Which scale of the pavement texture to capture to predict its skid resistance?

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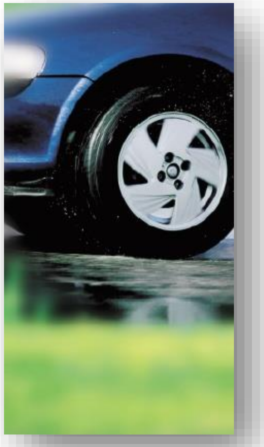
Skid Resistance ?

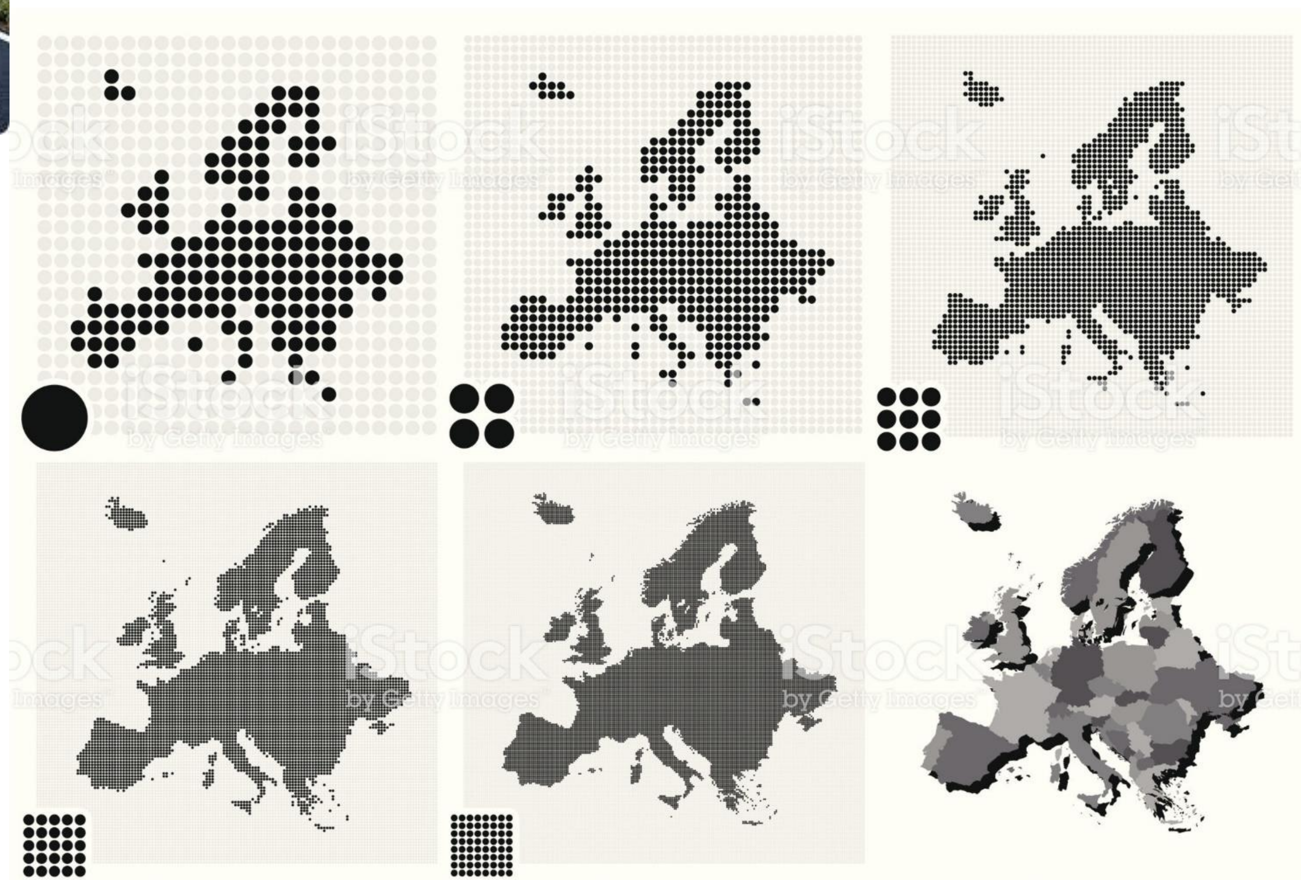
Skid Resistance ?

- Modeling SR, for what?
  - Optimize the surface texture of roads
  - Choose of materials
  - Predict the period of renewal
  - SR onboard for assistance of the safety systems (autonomous cars and metros…)
  - …
- Influent factors
  - Tire (materials, geometry…)
  - Operating conditions (Load, speed, slip ratio…)
  - Contaminants (Water, dust…)
  - **Texture** (Macrotexture, Macrotexture, aggregate types…)
  - …

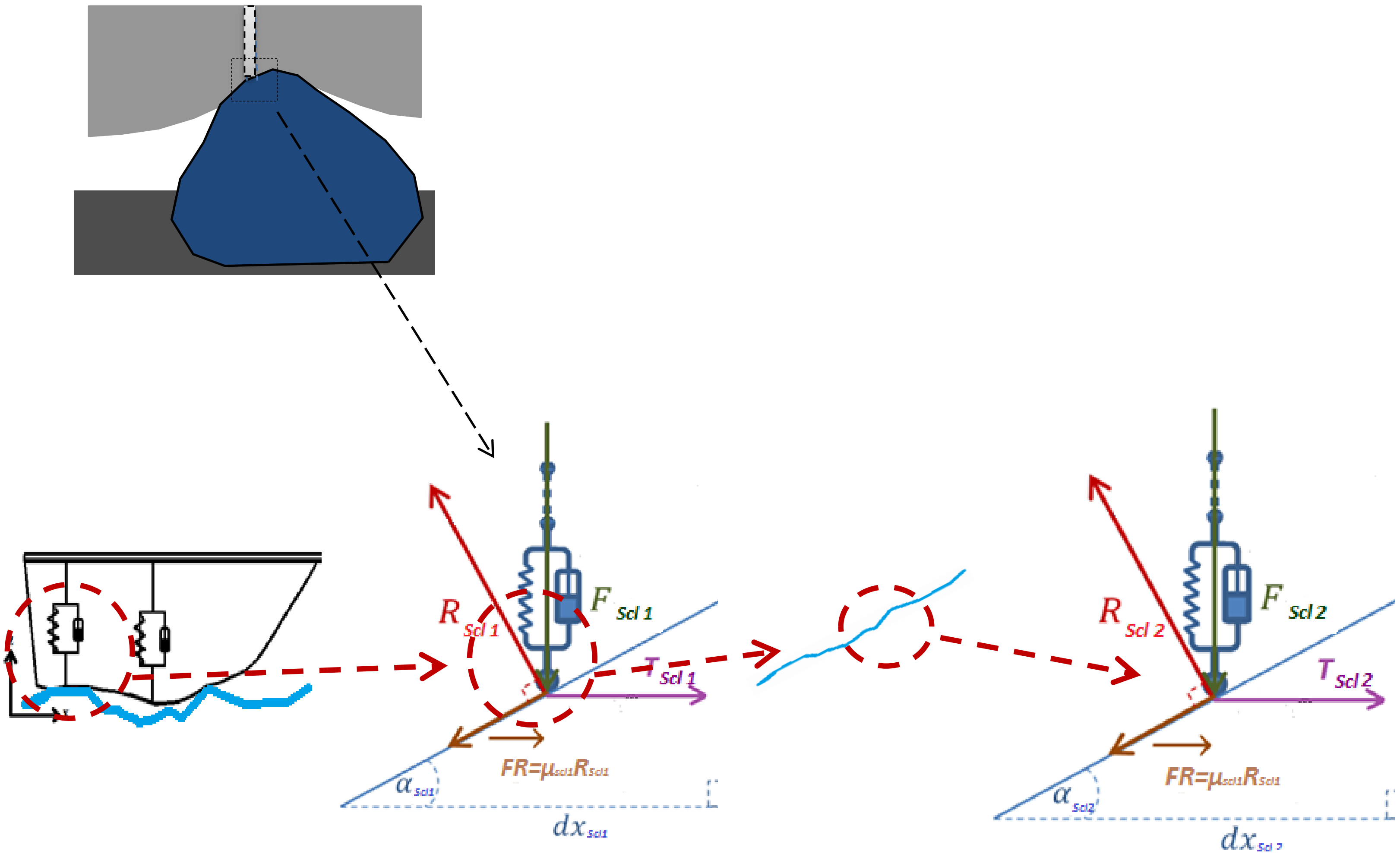


Texture scale?

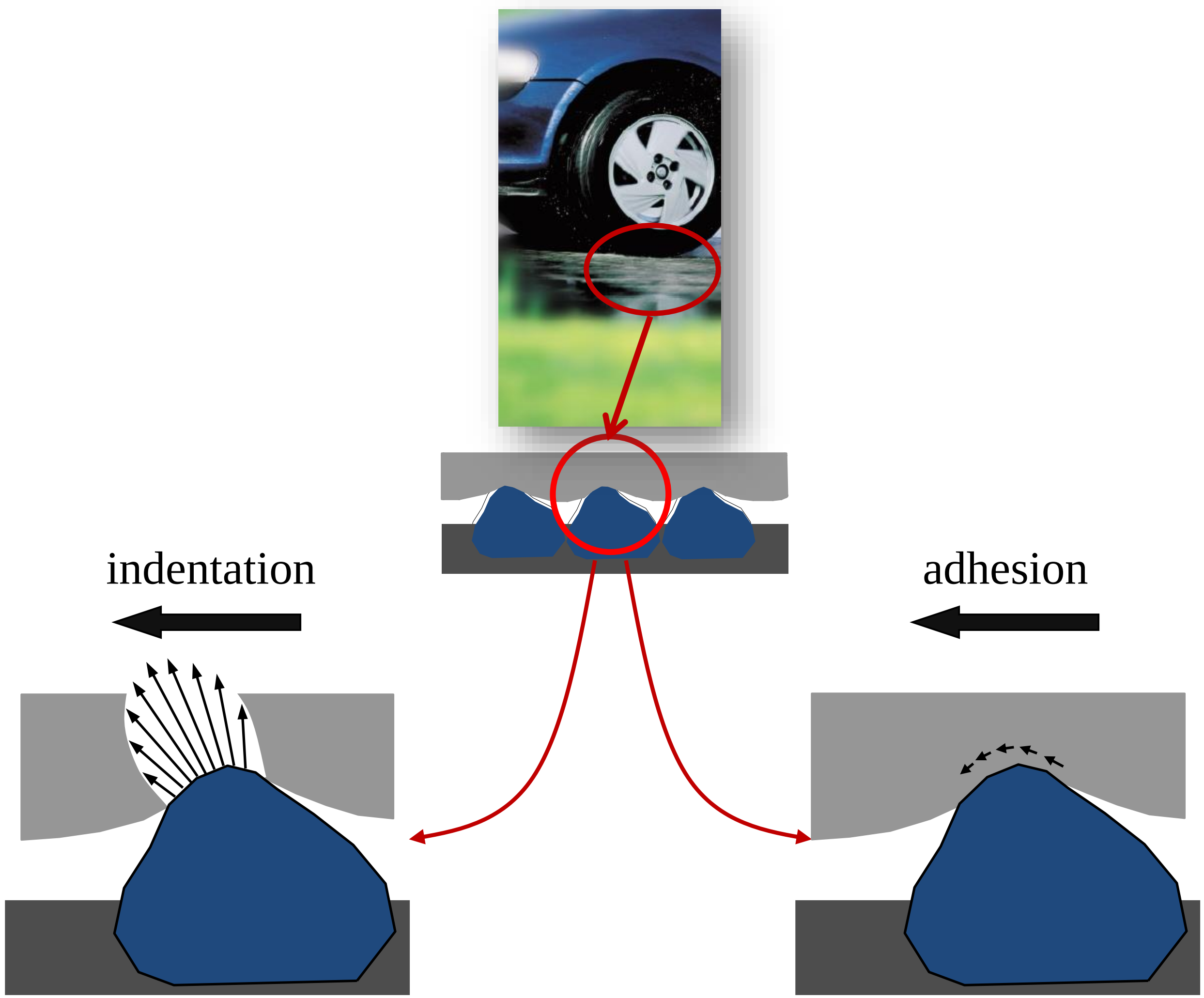
Small scale means
- Expensive
- Difficult …
- Etc…



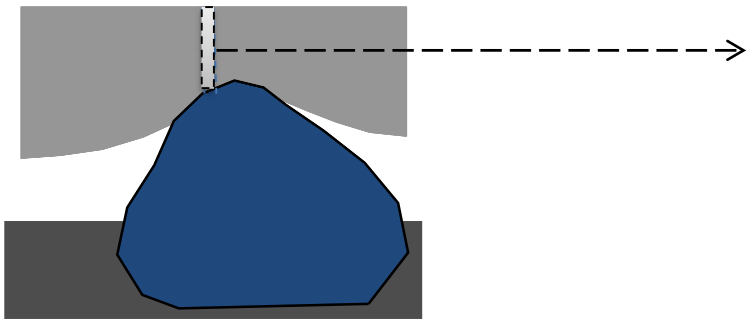
Basic Mechanisms

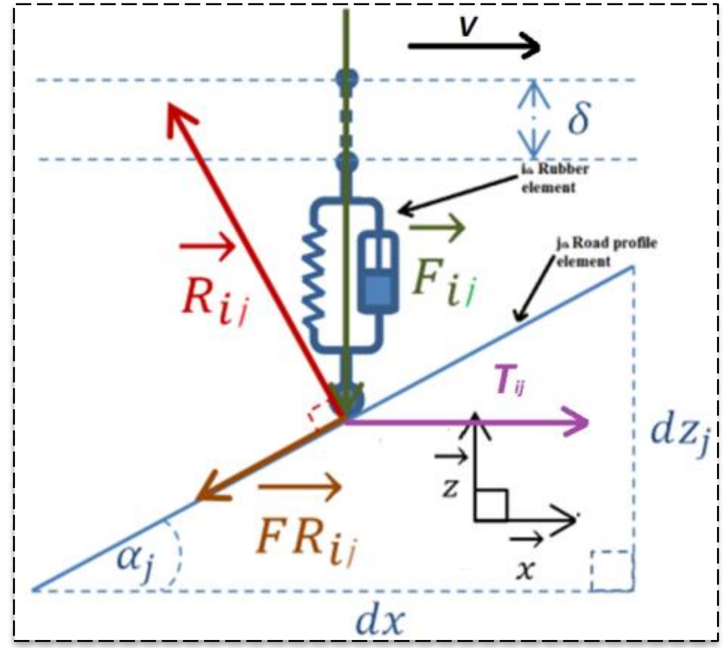


Basic Mechanisms



Basic Mechanisms





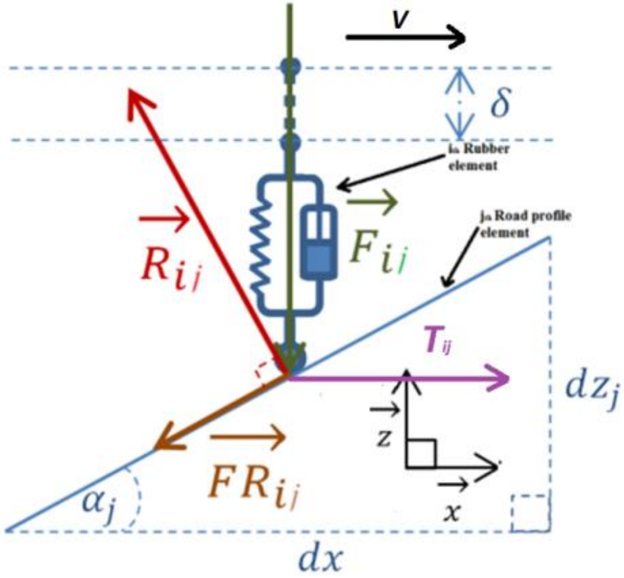
$\overrightarrow{F_{ij}}$ is the force applied by the element on the road surface.

$\overrightarrow{T_{ij}}$ is the traction force needed to move the element. This force must be just greater than the global friction force opposing against that movement ($T_{ij} \geq FF_{ij}$ where FF_{ij} is the friction force).

$\overrightarrow{R_{ij}}$ is the surface reaction.

$\overrightarrow{FR_{ij}}$ is a local friction force.

Basic Equations



- $\overrightarrow{F_{ij}} + \overrightarrow{T_{ij}} + \overrightarrow{R_{ij}} + \overrightarrow{FR_{ij}} = \vec{0}$
- $\overrightarrow{FR_{ij}} = \mu_{loc} \overrightarrow{R_{ij}}$

where μ_{loc} represents a friction coefficient of two different contributions:

– an adhesive contribution due to the molecular bonding of the two contacting surfaces. It may be close to zero or even nil when the contact is wet.

– a local hysteretic contribution of all texture scales smaller than the resolution with which the profile is recorded

Basic Equations

Projection onto axes *x* and *z* leads respectively to the system of two equations below:

- $$\begin{cases} -F_{ij} + R_{ij}cos(\alpha_j) - FR_{ij}sin(\alpha_j) = 0 \\ T_{ij} - R_{ij}sin(\alpha_j) - FR_{ij}cos(\alpha_j) = 0 \end{cases}$$

Their combinations coupled the condition of $\overrightarrow{\mathrm{FR}_{\mathrm{ij}}} = \mu_{\mathrm{loc}} \overrightarrow{\mathrm{R}_{\mathrm{ij}}}$ conduct to following:

- $$\boldsymbol{T_{ij}(t) = F_{ij}(t) \frac{sin(\alpha_j) + \mu_{loc} \, cos(\alpha_j)}{cos(\alpha_j) - \mu_{loc} \, sin(\alpha_j)}}$$

Basic Equations

So, the global friction coefficient $\mu_j(t)$ is then calculated below:

- $\mu_j(t) = \frac{\sum_i^N T_{ij}(t)}{W}$

And the averaged global friction coefficient μ_{av} for each pavement profile is calculated by averaging the friction coefficient $\mu_j(t)$ at any time as following:

- $\mu_{av} = \frac{1}{M} \sum_j^M \mu_j$

Where, M is the number of elements of the discretized pavement profile.

Solving the Dynamic Contact Problem

- **MDR (Method of Dimensionality Reduction)**
  - 10^6 (resp. 10^3) time faster than FEM (resp. BEM),
  - dynamic problems,
  - …
- **The behavior of the rubber elements is represented through a "Kelvin-Voigt"** model where K is the spring's elastic modulus per unit length and C is the dashpot's viscosity per unit length,

- The number and size of the rubber elements depends to the surface topography resolution,
- …

Solving the Contact Problem

When an element is in contact with the pavement surface, F_{ij} is balanced by the load through the contact pressure p_{ij}:

$$F_{ij}(t) = l \times dx \times p_{ij}(t)$$

With

$$p_{ij}(t) = Ku_{ij}(t) + C\frac{du_{ij}(t)}{dt} \quad \text{And} \quad u_{ij}(t) = \delta(t) - h_i + z_j$$

Where,

t represents the time. $u_{ij}(t)$ is the displacement of the rubber i^{th} element contacting j^{th} element on the pavement at time t. $\delta(t)$ is the solid displacement of the rubber at time t. h_i represents the discretized $h(x)$ at the i^{th} point representing then the rubber geometry. z_j is the height of the j^{th} point of the pavement surface.

Solving the Contact Problem

When an element is not in contact with the pavement surface, its contact pressure is nil and the element is subjected to a relaxation phase. Its position on the Z axis is determined by solving:

$$F_{ij}(t) = 0$$

That is equivalent to:

$$Ku_{ij}(t) + C\frac{du_{ij}(t)}{dt} = 0$$

At any time t and irrespective of the location of the pad on the profile, the normal contact pressure must be balanced by the total load W applied on the DFT pad:

$$W = \sum_i^N F_{ij}(t)$$

Where N is the number of discret elements composing the rubber pad.

Introducing the Lubricant (Wet)

To calculate the hydrodynamic pressure p_h (and therefore hydrodynamic load capacity W_h), one integrates the Reynolds equation

- $\frac{d}{dx}\left(H(x)^3 \frac{dp_h(x)}{dx}\right) = 6\eta V \frac{dH(x)}{dx}$
- A mixed calculation with boundary condition at the border between dry and wet that impose a zero flow velocity to the water particles when they hit the asperities...
- Simplification → hydrodynamic bearing with a continuous lubricant film

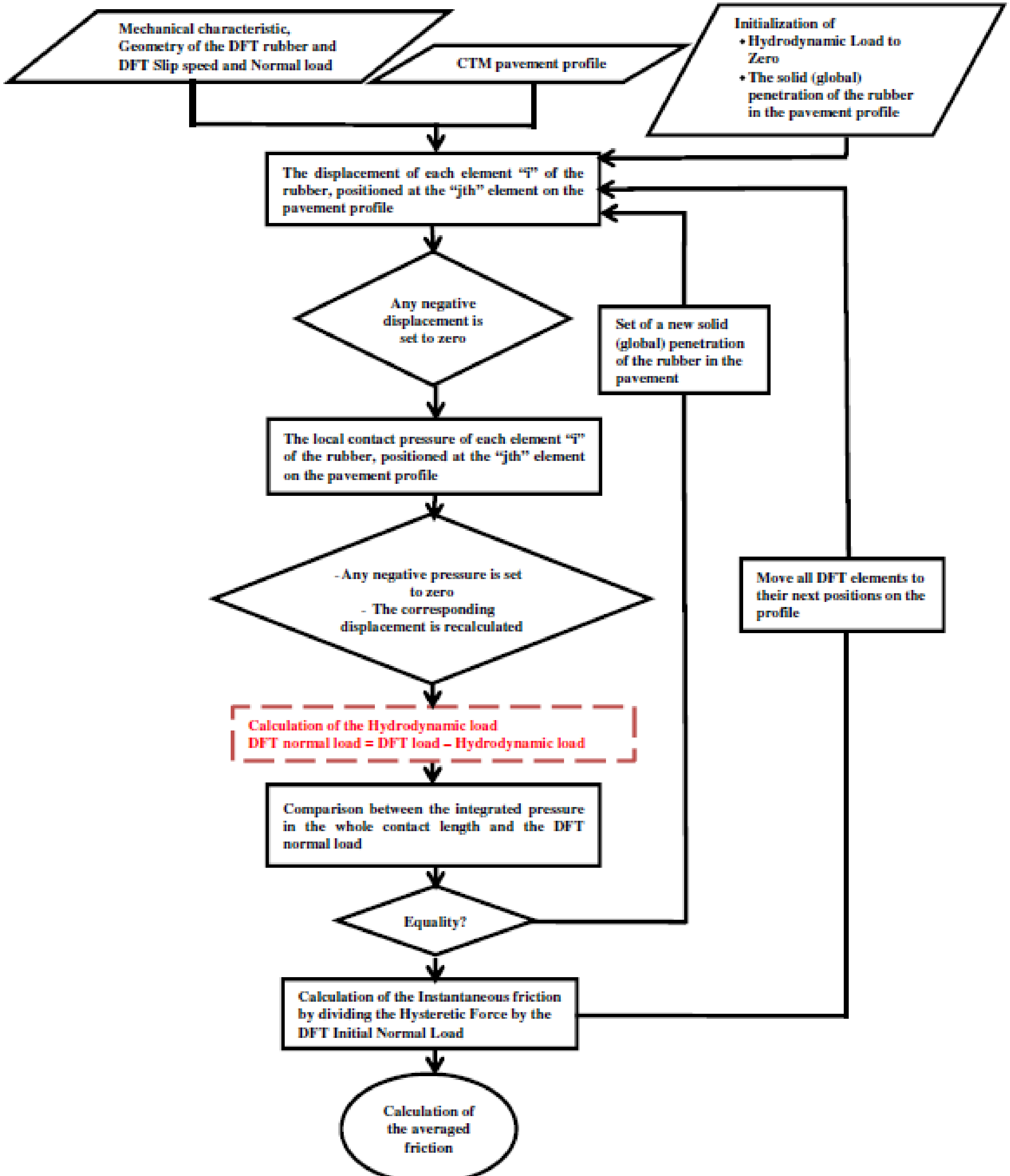
Applicability

- First 1^{st} body (Rubber tyre):
  - Geometry
  - Characteristics of the rubber

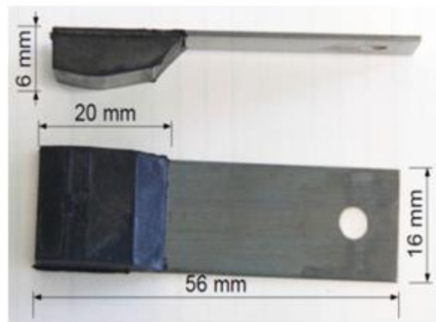
- Second 1^{st} body (Road surface):
  - Topography (profile in 2D) of the surface (and its resolution)
  - μ_{loc} (in case the resolution is not enough and/or in dry condition)

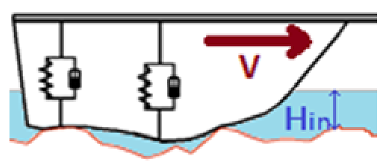
- Third body (Water)
  - Thickness
  - Dynamic viscosity

- Operating conditions
  - Load
  - Speed


Mechanical characteristic, Geometry of the DFT rubber and DFT Slip speed and Normal load
CTM pavement profile
Initialization of
• Hydrodynamic Load to Zero
• The solid (global) penetration of the rubber in the pavement profile
The displacement of each element "i" of the rubber, positioned at the "jth" element on the pavement profile
Any negative displacement is set to zero
Set of a new solid (global) penetration of the rubber in the pavement
The local contact pressure of each element "i" of the rubber, positioned at the "jth" element on the pavement profile
- Any negative pressure is set to zero
- The corresponding displacement is recalculated
Move all DFT elements to their next positions on the profile
Calculation of the Hydrodynamic load
DFT normal load = DFT load – Hydrodynamic load
Comparison between the integrated pressure in the whole contact length and the DFT normal load
Equality?
Calculation of the Instantaneous friction by dividing the Hysteretic Force by the DFT Initial Normal Load
Calculation of the averaged friction

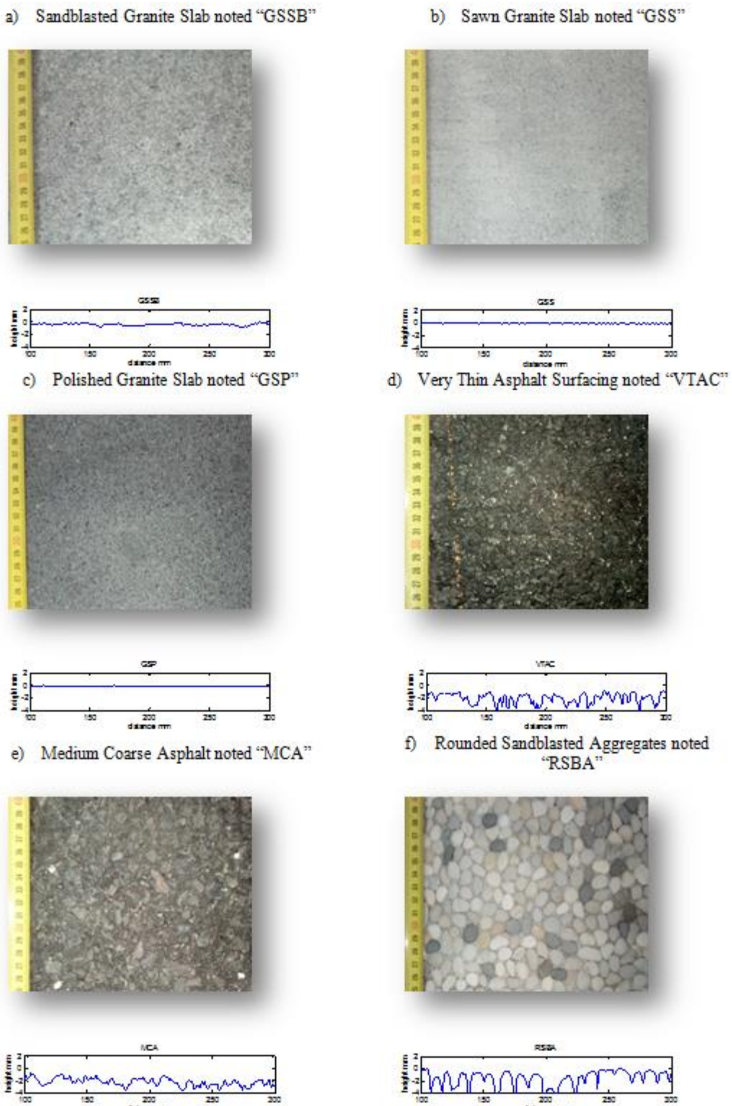
Application: The DFTester





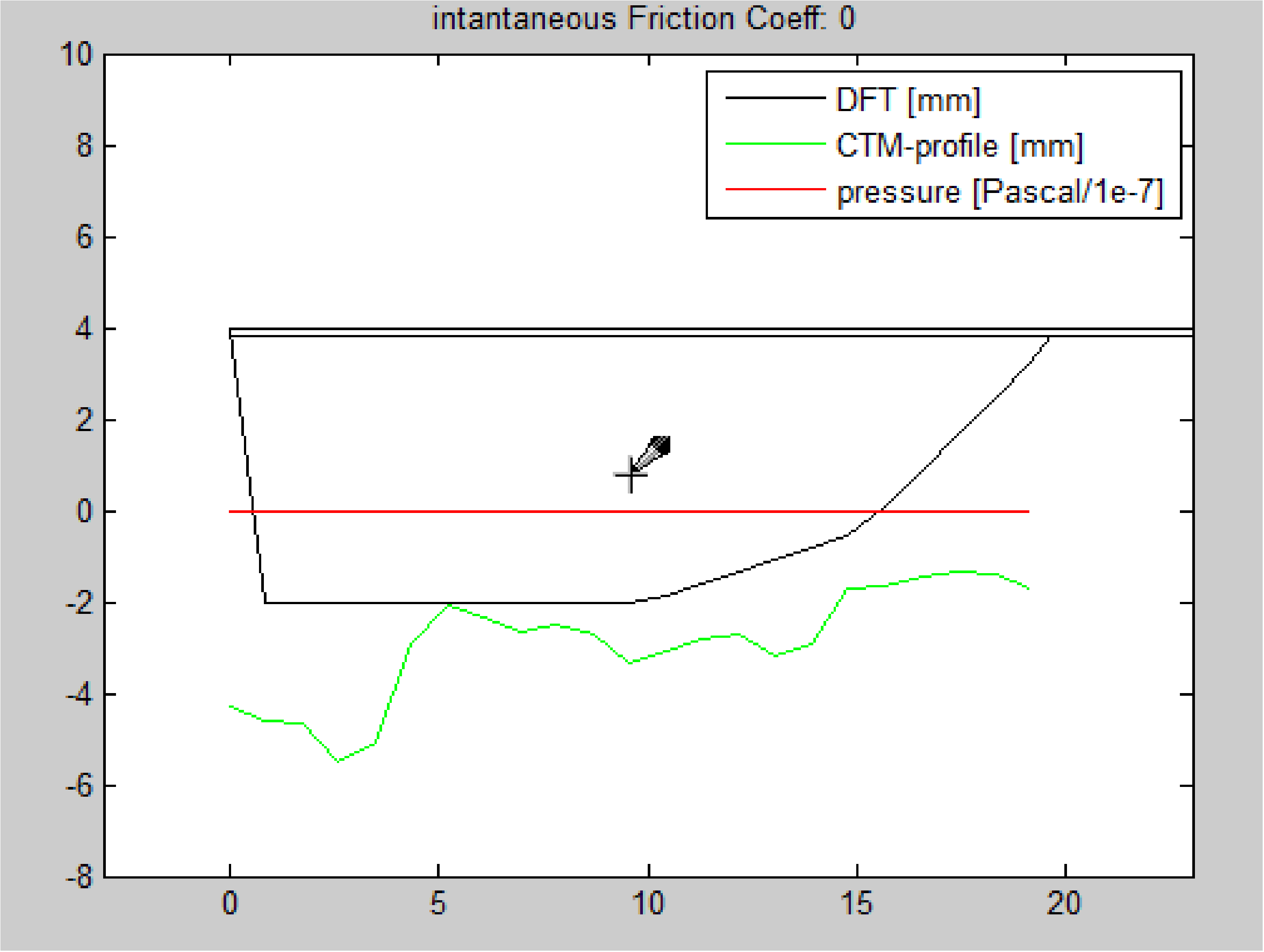
K	C	**dx**	W	h	l	L	H_{in}	η
spring's elastic modulus N/m^3	dashpot's viscosity $N.s/m^3$	**measuring scale of the profiles mm**	applied load on the rubber N	thickness of the rubber mm	width of the rubber mm	length of the rubber mm	Water thickness mm	Dynamic viscosity Pa.s
$1.4.10^8$	10^2	**0.87**	11.8	6	16	20	10^{-3}	10^{-3}

Application: The DFTester



Name	μ_{loc} (BPN)
GSP	0,3
GSS	0,55
GSSB	0,69
RSBA	0,73
MCA	0,75
VTAC	0,6

Application: The DFTester



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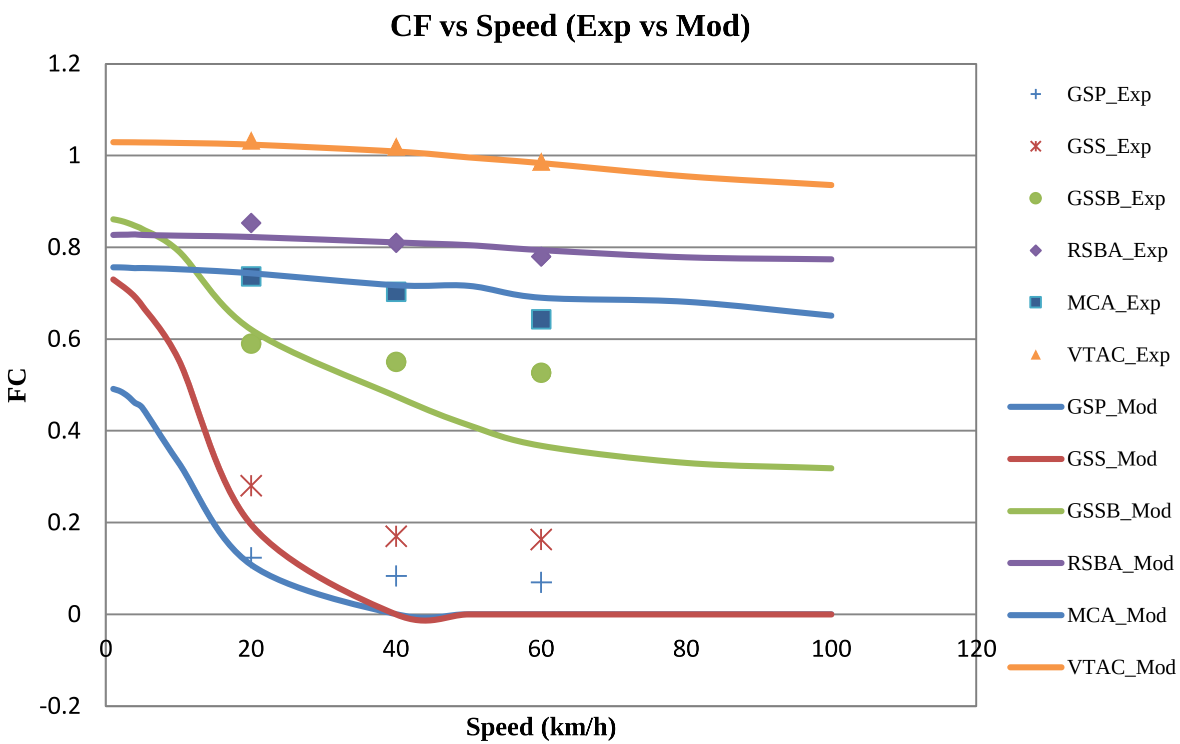
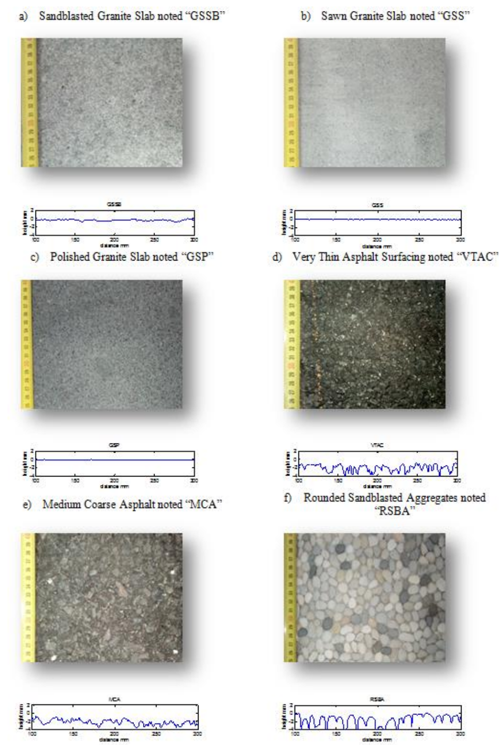
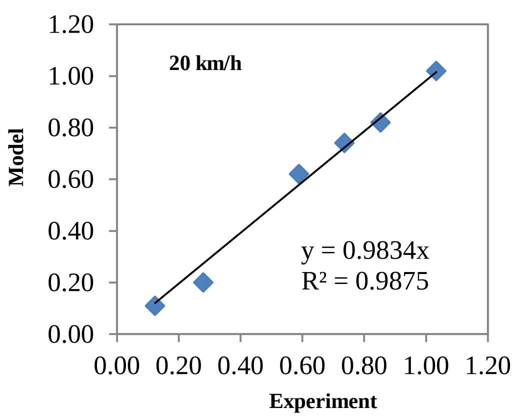
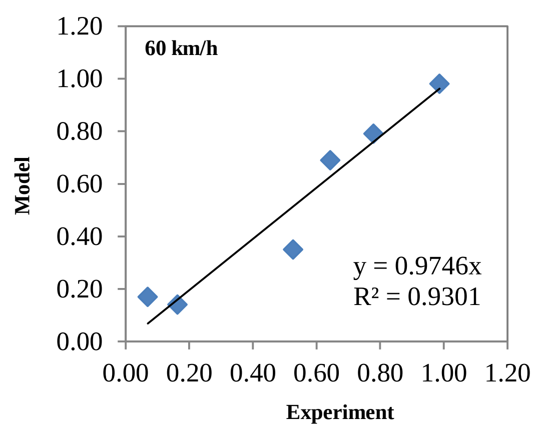
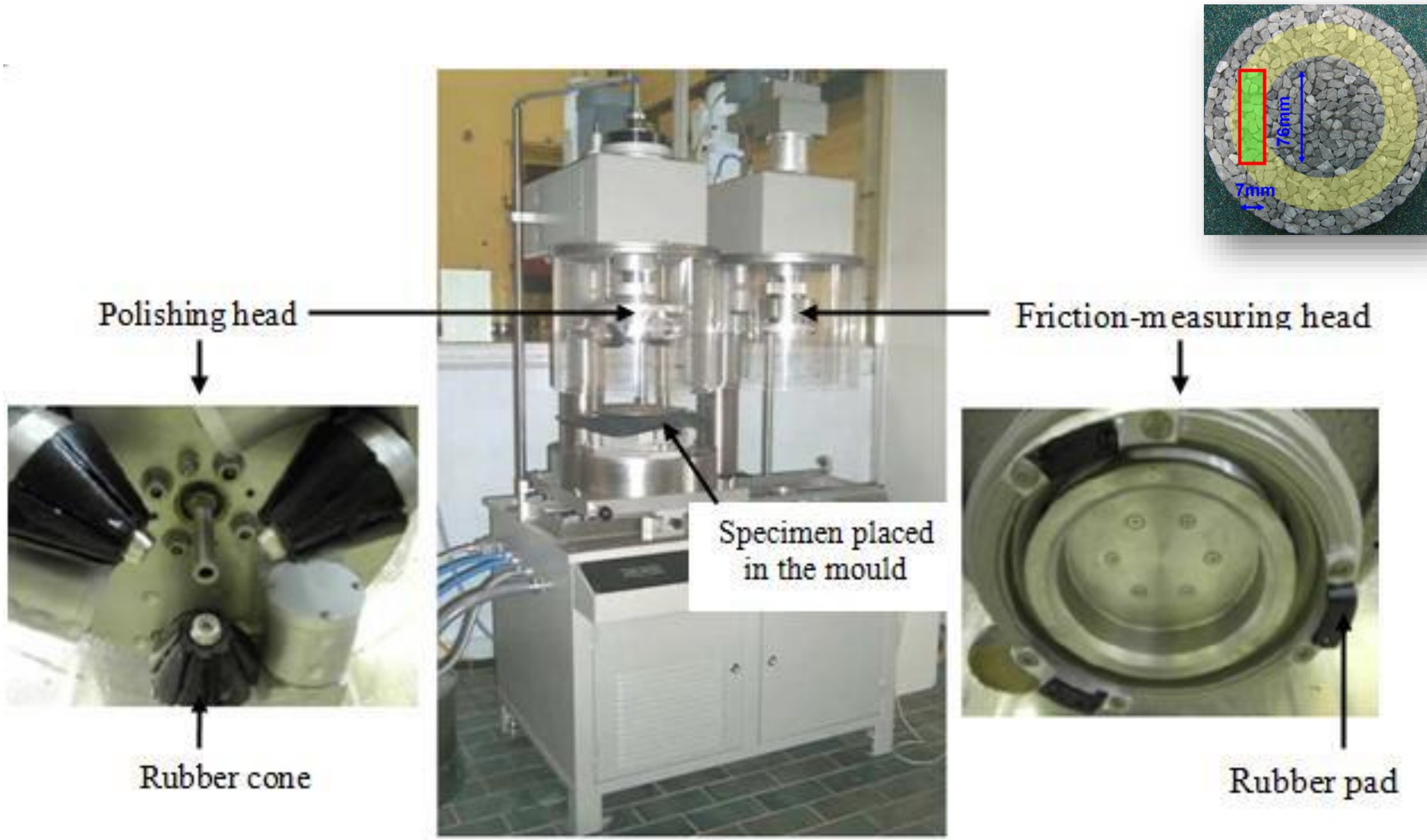








Application: The WS machine



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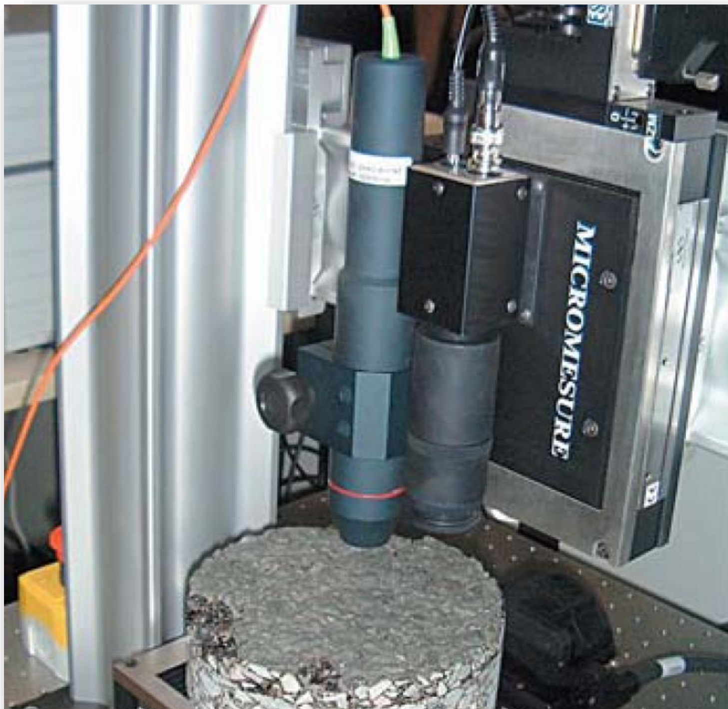
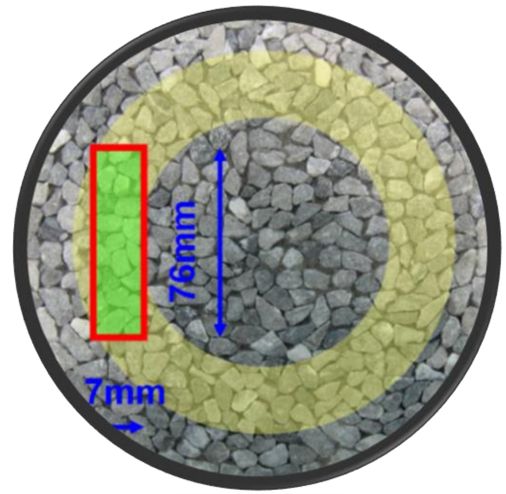
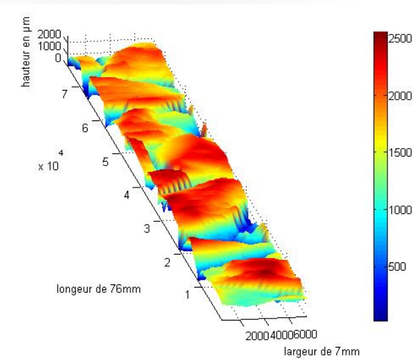
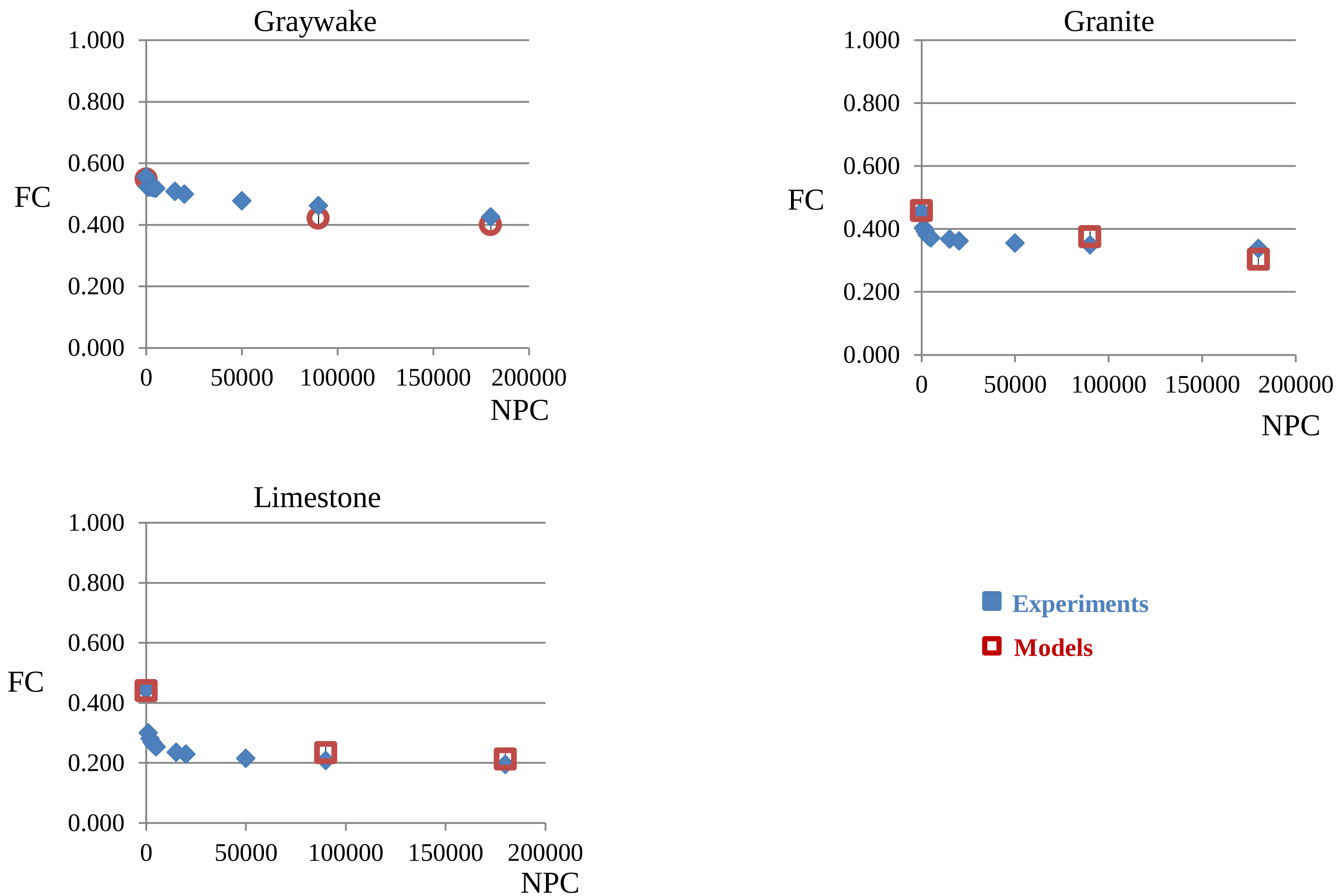






- measuring range in the direction "x": 10 microns
- number of measuring points per profile: 7601
- 15 profiles measured by length: 76 mm

Application: The WS machine



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2.10^8	10^6	**10 (x10, with µloc = 0,145)**	56	4	15	30	10^{-3}	10^{-3}

Discussion and Conclusions

- The model reproduces part of the physics governing the friction and thus opens a promising and attractive way to predict friction for real tires.

- Any other complex model of rubber after a suitable characterization (via the use of viscoanalyzer) or geometry can work with this proposed approach .

Discussion and Conclusions

- The determination of μ_{local} is an open question and needs deeper investigations too:
  - How to define the limit wavelength from which a section of profile between two points (corresponding to the measuring resolution) can be considered as smooth?
  - In others words → the limit scale from which any smaller asperities will no longer participate to the generation of hysteretic friction!
  - In case of impossibility to measure the texture at these determined scales, which experimental procedure would be better suitable for determining this μ_{local} (operating conditions)?