# Prediction of Tire/Wet Road Friction from Road Surface Microtexture and Tire Rubber Properties

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## ABSTRACT

In this paper, validation of a contact model for the prediction of low-speed friction from road surface microtexture is presented. The aim is to couple later this model with another model developed elsewhere to estimate the friction – speed curve from road- and tire measurable parameters.

The model development is briefly presented. Microtexture parameters are also described. The experimental program carried out for the validation of the model is detailed. Diverse comparisons are made to show:
- The influence of rubber properties on friction;
- The correspondence between the British Pendulum Number and the tire $\mu_{peak}$;
- The correlation between calculated and measured friction.

Promising results are found. Scatter problems are also raised and analyzed to define ideas for further investigations.


## RÉSUMÉ

Cet article traite de la validation d'un modèle de contact pour la prédiction du frottement à basse vitesse à partir de la microtexture des surfaces de chaussée. L'objectif est de coupler ce modèle ultérieurement avec un autre modèle développé ailleurs afin d'estimer la courbe frottement – vitesse à partir de données mesurables liées à la route et au pneumatique.

Le développement du modèle est présenté brièvement. Les paramètres de microtexture sont aussi décrits. Les détails sur le programme expérimental lancé pour valider le modèle sont donnés. Diverses comparaisons sont faites pour montrer :
- L'influence de la gomme sur le frottement;
- La correspondance entre le frottement mesuré au pendule et le $\mu_{max}$ du pneumatique;
- La corrélation entre frottement calculé et mesuré.

Des résultats encourageants sont trouvés. Des problèmes sont également soulevés. Ils sont analysés afin de dégager des pistes pour de nouvelles recherches.

# 1- INTRODUCTION

In another paper presented in this symposium [1], it is shown that the friction – speed curve has a general inverse-S shape (Fig. 1), which is widely known in tribology (research on contact between two or more bodies) as the Stribeck curve. The following formula is proposed to describe this typical shape [1]:

$$\mu = \mu_0 \exp\left[-\left(\frac{V}{V_s}\right)^{\alpha}\right] + \beta V \qquad (1)$$

Where
$\mu$: friction;
$\mu_0$: friction at zero (or very low) speed;
$V_s$: so-called "Stribeck" speed, estimated from the surface macrotexture and the wheel slip [1];
$\alpha$: constant defining the curve shape, estimated from the water thickness and the tire tread depth [1];
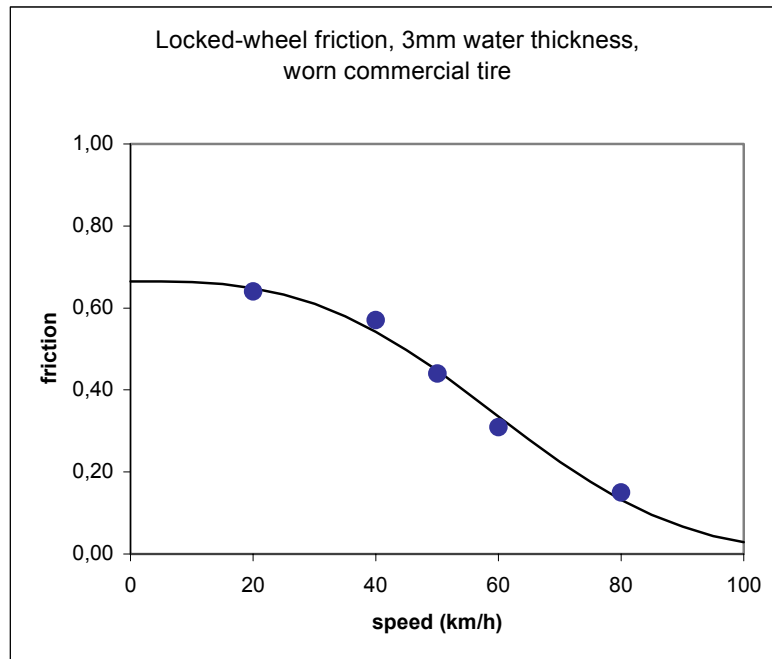$\beta$: constant defining the "viscous" component of friction.

**Figure 1. General shape of friction – speed curve**
*(Data source: CETE Lyon)*

It can be seen that the PIARC model is a particular case of the formula (1) ($\alpha$ = 1 and $\beta$ = 0). The starting point of the friction – speed curve is then defined by the constant $\mu_0$. In reference [1], it is shown that $\mu_0$ is strongly related to the British Pendulum Number (BPN). It could be explained by the fact that, according to the shape of the full line in the figure 1, friction is almost constant in the low-speed region and consequently, friction at theoretical zero speed is in the same order as friction at speed lower than say 20km/h, in particular BPN (measured at roughly 10km/h).

At LCPC, research has been started in the nineties to better understand the influence of road surface microtexture on friction. Relevant microtexture descriptors are defined and a contact model called "Stefani model" is developed to calculate very-low-speed friction from these descriptors [2]. First results on laboratory surfaces composed of coarse aggregates (100mm $\times$ 150mm rectangular plates) show that surface BPN can be predicted accurately by this model [2].

The Stefani model can be then applied to the calculation of $\mu_0$. If it works, the models from [1] and [2] can be fused to estimate the whole friction – speed curve from measurable road- and tire parameters. As a preliminary requisite, it is necessary to validate the Stefani model on actual road surfaces. The on-going work is presented in this paper.

## 2- MICROTEXTURE DESCRIPTORS

The microtexture descriptors were already presented in the last SURF symposium [3]; they are briefly reminded here.

Example of road profiles is shown in the figure 2. The Y-scale shows that the observed scale is the surface microtexture. The characterization method is based on the following established facts:
- Friction is generated only in direct-contact spots between the tire and the road surface;
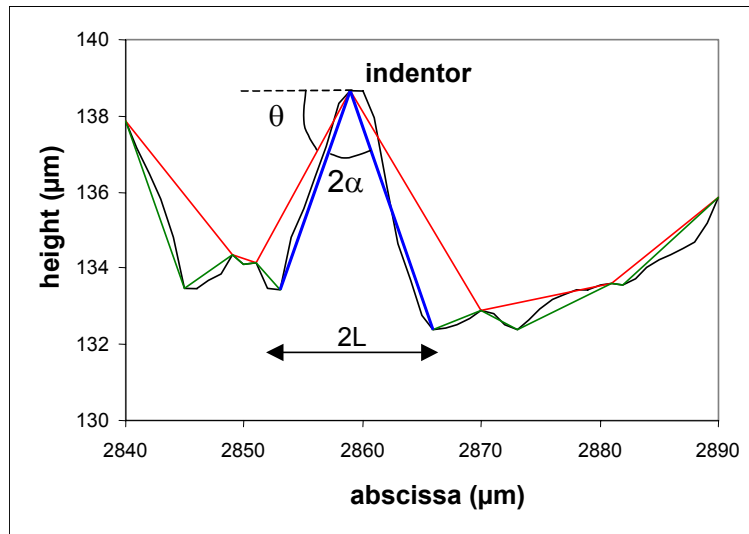- The road-asperity shape is the most relevant factor for friction generation.



**Figure 2. Road profile and microtexture descriptors**

Road asperities where contact occurs are defined as "indentors" (Fig. 2). An indentor is then part of the profile between two valleys. The indentor distribution is characterized by two parameters: the shape (cotangent of angle $\alpha$) and the relief (angle $\theta$). Simple algorithm is developed to detect all profile peaks and valleys called "extremes".

The characteristic angles are calculated by means of the following formulae:

$$\alpha = \frac{1}{2} \times \left[ \tan^{-1} \left| \frac{x_i - x_{i-1}}{z_i - z_{i-1}} \right| + \tan^{-1} \left| \frac{x_{i+1} - x_i}{z_{i+1} - z_i} \right| \right] \tag{2}$$

Where

$x_i$: abscissa of the $i^{th}$ extreme (if index (i) is a peak, the indexes (i-1) and (i+1) are valleys);

$z_i$: height of the $i^{th}$ extreme.

And

$$\theta = \tan^{-1}\left|\frac{z_{j+1} - z_j}{x_{j+1} - x_j}\right| \qquad (3)$$

Where
$x_j$: abscissa of the $j^{th}$ peak;
$z_j$: height of the $j^{th}$ peak.

# 3- STEFANI CONTACT MODEL

The contact model is developed with the original aim to simulate the hysteresis effect of friction (energy loss by viscoelastic properties of the rubber). The model geometry represents the contact between a rubber pad and part of a road profile between two peaks called "motif" (Fig. 3). ). No surface friction (adhesion) is considered. Therefore, the model assumes that friction forces are generated uniquely by deformation of the Kelvin solid representing the rubber pad. The relaxation time of this solid (ratio $\eta/K$) is used as the rubber characteristic.
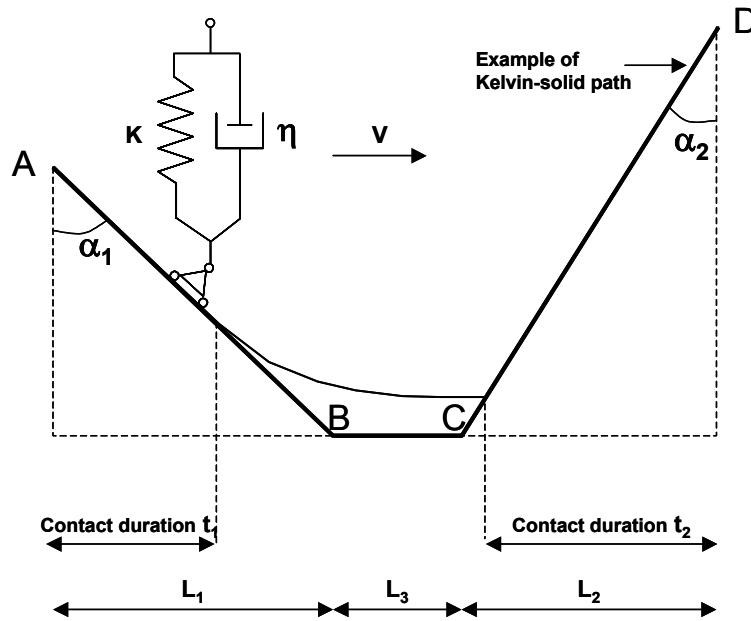


**Figure 3. Geometry of the contact model**

Due to the motif geometry, contact loss can occur between the solid and the motif. Vertical and horizontal forces are calculated and integrated over the contact durations $t_1$ and $t_2$. The ratio between their resultants ($f_v$ and $f_h$ respectively) is defined as a coefficient of friction $\mu$. Details of the calculations can be found in [2].

By setting $L_3 = 0$, this contact model can be coupled with the characterization method developed above to calculate µ from road profiles. The first results obtained on laboratory surfaces composed of coarse aggregates show that two friction values must be considered, which correspond to µ calculated at two scales: the "roughness" scale related to the profile and the "undulation" scale related to the its envelop (line connecting all profile peaks). Indentors of the roughness scale are determined from the "green" line of the figure 2, and those of the undulation scale from the "red" line (Fig. 2).

## 4- VALIDATION ON ACTUAL ROAD SURFACES

## 4.1- Experimental program

Within the frame of a 4-year LCPC project, seven road-test campaigns were carried out from 2001 to 2003. The main objective is to gather on the same road surface all texture- and friction information. Results can be used for the validation of diverse models, in particular the Stefani model presented above.

Each campaign includes the following tasks:
- Friction measurements: deceleration tests, BPN tests [4];
- Texture measurements: macrotexture (volumetric method [5]) and microtexture (road profiles)
- Core sampling, when it is possible.

The test sites include trafficked roads and test tracks. Their selection is based on the consideration of the mix formulation, the aggregates and the skid-resistance.

Deceleration tests and macrotexture measurements are done on road. BPN tests and microtexture-profile measurements are done on road surfaces when there is no core sampling, or in laboratory on specimens when core sampling is possible. Scheme of a typical test section with respective locations for BPN tests, volumetric and road profile measurements, and core sampling is illustrated in the figure 4.

Microtexture profiles are sampled every 10µm. On road, since time is limited, only one profile of 200mm long is measured. In laboratory, 13 profiles of 80mm long are measured on each specimen.
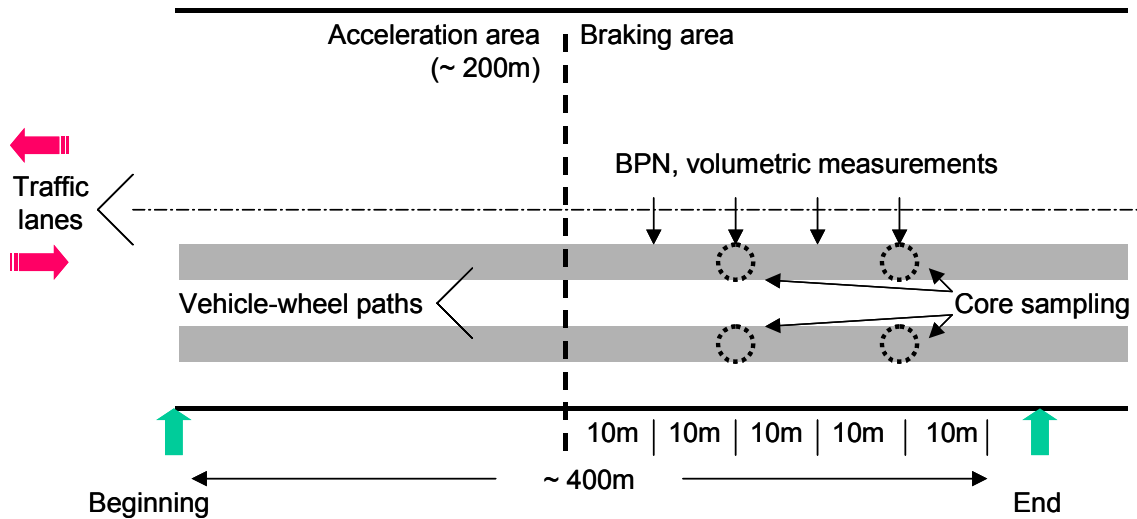
**Figure 4. Typical test section**

## 4.2- Deceleration tests and friction estimation

Front-wheel braking tests are performed by means of a light instrumented vehicle (Peugeot 406) with and without ABS activation (Fig. 5). Surfaces are wetted by a tank truck. Decelerations are recorded between two speeds $V_1$ and $V_2$, then the brake is released. Tests are performed for two ranges of speeds: 90km/h ($V_1$) to 70km/h ($V_2$), and 60km/h ($V_1$) to 40km/h ($V_2$).



**Figure 5. LCPC instrumented vehicle**

Friction is estimated from the average deceleration by the following formula:

$$\mu = \frac{M\left(\left[\dfrac{V_1^2 - V_2^2}{2 \cdot d}\right] - \left[A + B \cdot \dfrac{(V_1 + V_2)^2}{2}\right]\right)}{Z_{AV} + M \cdot \left(\dfrac{V_1^2 - V_2^2}{2 \cdot d}\right) \cdot \dfrac{h}{L}} \qquad (4)$$

Where

    $\mu$: estimated friction;
    M: vehicle mass;
    d: braking distance;
    $Z_{av}$: load on the front axle;
    h: height of the vehicle center of gravity (Fig. 5);
    L: vehicle wheelbase (Fig. 5).

The estimation is $\mu_{peak}$ (respectively $\mu_{locked}$) for braking with ABS (respectively without ABS). The associated speeds are the mean of the speed range: 80km/h for high-speed deceleration test and 50km/h for low-speed deceleration test.

## 4.3- Results

The first objective of the work presented in this paper is to check the ability of the Stefani contact model to estimate BPN of road surfaces from the microtexture descriptors.

Since it is well known that rubber properties affect friction, comparison is made between BPN measured with two rubber pads: one made from the standard rubber [4] and one from the tire rubber (front wheels) of the instrumented vehicle. Results are shown in the figure 6. It can be seen that BPN values depend on the employed rubber. It is then decided to use the values obtained with the tire rubber for further comparisons.
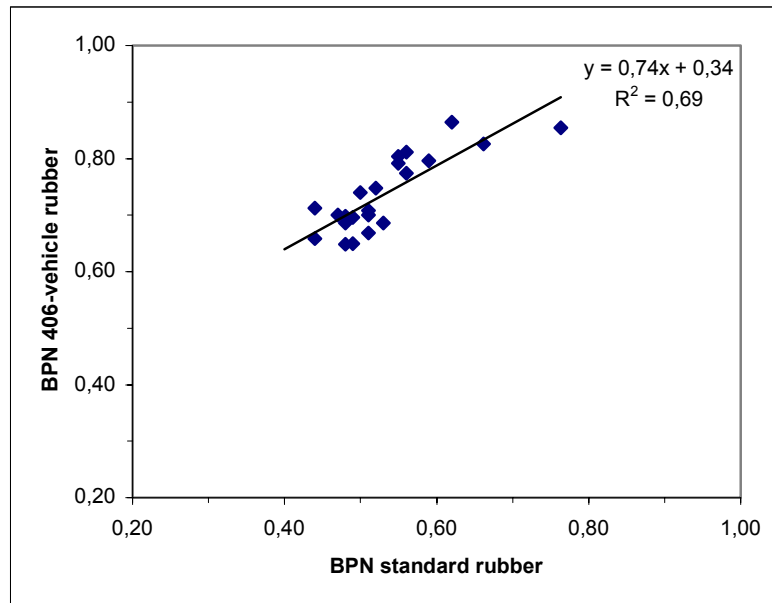
$$y = 0{,}74x + 0{,}34$$
$$R^2 = 0{,}69$$

**Figure 6. Influence of rubber on BPN**

Regarding the profile analysis, preliminary investigations show that the analysis must be limited to the upper part of the profiles, say roughly 0.5 to 1mm. A mathematical tool is developed to extract this part from the whole profile. Example is shown in the figure 7.
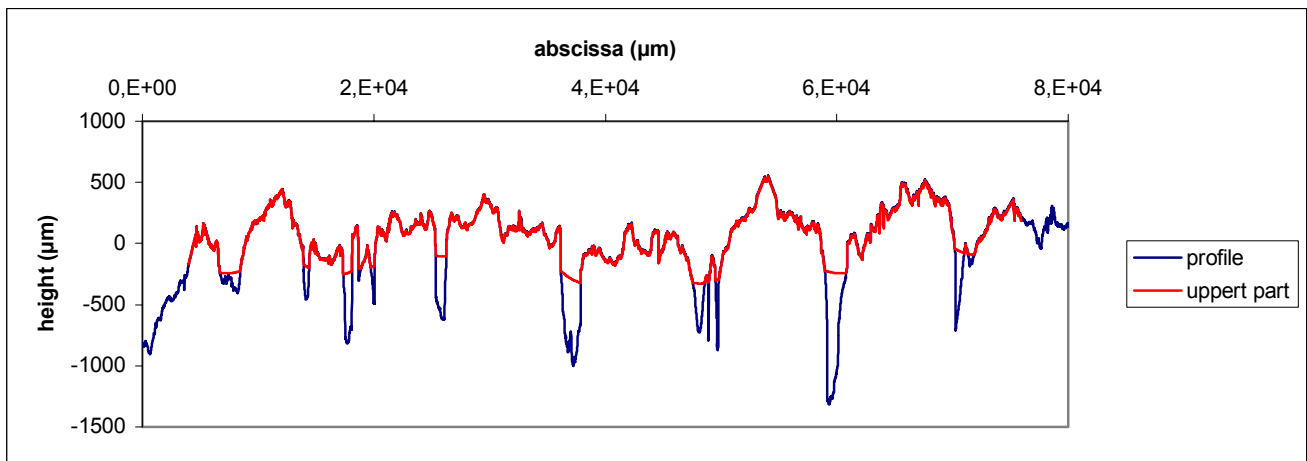


**Figure 7. Example of profile filtering**

Comparison between measured surface-BPN and calculated friction at the roughness- and undulation scale is shown in the figure 8. Despite some scatter, fair tendency is found. Friction at the roughness scale is closer to BPN than friction at the undulation scale. It does mean that all profile indentors contribute to friction in BPN test and therefore must be taken into account for in the model.
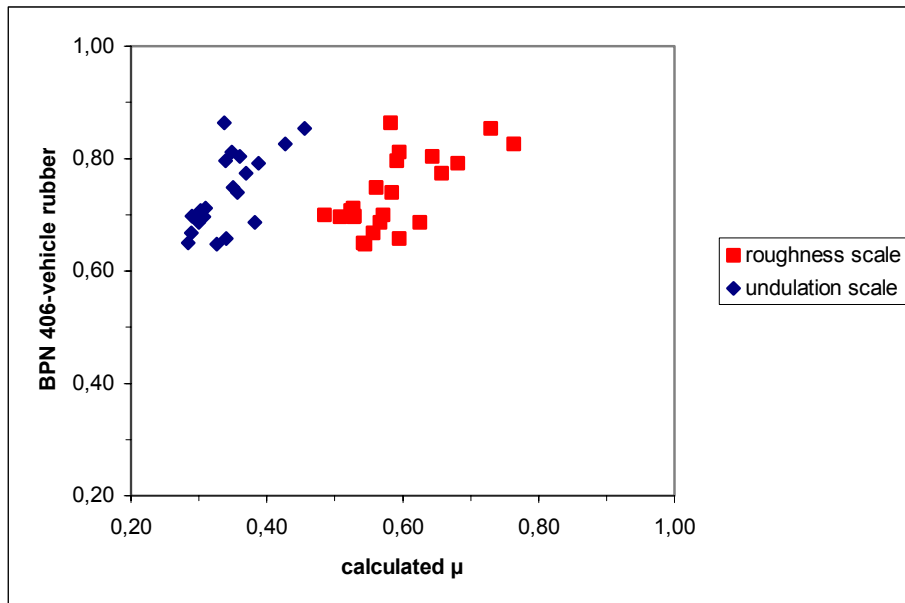
**Figure 8. Comparison between BPN and µ calculated from Stefani model**

Since the first results are promising, attempts are made to further validate the model. Since $\mu_{peak}$ is measured at low speed (for 80km/h, the slip speed is roughly 10km/h, assuming a wheel slip of 0.1), it is tempting to compare the calculated friction with $\mu_{peak}$.

A first comparison is made between $\mu_{peak}$ at 80km/h and 50km/h. It can be seen from the figure 9a that they are almost equal. Further comparison between $\mu_{peak}$ and BPN shows significant scatter, even if the "cloud" is close to the graph bisector (Fig. 9b). The scatter can be due to the number of BPN-test zones, which are not representative enough compared with the braking distance.

Despite some scatter due to sampling problem, results from the figure 9 are going to confirm the existence of the stable-friction zone of the Stribeck curve in low-speed region (Fig. 1).
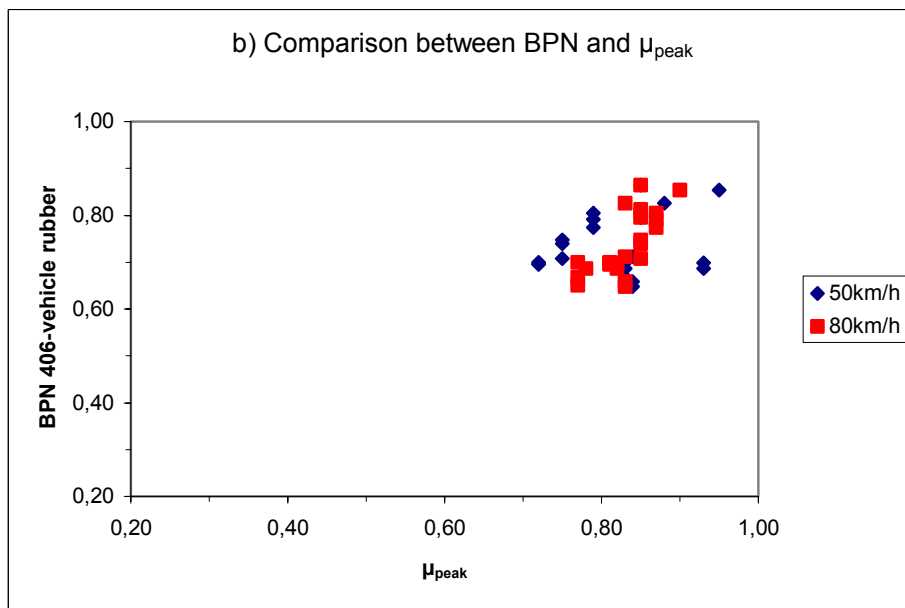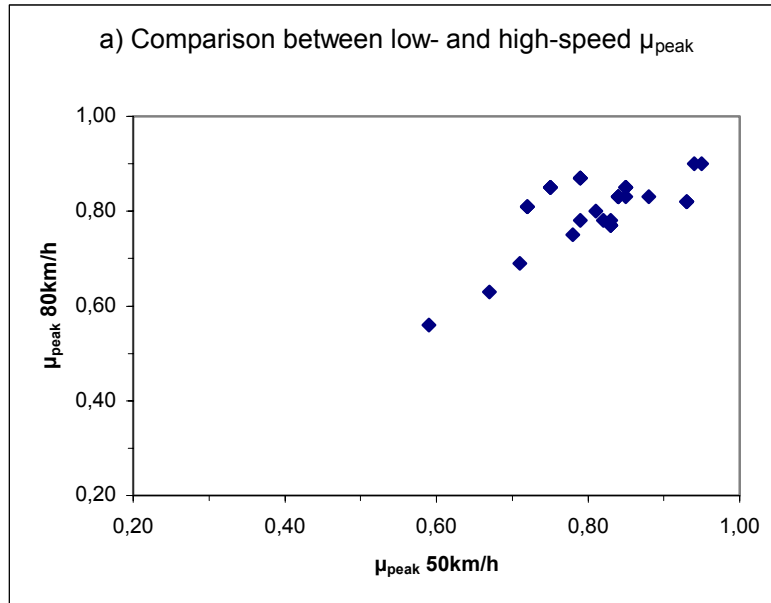
**Figure 9. Comparison between BPN, low- and high-speed $\mu_{peak}$**

Comparison between $\mu_{peak}$ at 80km/h and calculated friction is shown in the figure 10. Big scatter can be seen (Fig. 10a). Closer examination of individual results displays two groups corresponding to measurements on road and in laboratory respectively. It is found that scatter is due to measurements on road. Since no artifact is found, assumption is made on the insufficient sampling on roads, but it needs to be investigated. Suppression of on-road points gives a fairer tendency (Fig. 10b).
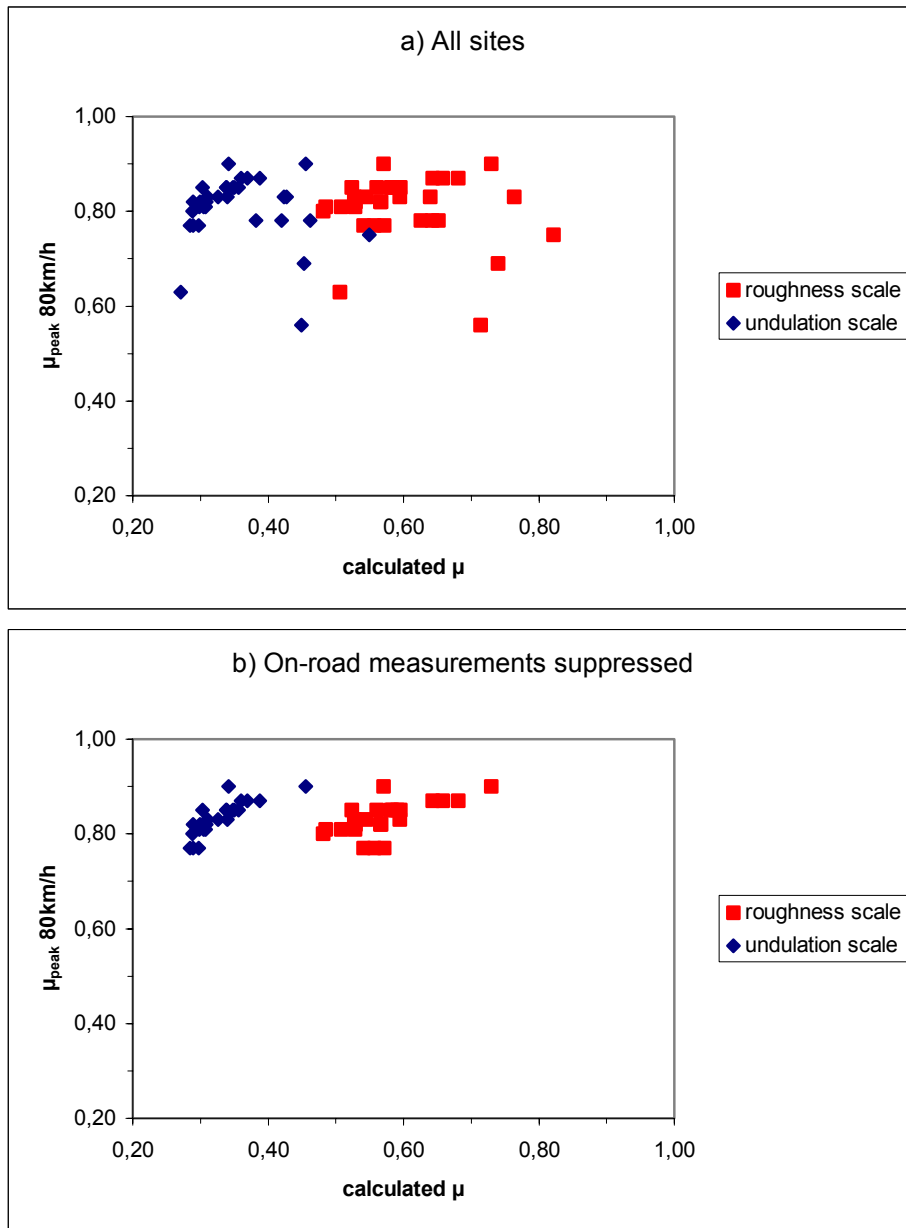
**Figure 10. Comparison between $\mu_{peak}$ and $\mu$ calculated from Stefani model**

## 5- CONCLUSIONS

In this paper, validation of a contact model for the prediction of low-speed friction from road surface microtexture is presented. The calculated friction is compared to the BPN and the $\mu_{peak}$ estimated from vehicle braking tests.

Generally, the comparison is fair, showing the possibility to couple this contact model with another model developed elsewhere [1] to estimate the whole friction – speed curve from measurable parameters such as the road surface macro- and microtexture, the wheel slip and the water layer thickness.

However, the great scatter observed in some comparisons show that many efforts are still needed before the prediction of friction from surface microtexture is solved. The following problems are raised from this work:
- Profile measurement. The profile fineness (10µm) seems to be sufficient. However, a sampling procedure needs to be investigated to provide representative profiles regarding the friction process.
- Profile analysis. It is shown that the analysis must be done only on the upper part of the profile. Tool is developed to extract mathematically this part. However, the method needs to be improved and supported by physical proofs.
- Microtexture description. The shape and relief descriptors seem to be relevant. However, robustness of the characterization needs to be improved.

## 6- REFERENCES

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