**Effect of road surface Macrotexture and Microtexture on skid resistance: Parametric study using the DFM**

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# Abstract

Skid resistance is related to the friction generated between car tyres and the road surface. It enables drivers to shorten their stopping distances and to follow their desired trajectories along a road. It depends as much on the road surface characteristics, as on the car tyres and the operating conditions. For the road surface, texture remains the main parameter governing its contribution to skid resistance. This texture is composed of a multitude of irregularity scales, but two of them (Macrotexture and Microtexture) are mainly considered to contribute to skid resistance.

The work proposed within this paper aims to proceed to a study to identify the exact role of Macrotexture and Microtexture on a road surface, by investigating the effect of different smoothing levels upon these scales using the ‘Dynamic Friction Model’ (DFM), a computational skid resistance model recently developed. The smoothing procedure of the road surface is conducted as following:

* The original profile of the road surface is decomposed via an Empirical Mode Decomposition method (part of the Huang Hilbert Transform (HHT)) to a multitude of constituent fundamental profiles of different scales termed “Intrinsic Mode Functions” (IMF).
* The first IMF is subtracted from the original profile to give derive to a smoother profile.
* The second IMF is subtracted from that smoothed profile to derive a further second even smoother profile.

Accordingly,, the derived two new profiles displays the texture within different Macrotexture and Microtexture. The DFM is then applied to these new profiles to highlight the role of the respective two roughness scales. The results from these simulations show that for two wet road surfaces with the same Macrotexture, the higher the Microtexture can be maintained, the better the skid resistance will be at all speeds, even at a speed limit at which the skid resistance will start to drop. Furthermore, for two wet road surfaces with same Microtexture, the higher the Macrotexture can be maintained, the later hydroplaning will occur.

# Keywords

Macrotexture, Microtexture, road surface texture, skid resistance, Dynamic Friction Model (DFM), Empirical Mode Decomposition (EMD), Huang Hilbert Transform (HHT)

# Introduction

Skid resistance, related to the friction generated between car tyres and road surface, is a key parameter for road safety. Indeed, it enables drivers to shorten their stopping distances and to follow their desired trajectories on roads. Skid resistance depends as much on the car tyres and operating conditions, as on the road surface characteristics. For the road surface, the texture remains the main parameters governing the contribution to skid resistance. That texture is composed of a multitude of roughness scales, which are usually grouped into two sets termed Macrotexture and Microtexture [1].

Recently, a computational model named the ‘Dynamic Friction Model (DFM)’ has been proposed to predict the contribution to skid resistance from road surfaces, via their texture topographies [2, 3]. Although the suitability of this DFM to evaluate the wet skid resistance of road surfaces has been demonstrated [2], a study is yet to be done to identify exactly the involvement of the two different roughness scales (Macrotexture and Microtexture) in the generation of tire/road friction [2 – 6].

The proposed work in this paper aims to proceed to this study using the DFM in order to capture the influence of both Macrotexture and Microtexture. The study will be based upon a real road surface, that the DFM has already been validated against following experimental tests [2]. Utilising the Empirical Mode Decomposition (EMD) method (a part of the Huang Hilbert Transform (HHT)), a profile of this texture will be decomposed to a multitude of constituent fundamental profiles at different roughness scales termed “Intrinsic Mode Functions” (IFM) [7-9]. The derived IMF functions are then subtracted from the original profile, to produce a set of new smoother profiles with more or less Microtexture and Macrotexture. The DFM will then be applied to these profiles to highlight the contributions of the Macrotexture and Microtexture in the generation of skid resistance.

# The DFM and its validation

1. **Revisiting the DFM**

The equations governing the DFM are derive from the balance forces, made in the contact between a rough surface with a rubber pad moving upon it (equation 1) (Figure 1) [**2**].

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|  Equation 1

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| *Figure 1: Forces acting in the contact between a rubber element and a road profile* |

Where,

* is the force applied by the rubber element on the road surface. In the present work, it is calculated using 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. is balanced by the load through the contact pressure .

 with and

With, *t* representing the time and *uij* the displacement of the rubber *ith* element contacting *jth* element on the road at time *t*. *δ* is the solid displacement of the pad at *t*. *hi* represents the pad geometry. *zj* is the height of the *jth* point of the road profile.

* is the traction force. This force must be just greater than the global friction force opposing the movement.
* is the surface reaction force.
* is a local friction force. when the element is moving on a “pseudo smooth inclined plan” with angle and where represents a local friction coefficient.

The projection of equation 1 local contact coordinates, onto global contact axes x and z, coupled with the condition that leads to:

 Equation 2

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

 Equation 3

At any time *t* the total load applied on the DFT pad must be balanced by the normal contact pressure:

 Equation 4

Where *N* is the number of discrete elements comprising the rubber pad. Accordingly, the global friction coefficient can then be calculated using the following formula:

 Equation 5

Furthermore the averaged global friction coefficient for each road profile can be calculated by averaging the friction coefficient at any time:

 Equation 6

Where, M is the number of elements of the discretized road profile. At this stage, the only unknown factors are those relating to , representing the contact force applied by the rubber elements on the road surface. To obtain the calculation details of these dynamic viscoelastic contact forces, the reader is advised to referrer to the following publications [2].

Additionally, depending on the operating conditions a hydrodynamic pressure will be generated in the water trapped between the rubber pad and the road surface. This hydrodynamic pressure exerts a force to lift up the rubber from the road and thus decreases the penetration depth of road asperities into the rubber reducing therefore the contribution to skid resistance. To take into account this phenomenon, a “pseudo hydrodynamic bearing” simplification is adopted. The reader is advised to referrer to the following publications to get the details of this approach [2].

 Equation 7

Where, , with and are respectively the outlet and inlet water thicknesses of the “pseudo hydrodynamic bearing”. is the water viscosity. *L* and *l* are the length and the width of the bearing. *α* et *β* are two empirical coefficients (105 and 1.75 respectivly) added to adjust the load capacity of the“pseudo hydrodynamic bearing”. For the calculation details, the reader is invited to refer to the following publication [2].

1. **Validation of the DFM**

Before proceeding to the decomposition of the road profile and the application of DFM to the recombined smoothed profiles to highlight the contributions of the Macrotexture and Microtexture in the generation of skid resistance, the suitability of the model needs to be demonstrated. The validation of the DFM has been done in several situations involving different road surfaces [2].

For this work, a “very thin asphalt surfacing” noted VTAC slabs is prepared. This road surface displays high Macrotexture and Microtexture. To capture the profile of the VTAC and to measure the friction generated upon it, the Circular Track Meter (CTM) and the Dynamic Friction Tester devices are used respectively (See figure 2). The bottom of the figure 2 displays the profile captured from the VTAC using the CTM. The vertical axis represents the height of the each point of the profile and is in mm. The horizontal axis the position of a point in the profile (the distance between two points can be considered by the reader to be 0.87 mm). The reader is a directed to read the following reference to obtain more information about the operating procedure of these two devices [10, 11].

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| *VTAC (road surface)* | *DFT* | *CTM* |
|  | *DFT_Bottom.jpg* | *CTM_Bottom.jpg* |
|  |  |  |
|  |  |  |
| *The original profile captured with the CTM from the VTAC road surface (0.87 mm of resolution)* |
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*Figure 2: up left – the VTAC slabs, up middle – the Dynamic Friction Tester, up right – the Circular Track Meter, down – the captured profile from the VTAC using the CTM (The vertical axis represents the height of the each point of the profile and is in mm. The horizontal axis the position of a point in the profile (the distance between two points can be considered by the reader to be 0.87 mm)*

The left and right plots of figure 3 display the correlations of the friction coefficients (the vertical and horizontal axes represent respectively the friction coefficient and the speed per km/h.) predicted by the DFM (yellow points) and the obtained DFT measurements (red points) on the VTAC at 20 and 60 km/h, at respectively linear and logarithmic scales. For the calculation details, the reader is invited to refer to the following publication [2]. The results obtained show very good correlations for the three speeds and demonstrate the suitability of the DFM to predict the skid resistance of VTAC surfaces.

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*Figure 3: Comparison between the predictions of the DFM (yellow points) and DFT measures on the VTAC road surface (red points). The vertical and horizontal axes represent respectively the friction coefficient and the speed per km/h. The DFT and CTM measures are done exactly at the same location on the VTAC slabs (Left: linear scale, Right: logarithmic scale)*

# Texture smoothening

1. **Texture decomposition**

The profile decomposition procedure to derive the constituent fundamental Intrinsic Mode Functions IMFs follows a method called Empirical Mode Decomposition (EMD) that is part the a part of the Huang Hilbert Transform (HHT) (See Equation 8). The details of that decomposition can be found in Huang's publication cited at [7].

 Equation 8

Where, x represents the distance in the texture profile, *Z(x)* is the height of a point located at distance *x* in the profile, *Cj(x)* is the *jth* IMF, *n* is the total number of IMF and *rn(x)* is the residue obtained after the decomposition.

1. **Creating the new profiles**

After the original profile of the VTAC slabs is captured with the CTM it is decomposed to a multitude of constituent IMF, the first IMF is subtracted from the original profile to derive the first smoother profile (in comparison to the original profile) named “*Profile 1*”. Then, the second IMF is subtracted from *Profile 1* to obtain a second even smoother profile named “*Profile 2*”. The original profile will named “*Original Profile*” for the rest of the text. The figure 4 displays the original profile and the two newly created smoother profiles. It can be seen that the original profile, the profile 1 and profile 2 display different level of Macrotexture and Microtexture.

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| *Original Profile* |
|  |
| *Profile 1* |
|  |
| *Profile 2* |
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*Figure 4: Original Profile (Top) and the two smoother new created profiles, Profile 1 (Middle) and Profile 2 (Bottom)*

#  Results and discussion

The following figure 5 show the skid resistance against speed predicted by the DFM for the *Original Profile* (yellow points), *Profile 1* (red points) and *Profile 2* (blue points). The vertical and horizontal axes represent respectively the friction coefficient and the speed per km/h. The left and right figures mean the same, but have different scales for the speed axis (respectively linear and logarithmic).

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*Figure 5: skid resistance against speed predicted by the DFM for the Original Profile (yellow points), Profile 1 (red points) and Profile 2 (blue points). The vertical and horizontal axes represent respectively the friction coefficient and the speed per km/h. The left and right figures mean the same but have different scales for the speed axis (respectively linear and logarithmic)*

The *Original Profile which* embeds both sufficient Microtexture and Macrotexture, maintains high skid resistance at almost all speed increases. It is from 40 km/h that is a slight drop of the skid resistance is noted. This slight drop of the skid resistance draws attention to the fact that whatever the quality of the Macrotexture and Microtexture present on the road surface, there exists a speed limit from which skid resistance will drops down.

The *Profile 1*, smoother than the *Original Profile* at the Microtexture scale, produces lower skid resistance than the latter at all simulated speeds. This behavior highlights the key role of the Microtexture in insuring skid resistance. The drop of the skid resistance with increased speed is faster for the *Profile 1* compared to the *Original profile*. This shows also the importance of the Microtexture in maintaining skid resistance at all speeds. Furthermore, the speed limit at which the skid resistance starts dropping arrives earlier than of the *Original Profile*.

The *Profile 2*, smoother than the *Profile 1* at the Macrotexture scale, produces the same skid resistance as *Profile 1* at very low speeds. But, this skid resistance drops down drastically when the speed starts to increase and becomes eventually nil (total hydroplaning) at 40 km/h. This behavior points out the crucial role of the Macrotexture in maintaining the skid resistance on wet roads when at high speeds. Indeed, this scales contributes actively to the escape of the water trapped in contact.

For two wet road surfaces with same Macrotexture, the higher the Microtexture is the better the skid resistance at all speeds will be, even if it exists at a speed limit, at which skid resistance will start to drop. For two wet road surfaces with same Microtexture, the higher the Macrotexture is, the later hydroplaning will happen.

# Conclusion

The paper aimed to identify the role the Macrotexture and Microtexture of road surface. To do so, the ‘Dynamic Friction Model’ (DFM), recently developed is used to simulate the skid resistance of a road surface smoothed to different degrees. The smoothing procedure of the road surface was derived by successively subtracting from the original profile of the road surface the first and second fundamental Intrinsic Mode Functions (fundamental profiles). These fundamental Intrinsic Mode Functions are obtained by decomposing the original profile of the road surface using an Empirical Mode Decomposition method that part of the Huang Hilbert Transform technique.

The results obtained by using the DFM on these three different surfaces show that for two wet road surfaces with same Macrotexture, the higher the Microtexture is, the better the skid resistance will be at all speeds, even if it exists at a speed limit from which the skid resistance will start to drop. Furthermore, for two wet road surfaces with same Microtexture, the higher the Macrotexture is, then the later the hydroplaning will occur.

# References

1. ISO 13473-2: 2002, Characterization of pavement texture by use of surface profiles - Part 2: Terminology and basic requirements related to pavement texture profile analysis, 2002.

2. Malal Kane; Minh-Tan Do; Veronique Cerezo; et al., Contribution to pavement friction modelling: an introduction of the wetting effect, International Journal of Pavement Engineering, Pages: 1-12, 2017, DOI: 10.1080/10298436.2017.1369776

3. Kane M. and Cerezo V., Sep 2015. A contribution to tire/road friction modelling: from a simplified dynamic frictional contact model to a ‘dynamic friction tester’ model Wear 342. 163–171. DOI: 10.1016/j.wear.2015.08.007

3. W.O. Yandell, A New Theory of Hysteretic Sliding Friction, Wear, Vol.17, April 1971, pp 229-244.

5. H. Gert, Hysteresis Friction of Sliding Rubbers on Rough and Fractal Surfaces, Rubber Chemistry and Technology, Vol. 70, No. 1, March 1997, pp 1-14.

6. M. Villani, I. Artamendi, M. Kane, A. Scarpas, The Contribution of the Hysteresis Component of the Tire Rubber Friction on Stone Surfaces, Journal of the Transportation Research Board, No. 2227, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp 153–162.

7. Kane, M., Rado, Z., and Timmons, A., 2014. Exploring the texture–friction relationship: from texture empirical decomposition to pavement friction. International Journal of Pavement Engineering, 16(10), 919–928. doi:10.1080/10298436.2014.9729567

8. H. Huang, J. Pan, Speech pitch determination based on Hilbert-Huang transform, Signal Processing 86 (4), 2006, pp. 792–803. DOI:10.1016/j.sigpro.2005.06.011.

9. C. Cho, S. M. Stoffels, Z. Rado, Application of Hilbert Huang Transformation to analyze pavement texture-friction relationship, Thesis of the Pennsylvania State University, 2010.

10. ASTM E1911, Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester, Developed by Subcommittee: [E17.21](http://www.astm.org/COMMIT/SUBCOMMIT/E1721.htm), Book of Standards Volume: [04.03](http://www.astm.org/BOOKSTORE/BOS/0403.htm). http://enterprise.astm.org/filtrexx40.cgi?+REDLINE\_PAGES/E1911.htm

11. ASTM E1960 - 07(2011), Standard Practice for Calculating International Friction Index of a Pavement Surface, Developed by Subcommittee: [E17.21](http://www.astm.org/COMMIT/SUBCOMMIT/E1721.htm), Book of Standards Volume: [04.03](http://www.astm.org/BOOKSTORE/BOS/0403.htm). http://enterprise.astm.org/filtrexx40.cgi?+REDLINE\_PAGES/E1960.htm