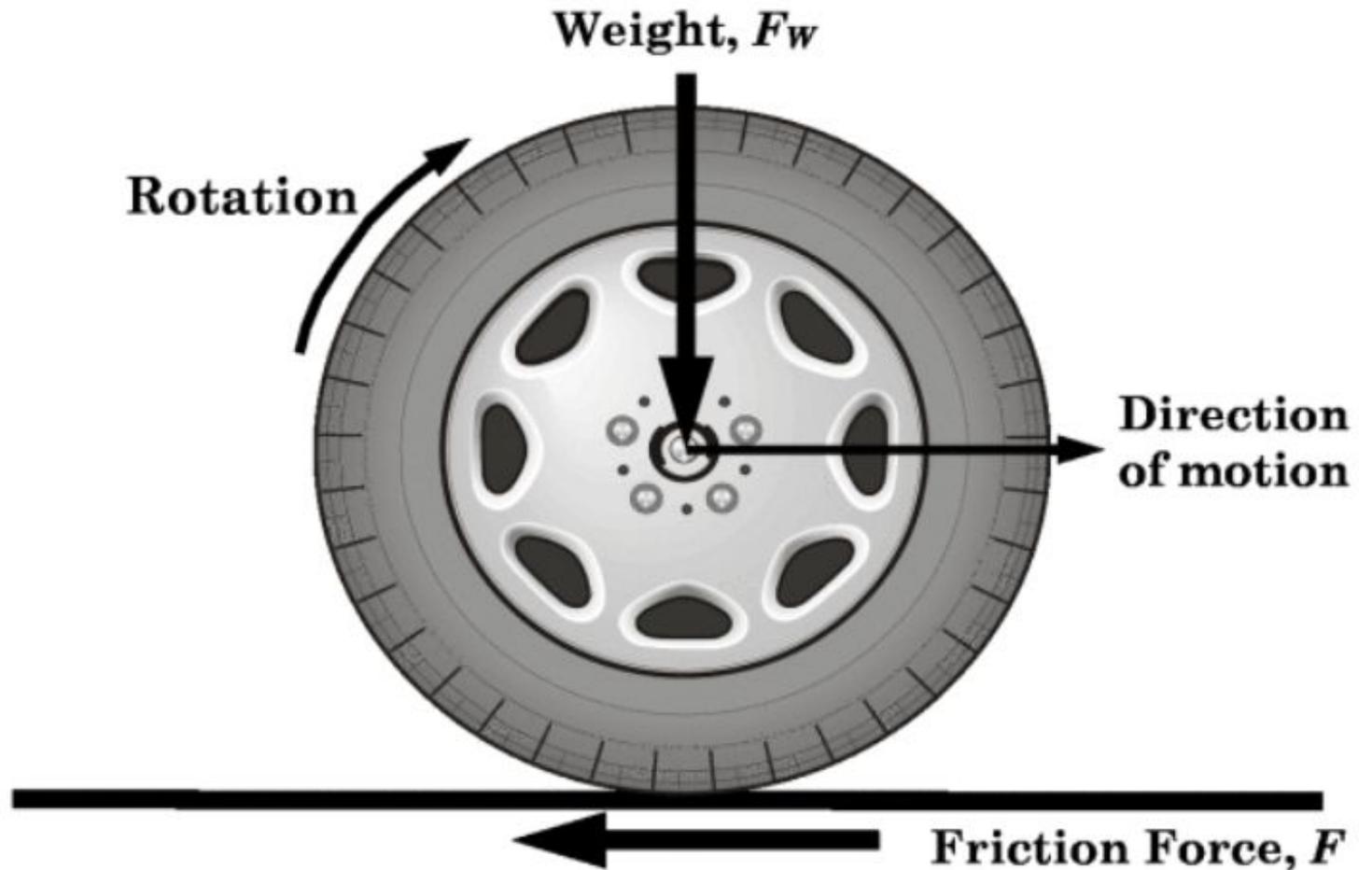**IN ORDER NOT TO SKID, THERE MUST BE MICRO-SLIPPAGE!**

Of all the forces generated upon the impact of the rubber with the road, only the tangential resultant force opposes skidding. If the rubber did not slip over the ground, the forces of reaction to strain and of molecular bonding would not be tangential, but only vertical. Only the onset of slippage can generate forces which oppose skidding.
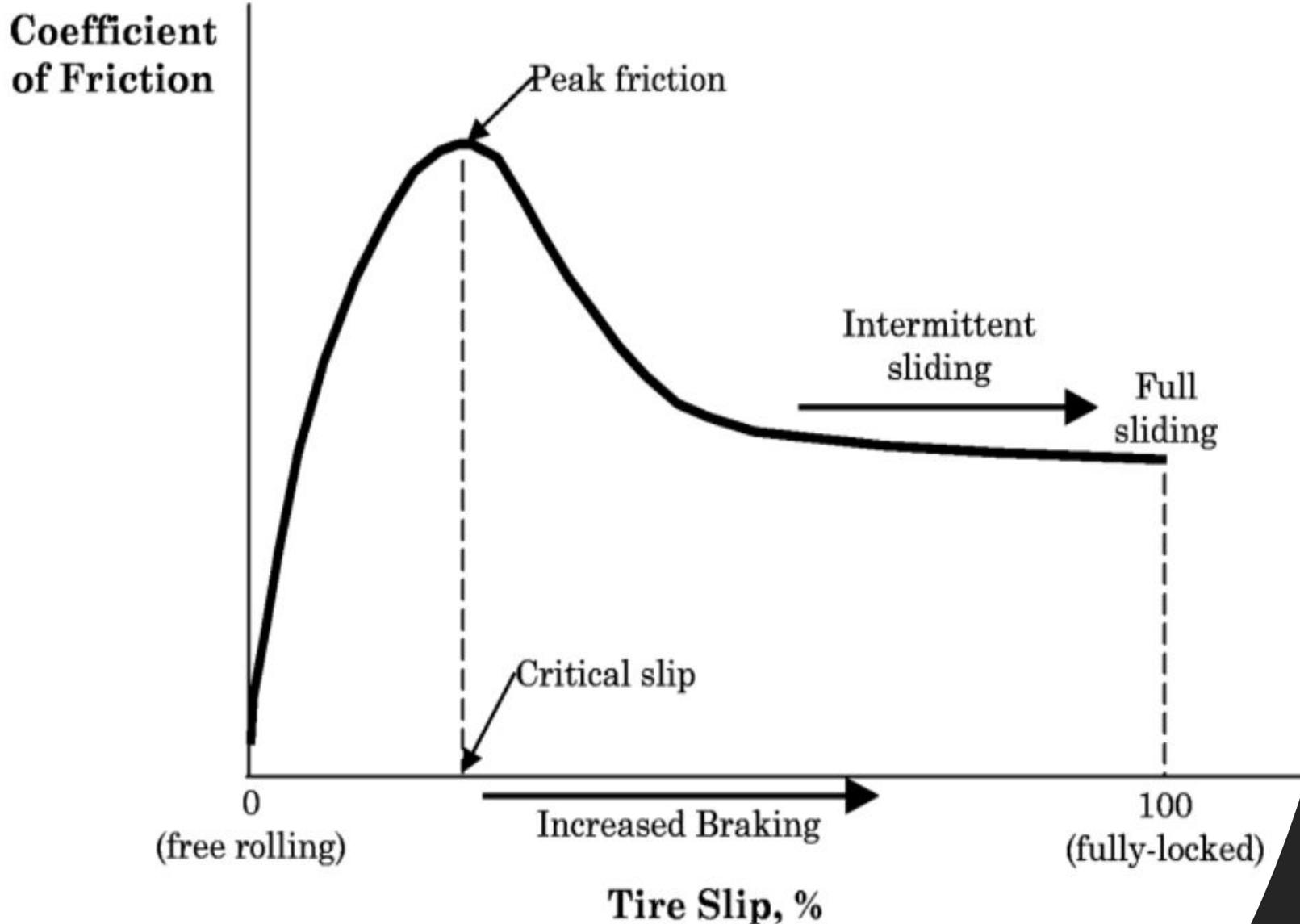
So, how is <u>longitudinal</u> friction quantified?

- Represented by Greek letter mu, µ

- Defined as the ratio of the tangential friction force (F) to the vertical load (Fw) <u>or</u> the deceleration (x) in m/s^2 to gravitational force (g)
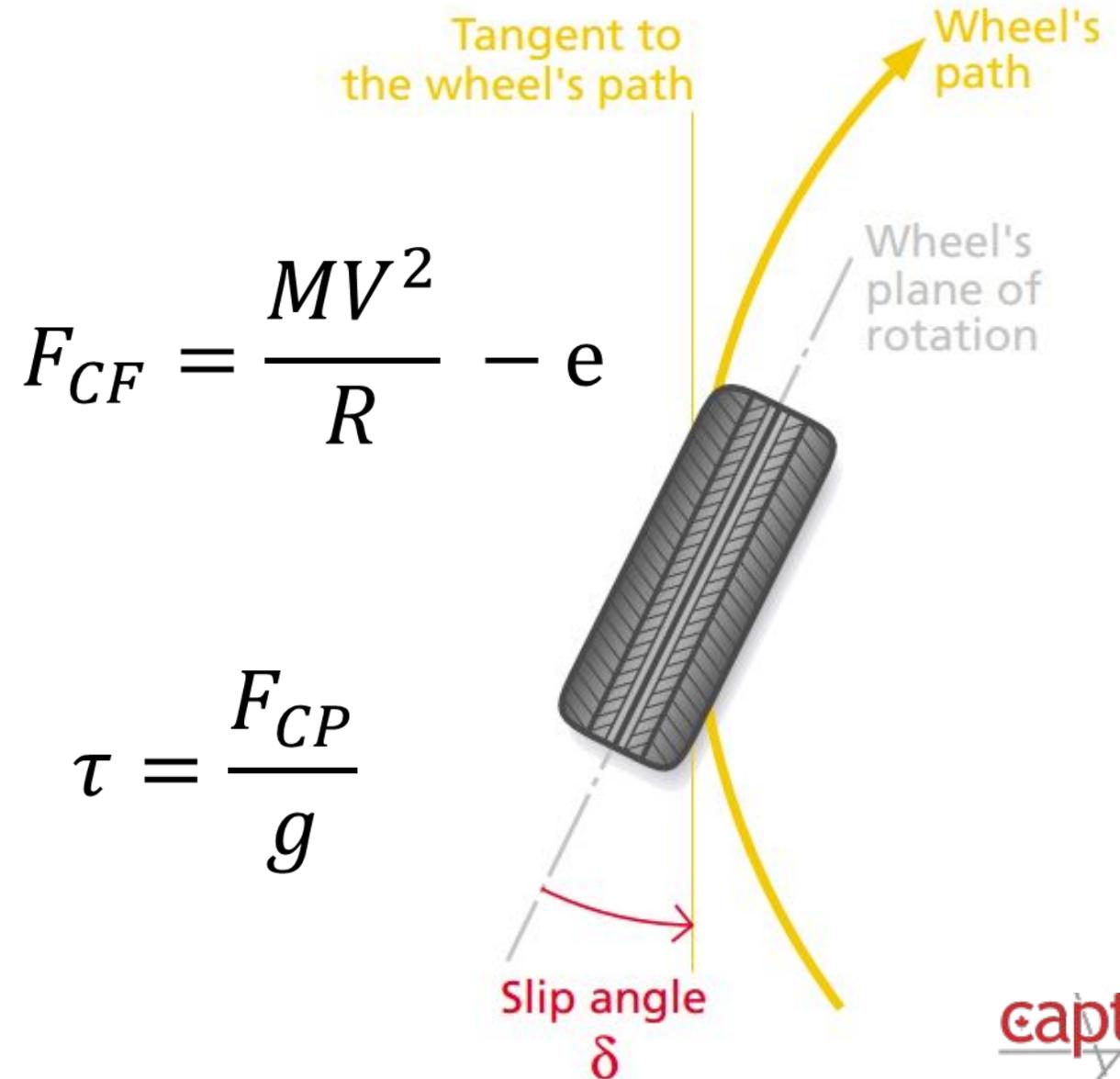
$$\mu = \frac{F}{F_W} = \frac{x}{g}$$

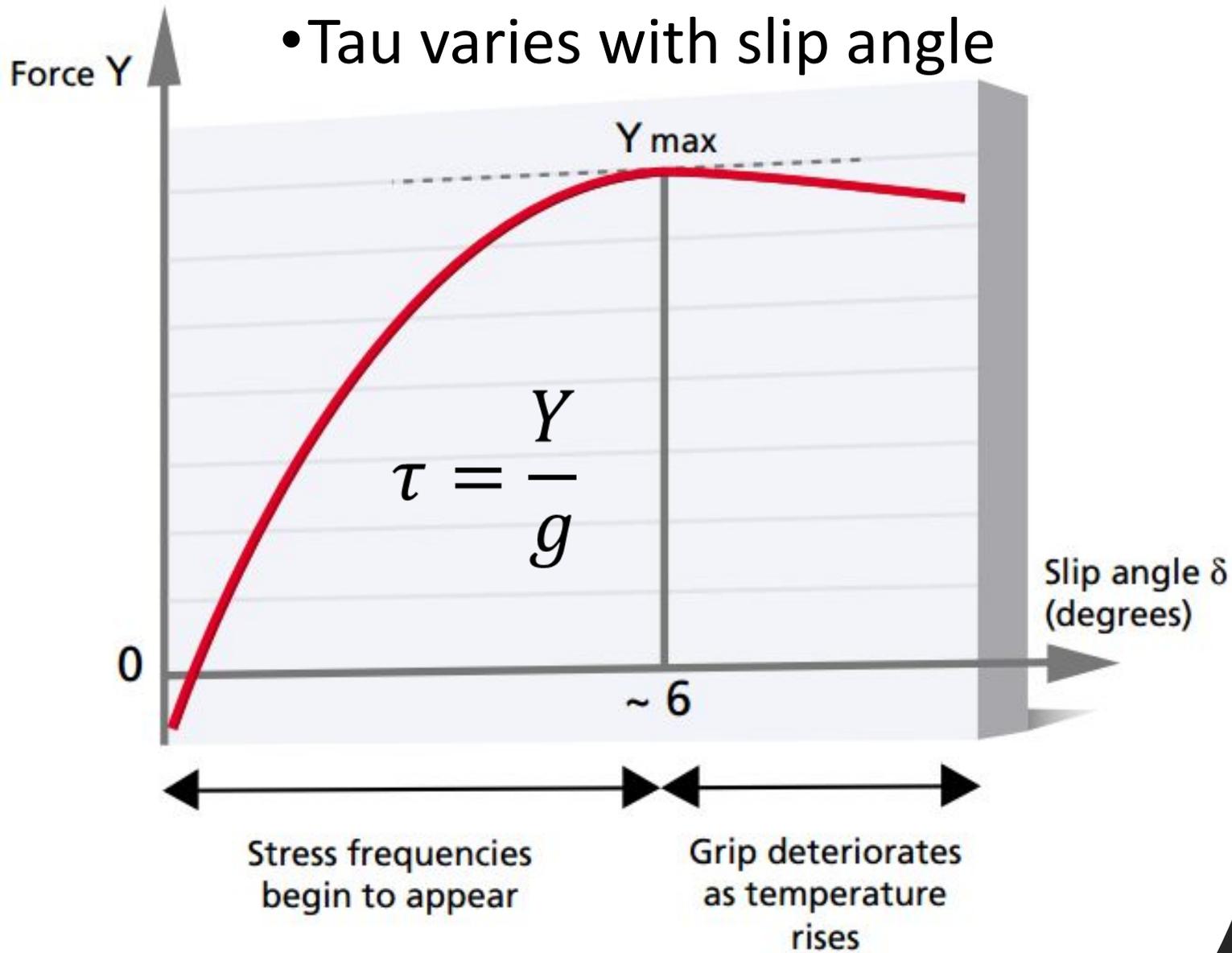# Available Longitudinal Friction varies with Slip

Transverse / Side-Force Friction

- As a vehicle changes direction or compensates for cross-slope or cross-wind, additional Side or Transverse Friction is required.
  - Centrifugal (outward) force on vehicle applied
  - Turning motion (slip angle) generates Centripetal (inward) resistive force by contact patch
    - Proportional to the square of speed
    - Need is reduced as curvature and/or superelevation, e increases

$$F_{CF} = \frac{MV^2}{R} - \text{e}$$

$$\tau = \frac{F_{CP}}{g}$$

Tangent to the wheel's path

Wheel's path

Wheel's plane of rotation

Slip angle
δ

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Transverse / Side-Force Friction

- Tau varies with slip angle

Force Y

Y max

$$\tau = \frac{Y}{g}$$

Slip angle δ (degrees)

0

~ 6

Stress frequencies begin to appear

Grip deteriorates as temperature rises

Combined Longitudinal & Side-Force Friction

$$Grip = \sqrt{\mu^2 + \tau^2}$$

X

μ

Y

τ

Tyre's maximum grip capacity
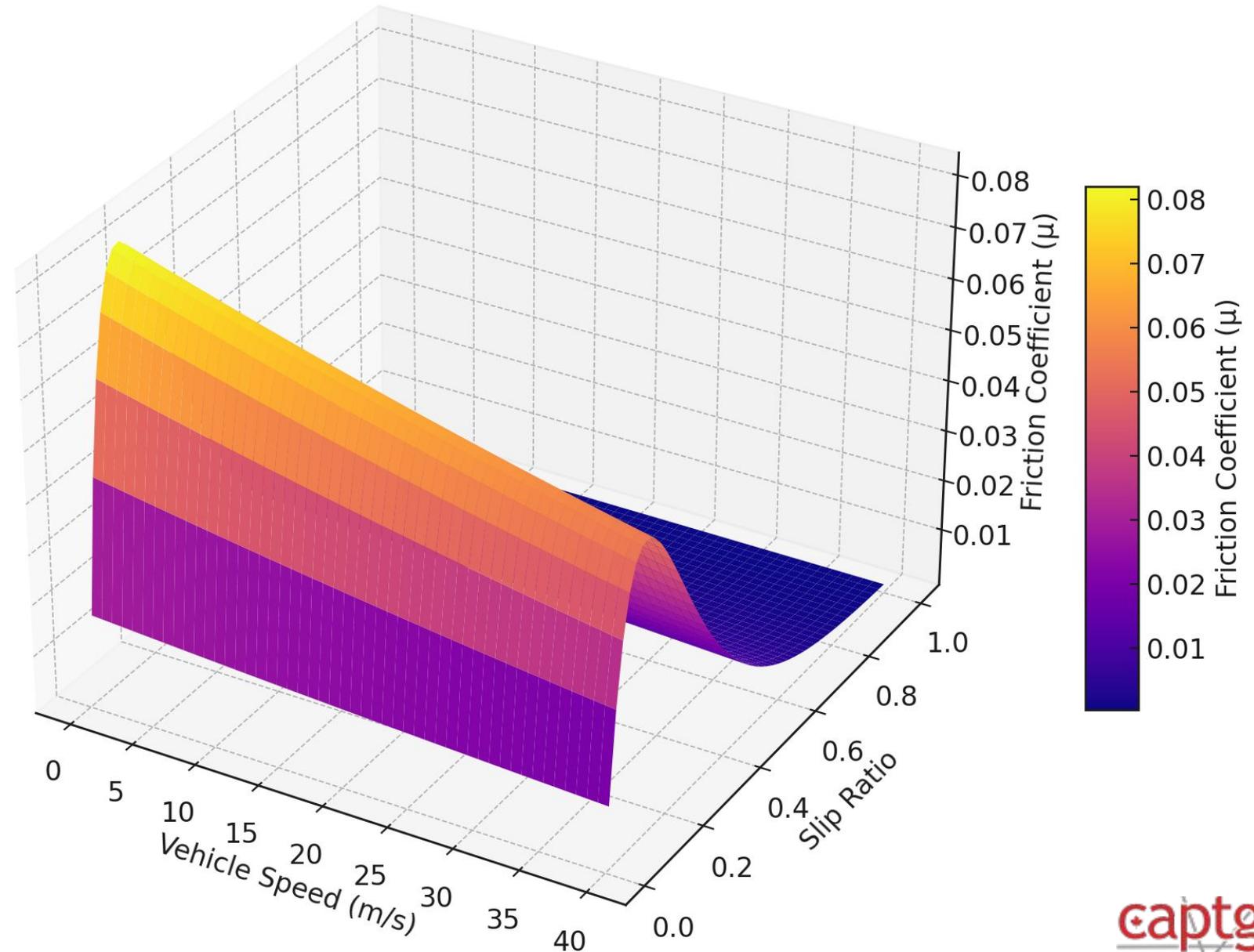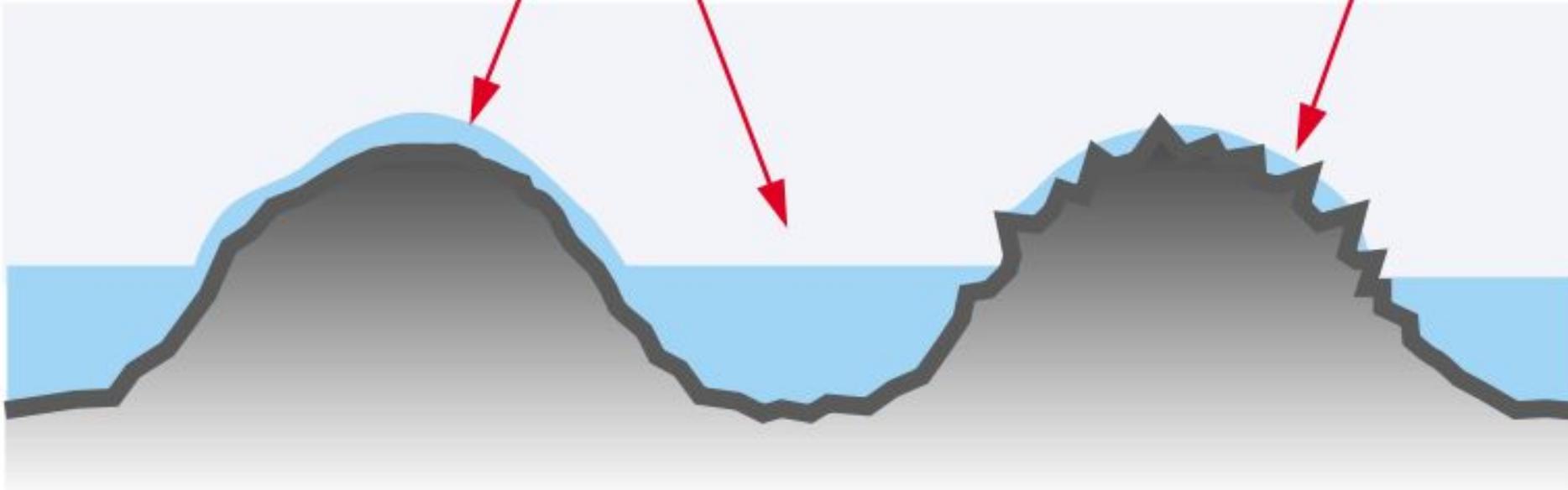
- Only so much combined grip is available!

Vehicle Speed

- Increasing vehicle speed reduces time available for indentation & adhesion,

- Also increases tire temperature

- Friction is reduced

Friction vs. Vehicle Speed and Slip Ratio
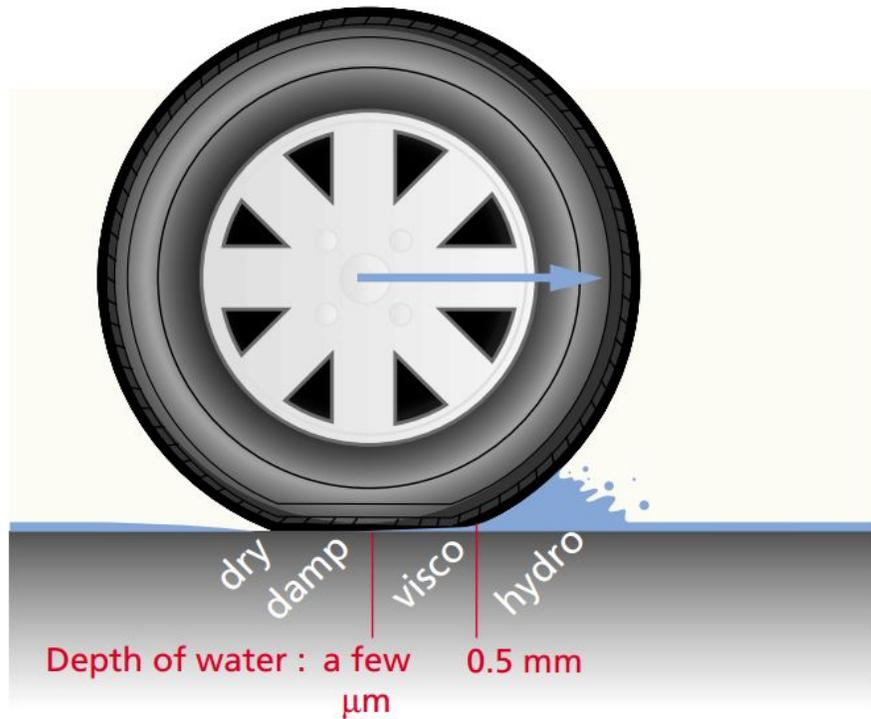
Macroroughness drains and stores water but does not break through the residual film of water

Microroughness, by creating individual high-pressure points between the surface and the tyre, breaks through the film of water

- When it rains, molecular adhesion cannot occur <u>unless</u> the water film is broken by microtexture
- Indentation still occurs via macrotexture <u>unless</u>…

Hydroplaning

$$P = \frac{1}{2}\rho(V\cos\beta)^2$$

Rounded contact patch

Wave front

$\beta > 0$

Depth of water : a few μm   0.5 mm

Water bank build-up zone

Vehicle direction

Tyre on a flooded road. A water bank builds up in front of the tyre, which disperses the water to the side.

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Hydroplaning – Tire Pressure Effect

- Hydroplaning occurs when Hydrodynamic pressure > Tire pressure, so…

EFFECT OF THE INFLATION PRESSURE ON THE AQUAPLANING SPEED

Pressure (bar)	Tyre category*	Speed at which aquaplaning begins** (V_A, in km/h)
1	Car tyre (under-inflated)	50
2	Car tyre (properly inflated)	70
4	Light truck tyre	100
8	Truck tyre	140
16	Commercial aircraft tyre	200
32	Fighter plane tyre	280

* slick tyres
** on bituminous concrete

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Grip / Friction vs. Rolling Resistance

- Both related to energy losses / hysteresis but at <u>different scales</u>

- RR a function of structural distortion of entire contact patch ($\cong$ 10 mm) with low frequency (15 Hz)

- Grip distortion $\cong$ 1 mm with high frequency (10^3 to 10^{10} Hz)

- New materials (silica) allow energy absorption to increase in higher frequencies

- - - - - high hysteresis rubber compound (good grip)
— new generation of compound combining low rolling resistance and good grip
- - - - - low hysteresis rubber compound (low rolling resistance)

Texture Scales of Influence

Texture Measurement Equipment

- Volumetric Technique
  - Sand Patch Test (ASTM E965)
- Flow Techniques
  - Outflow Meter
- Laser Profilers – Mean Profile Depth (MPD) to ASTM 1845
  - Circular Track Meter
  - ELAtextur
  - AMES
  - WDM TM2
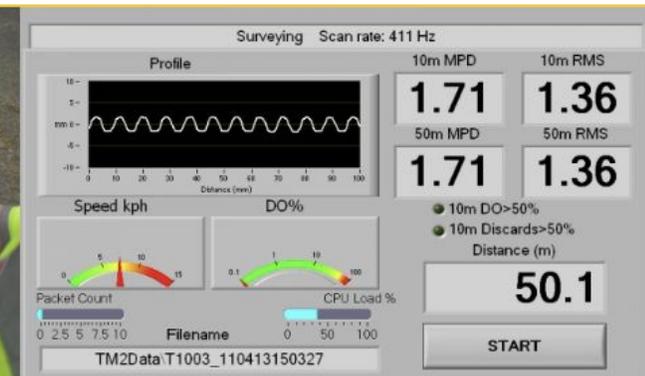 - High speed laser systems

Friction Measurement Equipment

- Locked Wheel (ASTM E 274)
  - Only tests 59 feet when travelling at 40 mph
  - Cannot be used in curves

- Side-Force (ASTM E 670)
  - Sideway-force Coefficient Routine Investigation Machine (SCRIM)
  - Continuous measurement at 100 mm intervals
  - Can be used in all pavement geometries

- Fixed Slip
  - Saab Friction Testers, T2Go, Griptester, British Pendulum
  - Continuous measurement (not BPT) over all geometries

- Variable Slip
  - Runar, Dynamic Friction Tester (DFT)
  - Provide entire friction-slip curve

Sarsys T2Go Continuous Portable Friction Tester

- Continuous Friction Device

- Fixed Slip of 20 percent

- Walking speed with readings @ 30mm intervals

- Water backpack

- Integral GPS, Temp & Humidity

- Phone interface

- Road markings, crosswalks, pathways, intersections, indoors

International Friction Index (IFI)

- Numerous friction measurement devices result in different friction values
- International Friction Experiment sponsored by PIARC in 1992 to develop a method of comparing devices
  - 47 measuring systems measuring 34 friction parameters and 33 texture parameters
  - 54 test sites
- ASTM E1960 International Friction Index (IFI) includes:
  - F60 the harmonized "Golden" friction estimate at 60 km/hr
  - Sp is the speed constant related to texture

$$IFI(F60, S_P)$$

Current Requirements

Standard	Runway Pavement Friction	Runway Texture	
FAA	0.50 Minimum 0.60 Maintenance Planning 0.82 New Construction	< 0.25 mm 0.40 to 0.76 mm 0.76 to 1.14 1.14 mm	(Correct < 2 months) (Correct < 1 year) (Monitor) (New Construction)
ICAO	Circular 355 Friction values "Agreed to by the State"	Class A: 0.10 to 0.14 mm Class B: 0.15 to 0.24 mm Class C: 0.25 to 0.50 mm Class D: 0.51 to 1.00 mm Class E: 1.01 to 2.54 mm	
Transport Canada	< 0.50 (Average for Entire Runway) < 0.30 (100-metre section)	No Requirements for HMA Surface Finishing for PCC	

Why Doesn't TC Have Texture Requirements?

- In <u>new HMA</u>
  - In Canada, dense-graded HMA historically required for durability, but…
  - …Dense-graded HMA provides little initial macrotexture
  - "Static" drainage primarily from crossfall of runway
  - "Dynamic" drainage primarily from aircraft tire tread

- In <u>new PCC</u>
  - Simply assumed that PCC requires tining/grooving

What Provides Texture?

- In <u>new PCC</u>
  - Microtexture & polish resistance generally from <u>fine</u> aggregates (i.e. sand)
  - Macrotexture must be <u>imposed</u>
    - Tining during construction or Grooving/Grinding after construction
- In <u>new HMA</u>
  - Microtexture & polish resistance generally from the <u>coarse</u> aggregates
  - Macrotexture comes from coarse aggregate size & gradation
- Texture Restoration
  - Shot and Water Blasting (possible pre-treatment with chemicals for RR)
  - Grooving & Grinding
- Surface Treatments
  - Microsurfacing, Slurry Seals, HFST
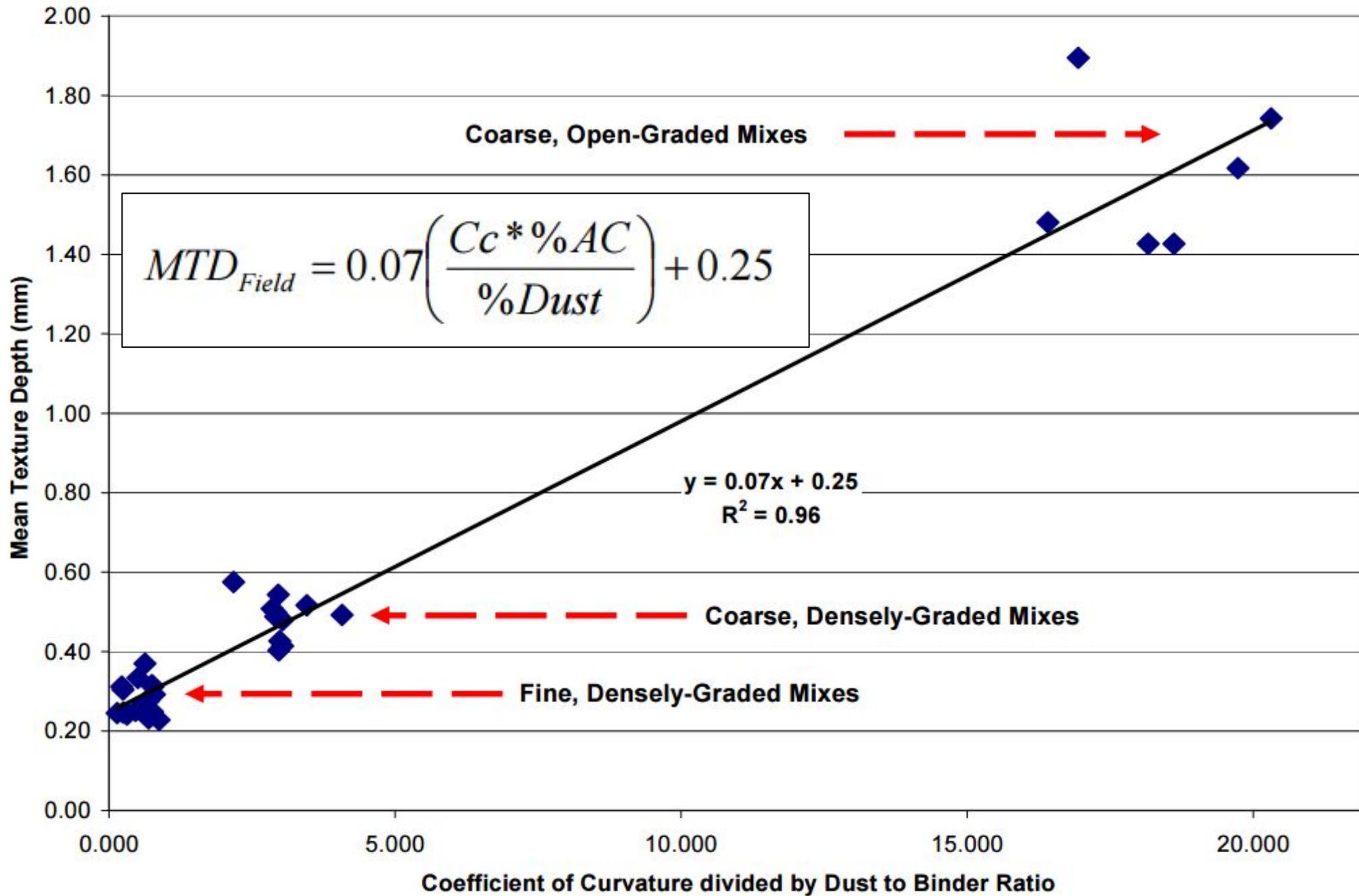
Realities of Dense-Graded HMA

- 12.5 mm NMAS dense-graded Hot Mix Asphalt (HMA)
  - Fine-graded: MTD = 0.24 to 0.30 mm
  - Coarse-graded: MTD = 0.40 to 0.60 mm
- Dense-graded 12.5 mm NMAS mixtures <u>CANNOT</u> meet FAA texture requirements without additional grooving, grinding, or blasting
  - Some ICAO levels are possible (Classes A, B, and C)
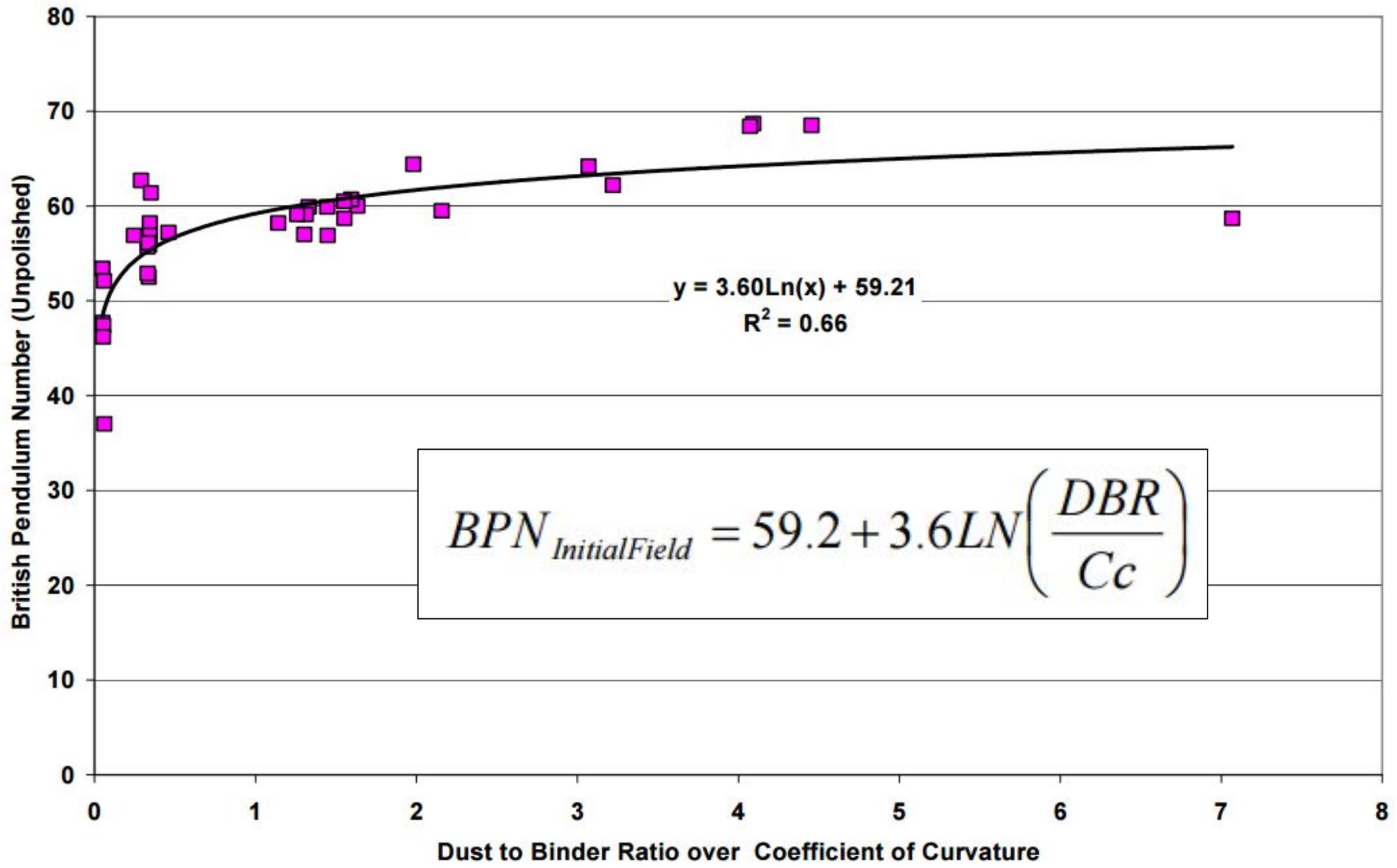- Possible to assess macrotexture at mix design stage and

From Conventional to Innovative

Laboratory Mix Design Assessment

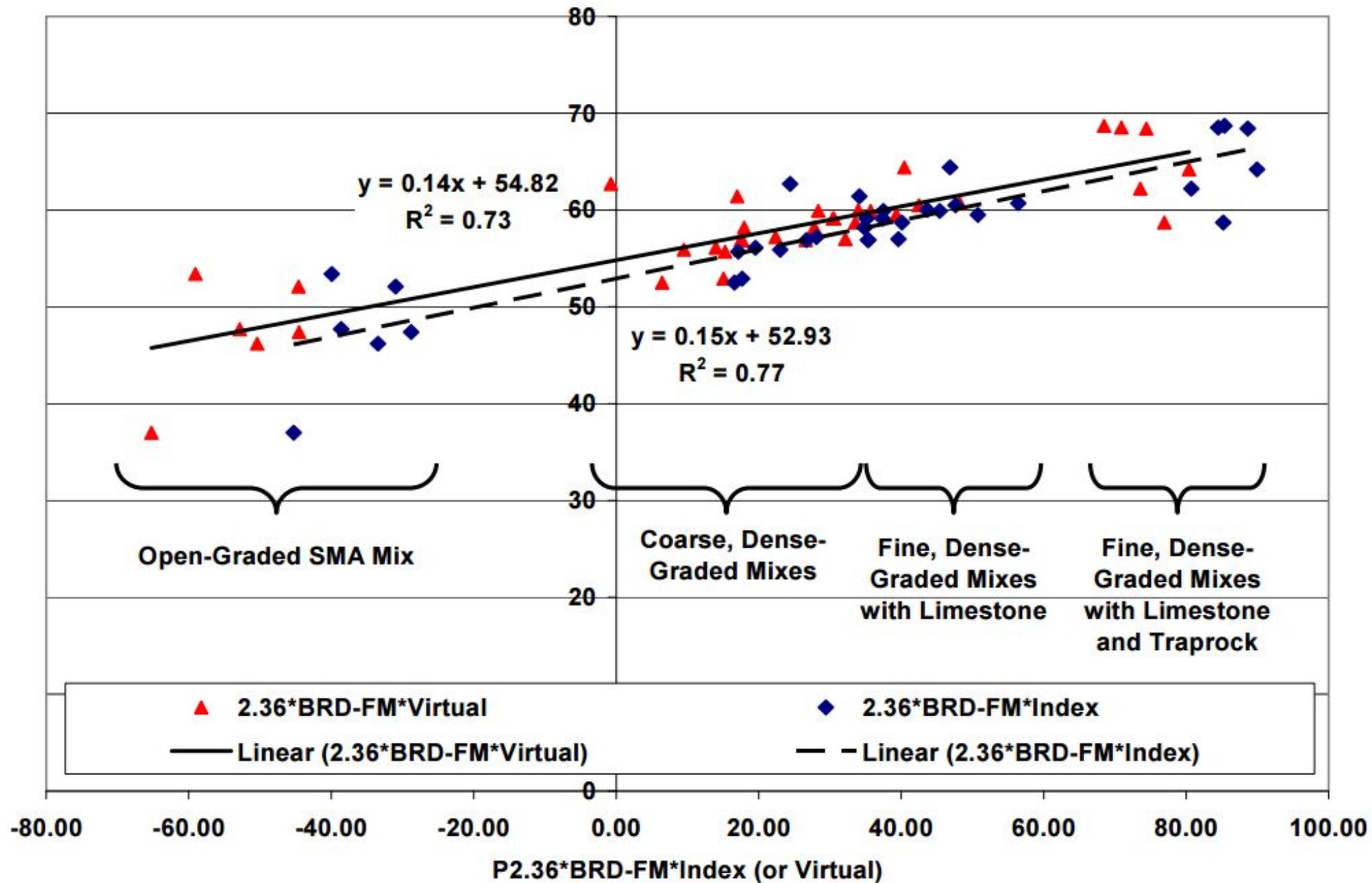- Test Superpave Gyratory specimen <u>macrotexture</u> during mix design
  - <u>Top</u> of gyratory specimen best correlated with core MTD
  - Gyratory specimens (150 mm diameter) large enough for laser MPD testing with ELAtextur or sand patch
- Test Superpave Gyratory specimen <u>friction</u> during mix design
  - Gyratory specimens (150 mm diameter) large enough for British Pendulum Testing

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$$MTD_{Field} = 0.07\left(\frac{Cc * \%AC}{\%Dust}\right) + 0.25$$

Coarse, Open-Graded Mixes

$y = 0.07x + 0.25$
$R^2 = 0.96$

Coarse, Densely-Graded Mixes

Fine, Densely-Graded Mixes

Mean Texture Depth (mm)

Coefficient of Curvature divided by Dust to Binder Ratio

$$BPN_{InitialField} = 59.2 + 3.6 LN\left(\frac{DBR}{Cc}\right)$$

Figure — Scatter plot of Initial British Pendulum Number versus P2.36*BRD-FM*Index (or Virtual)

$$y = 0.14x + 54.82$$
$$R^2 = 0.73$$

$$y = 0.15x + 52.93$$
$$R^2 = 0.77$$

Open-Graded SMA Mix

Coarse, Dense-Graded Mixes

Fine, Dense-Graded Mixes with Limestone

Fine, Dense-Graded Mixes with Limestone and Traprock

Legend:
- ▲ 2.36*BRD-FM*Virtual
- ◆ 2.36*BRD-FM*Index
- Linear (2.36*BRD-FM*Virtual)
- Linear (2.36*BRD-FM*Index)

Y-axis: Initial British Pendulum Number

X-axis: P2.36*BRD-FM*Index (or Virtual)
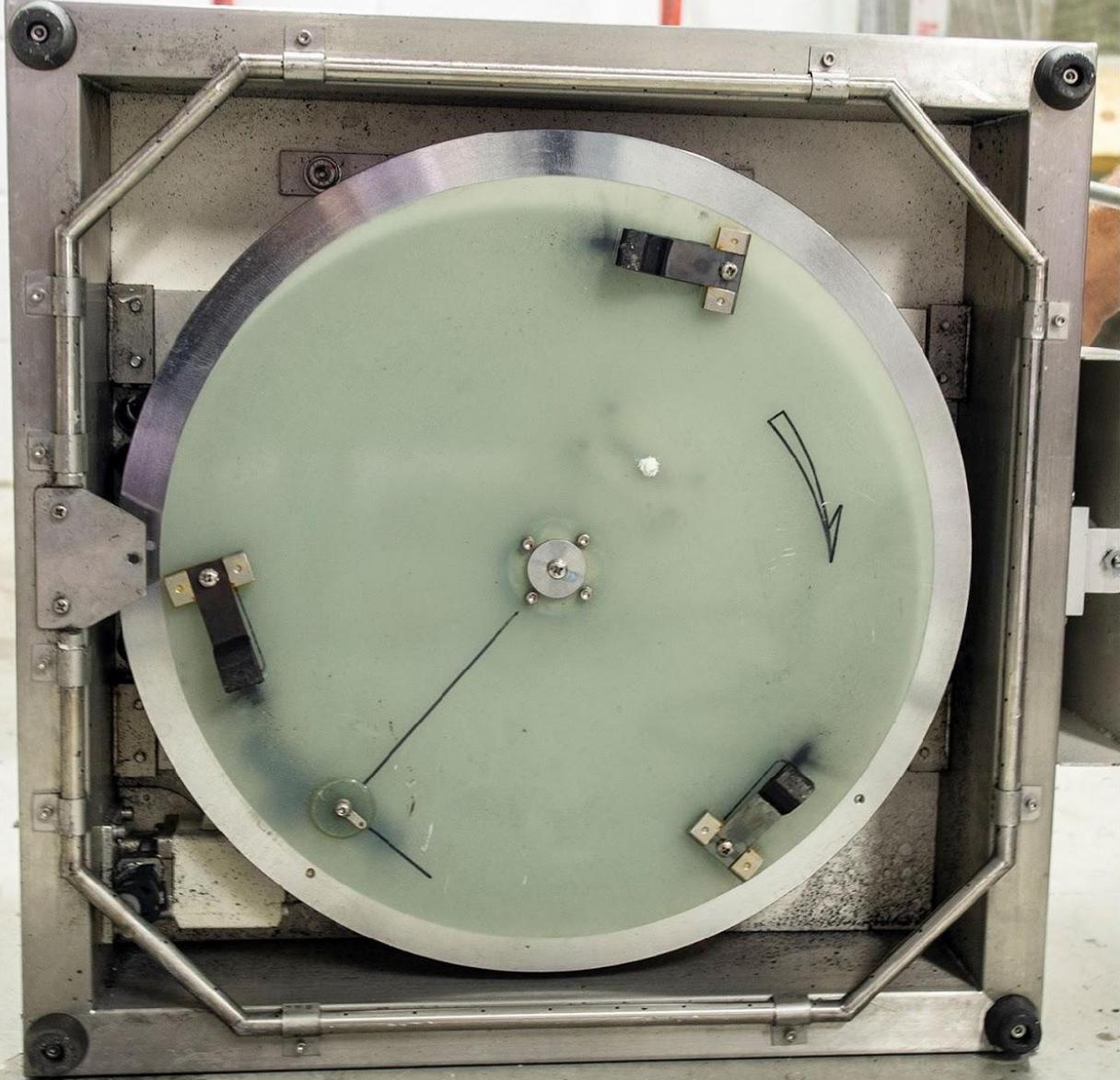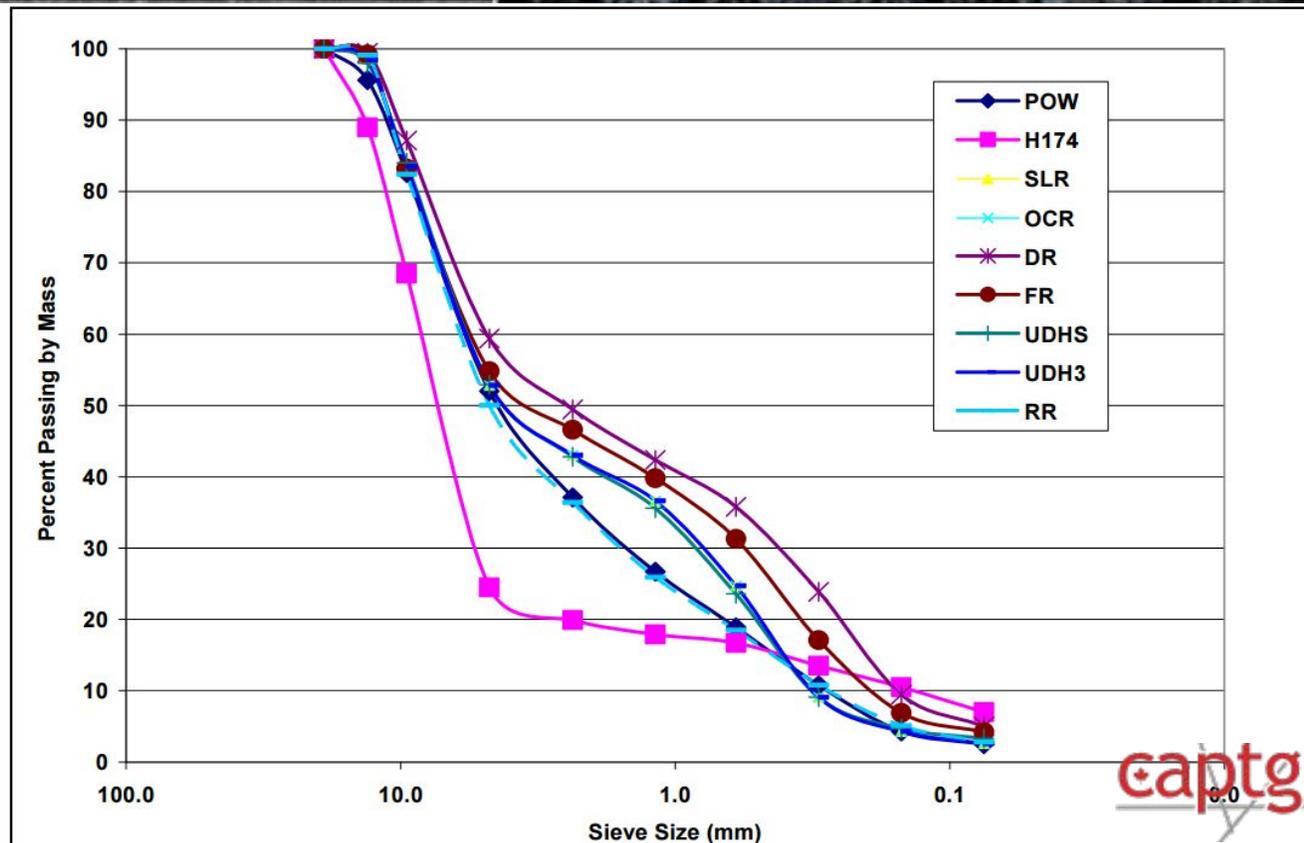
New Equipment

Next Generation

Current Research…

- Use of photogrammetry, laser scanning, digital imaging, etc. to generate surfaces for FEM

- Hysteresis models

- Environmental and contaminant modelling

- AI and machine learning for large datasets

- Groove geometry

- RAP/RAS in airport mixtures

- **Stone Mastic Asphalt (SMA)**

- **High Friction Thin Overlays / HFST**

- As-placed dense-graded mixes cannot meet FAA texture requirements

- SMA is gap-graded but also has high binder content (>5.8%) for durability (fibres)

- MTD = 1.60 mm for 12.5 mm SMA, so no grooving required

SMA Findings…

- NCAT Report AAPTP 04-04 (2009/10)
  - As-placed MTD values of 1.30 mm (9.5mm NMAS)
  - Lower initial friction, but greater than required
  - Friction increases as film thickness removed
  - Friction maintained over service life
  - *"SMA offers equal rutting performance and improved resistance to cracking, moisture damage, and fuel spills when compared to conventional mixes"*

High Friction Surface Treatment

- Calcined Bauxite aggregate embedded in epoxy resin (chip seal)

- Single-sized aggregates provide excellent macrotexture and polish resistance (highest PSV)

- Epoxy service life 7-12 years

- Reduces wet road accidents by 85%

- No domestic sources of C-B aggregates costly

- Alternative aggregates being researched

- FOD concern? Micro-surfacing likely a better option

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Questions?