Asphalt Rubber blends: technical and environmental benefits

Prof. Filippo G. Praticò

Framework

ELT management	Regulatory framework	Tyre composition	Recycling applications	Recycling into transportation infrastructures
Railways (sleepers, barriers)-Roads (asphalts/bases)	Tyre treatment	CR pre-treatment	Proprietary products	Mix design/Process
Wet/Dry//on site/in plant/at terminal/percentage/size?	CR-bitumen interaction	Mix curing/conditioning	CR impact on mixture/pavement	CR impact on agency-user/costs/sustainability

Tyre and plastics (Tyre composition)- che cosa c’è in un pneumatico

- Crude oil- Petroleum → plastics (from polymers), synthetic rubbers (artificial elastomer, polymers synthesised from petroleum)
- Tree latex → natural rubber.

coal tar, vegetable matter, or petroleum products → carbon black

Tyre composition:

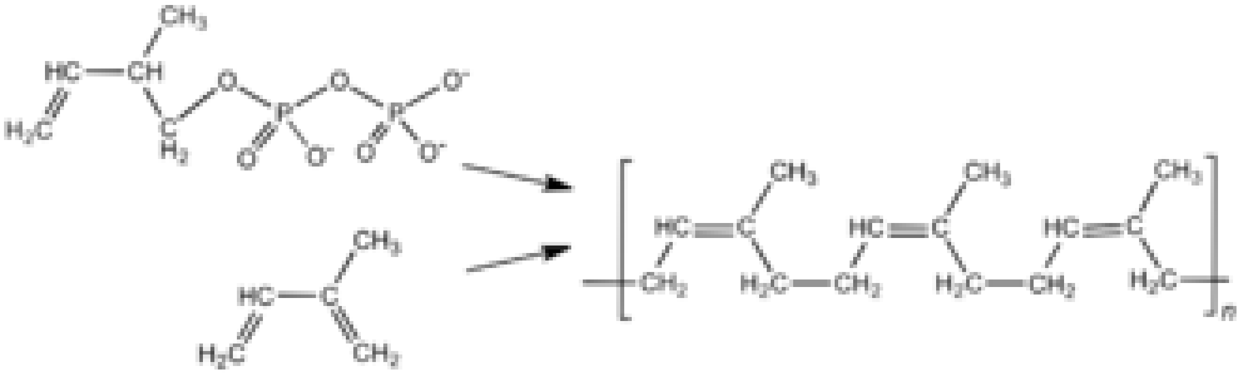
- Rubber (natural-15/30% and synthetic) 41%-47%
- Fillers (carbon black-22%, silica, carbon, chalk…) 30%
- Reinforcing materials (steel, polyester, rayon, nylon) 15%-17%
- Plasticizers (oils and resins)[1] 6%
- Chemicals for vulcanization (sulphur, zinc oxide…) 6%
- Anti-ageing agents and other chemicals 2%

https://btmauk.com/about/what-are-tyres-made-from/#:~:text=Focus%20on%20natural%20rubber&text=Truck%20tyres%20contain%20typically%2030,for%20heavy%20load%2Dbearing%20tyres.

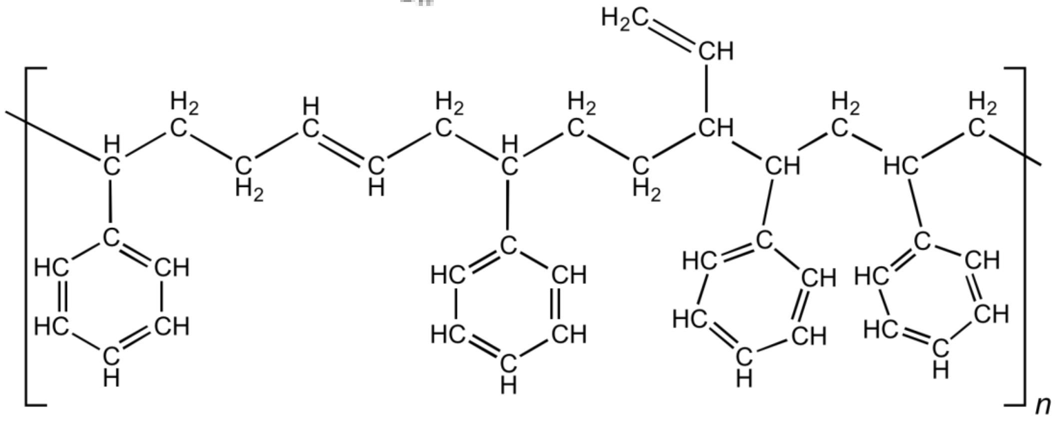
Nataural vs. Synthetic rubber (Che cosa è un pneumatico nelle componenti gommose)

HC: hydrocarbon… idrocarburi.
S: Sulfur (Zolfo).
O: Oxigen.

- Natural rubber

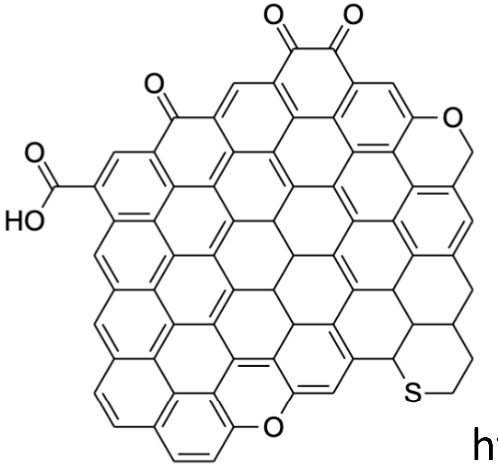


- SBR (styrene-butadiene rubber- Synthetic rubber)



https://en.wikipedia.org/wiki/Styrene-butadiene

Carbon black



https://en.wikipedia.org/wiki/Carbon_black

Why do they use natural/synthetic rubber and carbon black? Perchè?

The top advantages of natural rubber include:

- High tensile strength
- Resistant to tearing and abrasion
- Resistant to compression
- Dampens vibrations well
- Strong adhesion abilities

Generally, though, synthetic rubber has these functional benefits:

- Withstands extreme temperatures well
- Resistant to chemical damage
- Resistant to damage from sunlight, ozone, and weather
- Strong electrical insulation
- Flexible at low temperatures

Carbon black:

- improves tensile strength and wear resistance

Price/Density

- Synthetic Rubber: $2 - $9.4 / kg-------------- 1.22 g/cm3
- Certified Natural Rubber $2.30 - $2.65 / kg---1.43 g/cm3
- Bitumen: 0.5-1.5 $ / kg-------------------------------1.02 g/cm3
- Carbon black: 0.850-1.310 $ / kg-----------------1.8–2.1 g/cm3

https://www.yulex.com/post/natural-vs-synthetic-rubber-top-differences-and-why-you-should-go-natural

Pros and contras

Mechanics/Volumetrics	Other
• Rutting resistance ☺	• Blending quality ☹
• Thermal reflective cracking resistance ☺ (?)	• Settlement in the tank ☹
• Moisture resistance ☺	• Noise reduction ☺ 😐
• Resistance to fatigue cracking (?)	• Smooth ride ☺ 😐
• Premature reflecting cracks (?)	• Rolling resistance 😐 ☹
• Alternative to polymers ☺	• Reduction in maintenance costs ☺
• Ultraviolet resistance ☺	• Skid resistance 😐
• Mechanical impedance/Dynamic stiffness 😐	• Higher costs ☹
• Air Voids ☺ 😐	• Odours ☹
	• Mixing/Workability/compactability 😐
	• Recyclability 😐

Noise impacts (in general)

- Noise-induced hearing loss;

- Cardiovascular effects;

- Psychological impacts

- Stress/Annoyance;

- Children’s physical development and Cognitive development;

- effects on animals.

Noise reduction (case study: Life Sneak)

CPX before:92. CPX after: 87 (due to the use of a mixture containing CR and having different grading and characteristics).

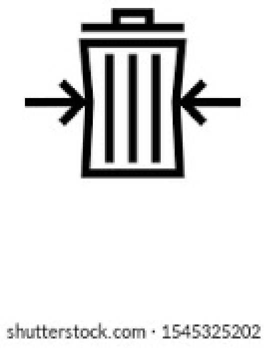
Noise reduction impacts (based on the relationship between CPX and noise levels, considering the relationships between health issues and noise levels) :

- during the first 10 years (approximate expected life of the two surfaces) the **noise-induced permanent threshold shift** (decrease in hearing ability, 50% percentile) in dB at various frequencies (e.g., 3kHz) will be lower (e.g., 1 dB) than for the existing pavement. (cf. Noise-induced permanent threshold shift, in dB, by ISO 1999 calculations).
- the reduction of
  - **%HSD** (self-reported Highly Sleep Disturbance) by 29%;
  - the **relative risk for hypertension** by 11%;
  - the **relative risk of myocardial infarction** by 14%;
  - the **present value of the noise-related externality costs** [126] by 20%;
  - %HA (**percentage of the population Highly Annoyed**) assessed with standardized scale by 25%.

Other CR-related impacts (case study: Life Sneak)

CPX before:92. CPX after: 87 (due to the use of a mixture containing CR and having different grading and characteristics).

- Waste reduction (tyres, 2.4 tons per year). Recycling of CR into the friction course. Main assumptions: 1) density and percentage of CR and tyres. 2) Lenghts as per project proposal. 3) Tyre type: common in commerce.
- Landfill saved (200 m3 per each maintenance cycle). Recycling of CR into the friction course
- Reduced resource consumption (Mineral aggregates): 0.1 tons/year. This is due to the use of crumb rubber in friction course mixture. The derivation of this value depends on the following baseline: HMA density, dimensions, CR percentage (w/w).



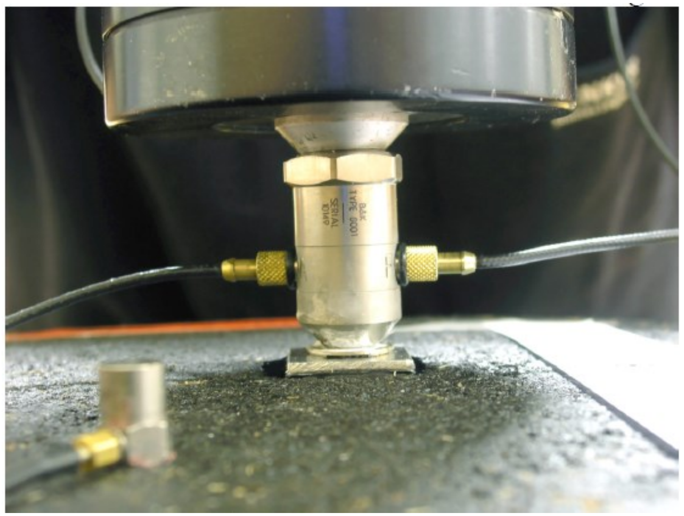
- Does “Softness” impact noise?

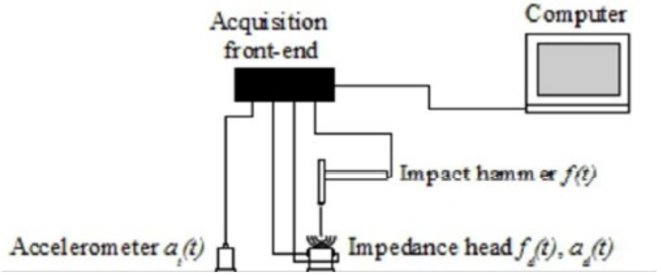
Road stiffness

Are Road Stiffness or/and other related physical properties relevant? (Cedric et al 2015)

Mechanical impedance and its reciprocal (mobility):

- **Z**=**F**(ω)/**v**(ω), **F** is the force vector, **v** is the velocity vector, **Z** is the impedance matrix and ω is the angular frequency.
- Resistance = the real part of an imp**e**dance;
- Reactance = the imaginary part of an impedance.
- Measures of mechanical impedance of roads and tires: see Cahlmers / Müller BBM, Project number: FP6-PL-0506437 – ITARI - Integrated Tyre And Road Interaction - D6.3 Technology for measuring mechanical impedance of road surfaces in-situ - 2004.
- **Standard: EN 29052-1**





Dynamic stiffness vs attenuation

$$s = \frac{F/A}{\Delta L} \qquad f_s = \frac{1}{2\pi}\sqrt{\frac{s'}{m'} - \frac{C^2}{4m'^2}} \approx f_{res} = \frac{1}{2\pi}\sqrt{\frac{s}{m}}$$

$$\Delta L_w = 18 + 15 \log \frac{m}{s}$$

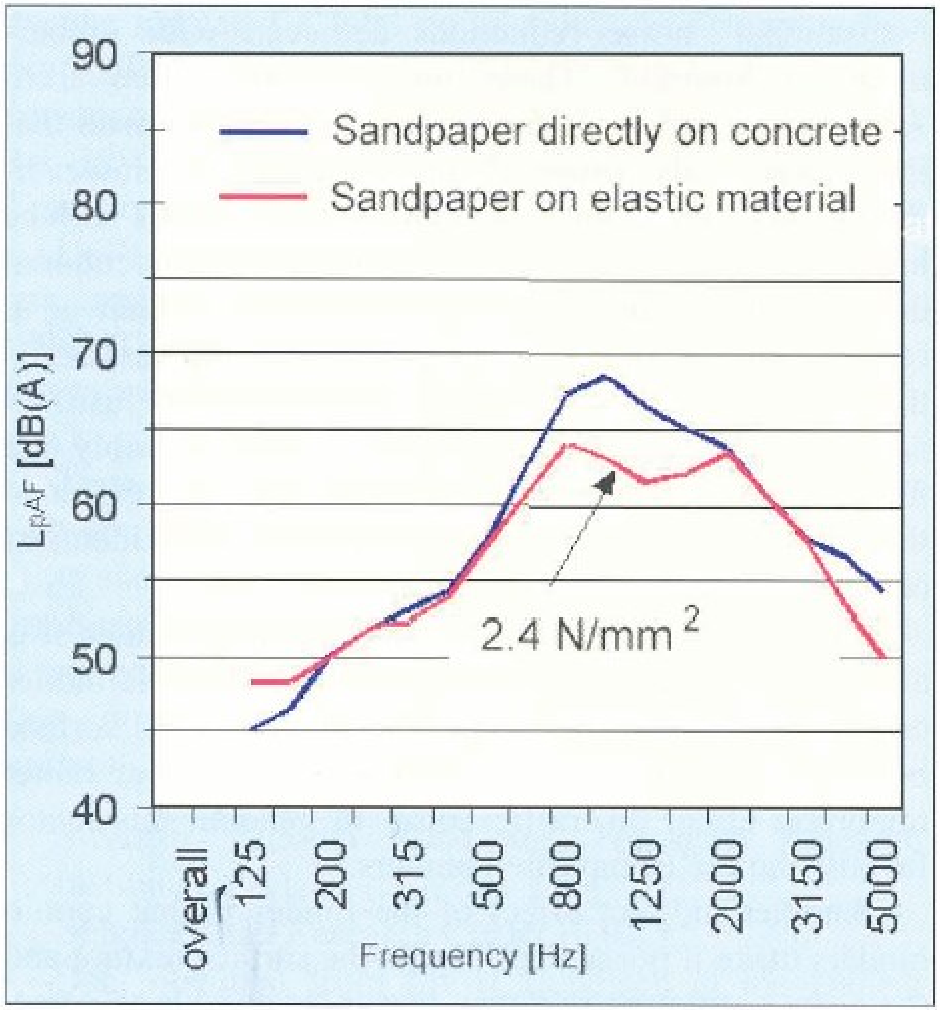
fs, Hz	s', MN/m3	m', kg/m2	DLw
61.00	29.38	78.40	24
137.70	149.64	65.00	13

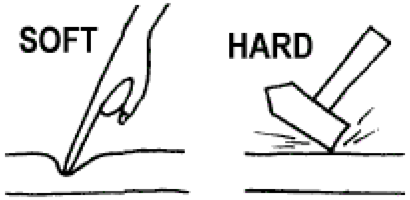
S=dynamic stiffness, N/m3;
F: the dynamic force acting perpendicularly to the sample,
A: the area of the sample
DL: the variation of length of the sample due to the force acting on it
M: the total mass/unit area placed on top of the material during the test, i.e. including the mass/unit area of the equipment used for the test (shakers, accelerometers etc.);
Fres= resonant frequency
C is the internal damping of the resilient layer [kg/s];
DLw= reduction in normalized impact sound pressure level

Dynamic Stiffness Of Materials Used For Reduction In Impact Noise: Comparison Between Different Measurement Techniques N. Baron, P. Bonfiglio, P. Fausti

Road Stiffness

Effect of inserting a soft rubber layer between a sandpaper sheet and a cement concrete (Sandberg and Ejsmont, 2002; Hamet and Klein, 2010)





Road stiffness and violins

Pavements and violins - Material properties vs. sound frequency

For instruments such as lutes, harps, guitars, pianos, violins and so forth:
f=resonant frequencies;
M=mass;
L=length of the string (for a string fixed at both ends);
T=tension (of the string);
V=speed of a wave traveling down the string;
ρ : **mass per unit length**.
Higher tension and shorter lengths increase the **resonant frequencies**. When the string is excited with an impulsive function (a finger pluck or a strike by a hammer), the string vibrates at all the frequencies present in the impulse (an impulsive function theoretically contains 'all' frequencies). Those frequencies that are not one of the resonances are quickly filtered out—they are attenuated—and all that is left is the harmonic vibrations that we hear as a musical note.

$$f = \frac{nv}{2L}$$

$$v = \sqrt{\frac{T}{\rho}}$$

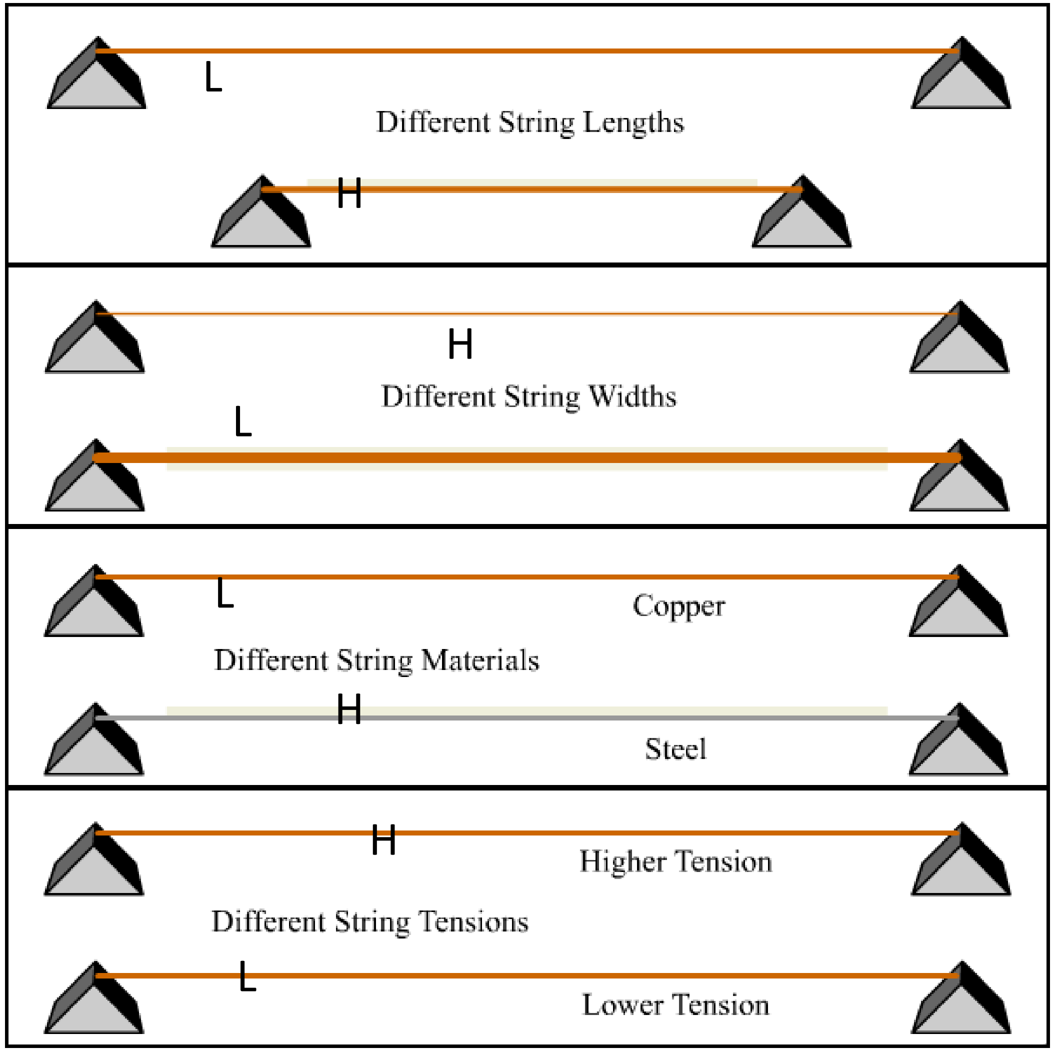
$$f = \frac{n\sqrt{\frac{T}{\rho}}}{2L} = \frac{n\sqrt{\frac{T}{m/L}}}{2L}$$

Copper 8940 *kg/m³*

Steel 7850 *kg/m³*

Road stiffness and violins

Pavements and violins - Material properties vs. sound frequency



$$f = \frac{nv}{2L}$$

$$v = \sqrt{\frac{T}{\rho}}$$

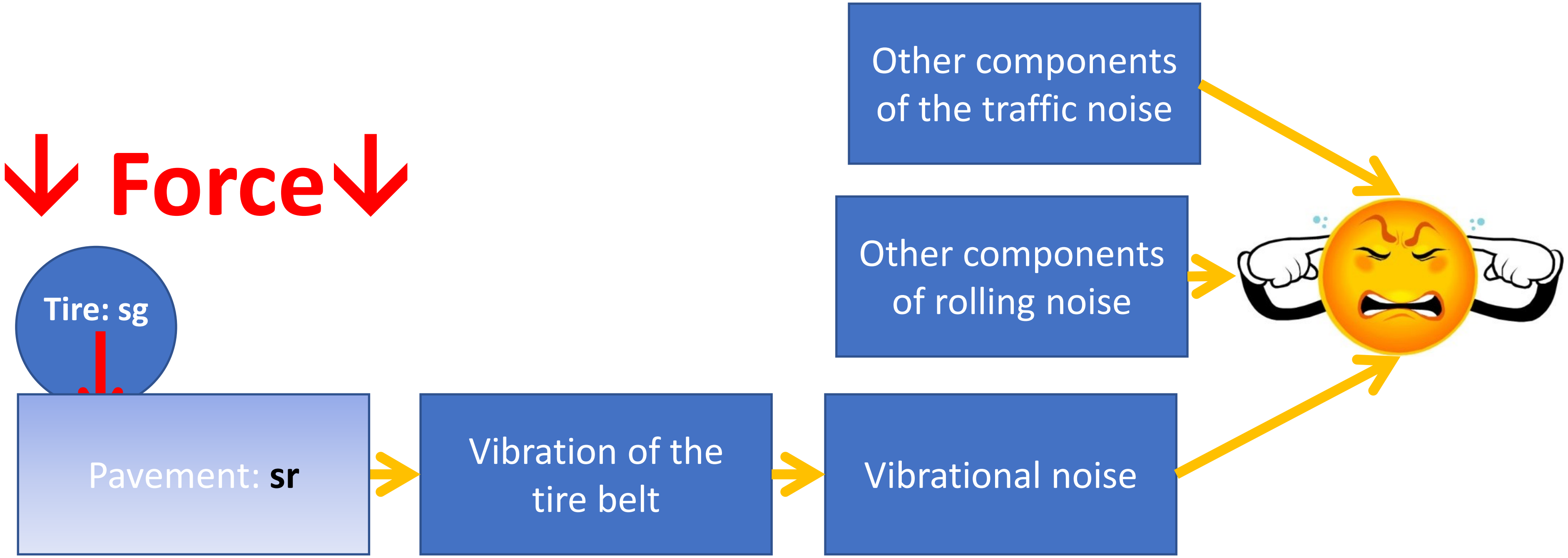
$$f = \frac{n\sqrt{\frac{T}{\rho}}}{2L} = \frac{n\sqrt{\frac{T}{m/L}}}{2L}$$

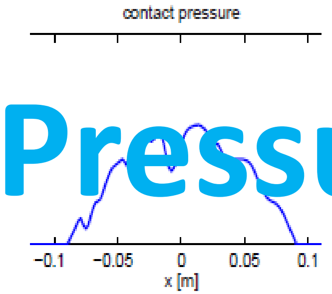
Copper: 8940 kg/m^3

Steel: 7850 kg/m^3

Road stiffness

How does pavement/tire stiffness affect rolling noise?





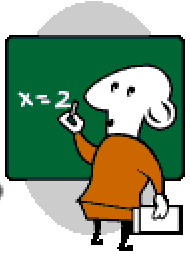
Pressures

Sg, sr=stiffness constant of the tire/road (N/m3)

Pavement and tyre stiffness generate tyre displacement

Hamet and Klein (2004-2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

$$m = \left(\frac{N}{m^2}\right) * \frac{\left(\frac{m}{s}\right)}{N} * m * m * s$$



F'': external pressure field in the contact zone

$$z_{tire}(x,y,t) = \int\int\int F''(x_o,y_o,t_o)G(x,y,t|x_o,y_o,t_o)dx_o\,dy_o\,dt_o$$

z, displacement of the tire

G, impulse response

$$F''(x,y,t) = s_g \Delta h_g(x,y,t)\,\mathrm{H}(\Delta h_g)$$

Stiffness constant of the gum (tire), *sg,* [N/m3]

Function H(*u*) = 1 if *u* > 0, H(*u*) = 0 otherwise.

Δhg=compression (> 0) of the gum at point (*x; y*) in the contact zone

Case A: Rigid road pavement

$$F'' = s_{eq}\,\Delta h_g\,\mathrm{H}(\Delta h_g) \qquad \frac{1}{s_{eq}} = \frac{1}{s_g} + \frac{1}{s_r}$$

Equivalent constant of the gum, *sg,* [N/m3]

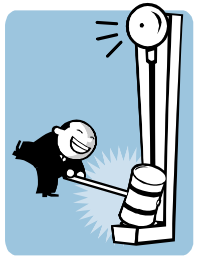
sr=stiffness constant of the road

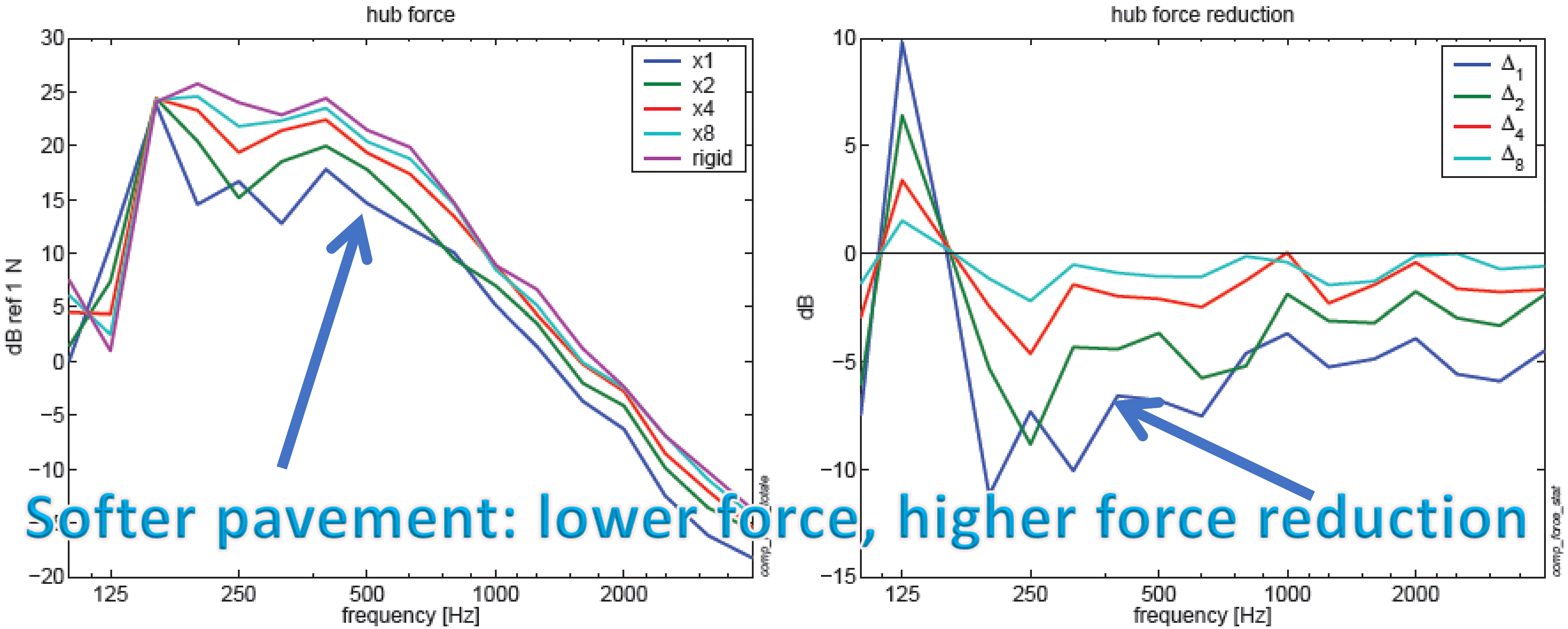
Case B: Elastic road pavement

Road stiffness **impacts global contact force**

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

- Hypotheses: given road profile; gum stiffness, sg = 65 MN/m3 or sg = 200 MN/m3 (rather hard gum). Pavement stiffness: sr =∞ or sr = n ·sg, where n = 1; 2;...Rolling speed: 30 to 150 km/h.
- Global contact force (the hub force, y-axis) as a function of frequencies : **the softer the pavement the lower the contact force.**



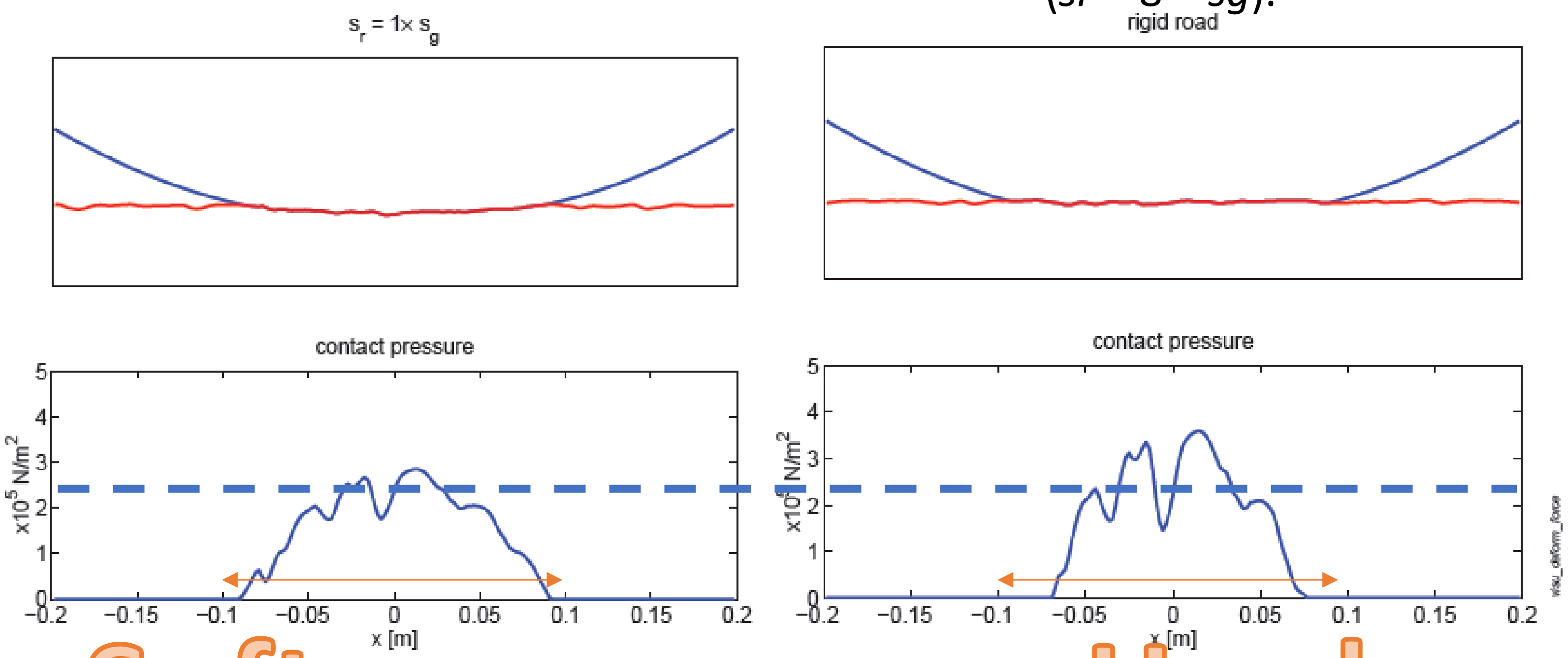


Road stiffness **impacts pressures and contact area**

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

- Contact pressure. Tire and road profiles (upper) and contact pressure (lower) for a soft (left) and a stiff (right) pavement. **<u>The softer the pavement the lower the contact pressure.</u>**

(*sr* = 8 * *sg*).



Softer Harder

Road stiffness **impacts the** radiated noise

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

- This noise evaluations address **the vibration noise only**. The road surface is acoustically reflective (no absorption). The results are presented in terms of noise power levels (i.e. the whole tire radiation) *LW*(*v; sr; f*). Note that unlike sound pressure, sound power is neither room dependent nor distance dependent. Sound power belongs strictly to the sound source. Vertical axis: ∆LW=Reduction of sound power, for the given speed and frequency, obtained with the road of stiffness sr=sg as compared to the rigid road case: **a negative value means that the non rigid road is quieter than the rigid road**.
- ***The higher the sg/sr ratio (the softer the pavement), the higher the speed, the higher the reduction of sound power which is caused from using a flexible and no rigid pavement.***

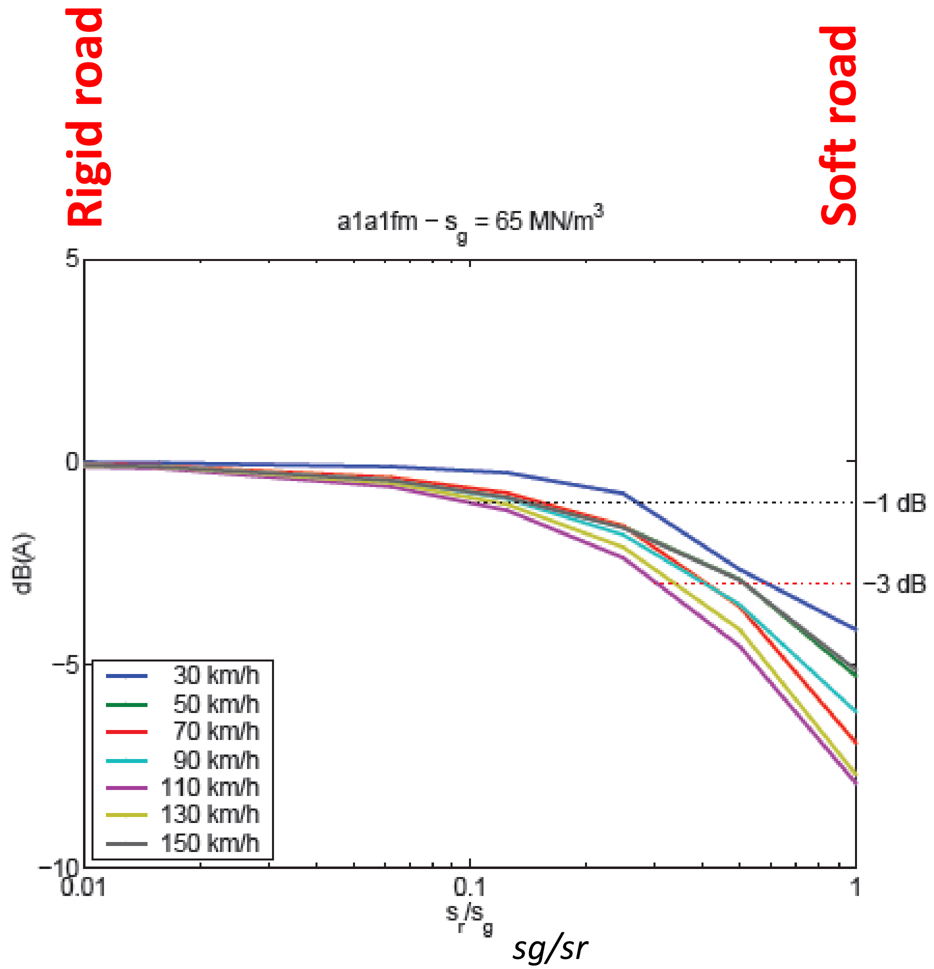
$$\Delta L_W = L_W(v, s_r, f) - L_W(v, \infty, f)$$

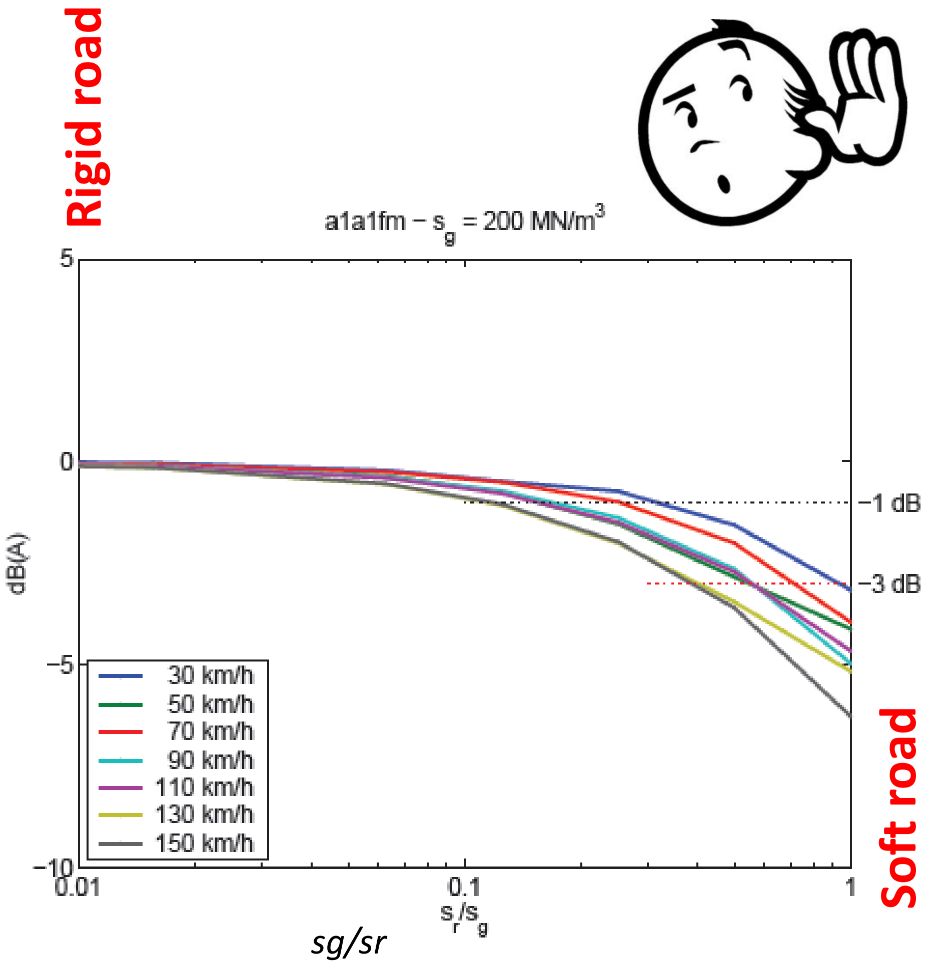
sg/sr *sg/sr*

Road stiffness **impacts** the radiated noise: simulations

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

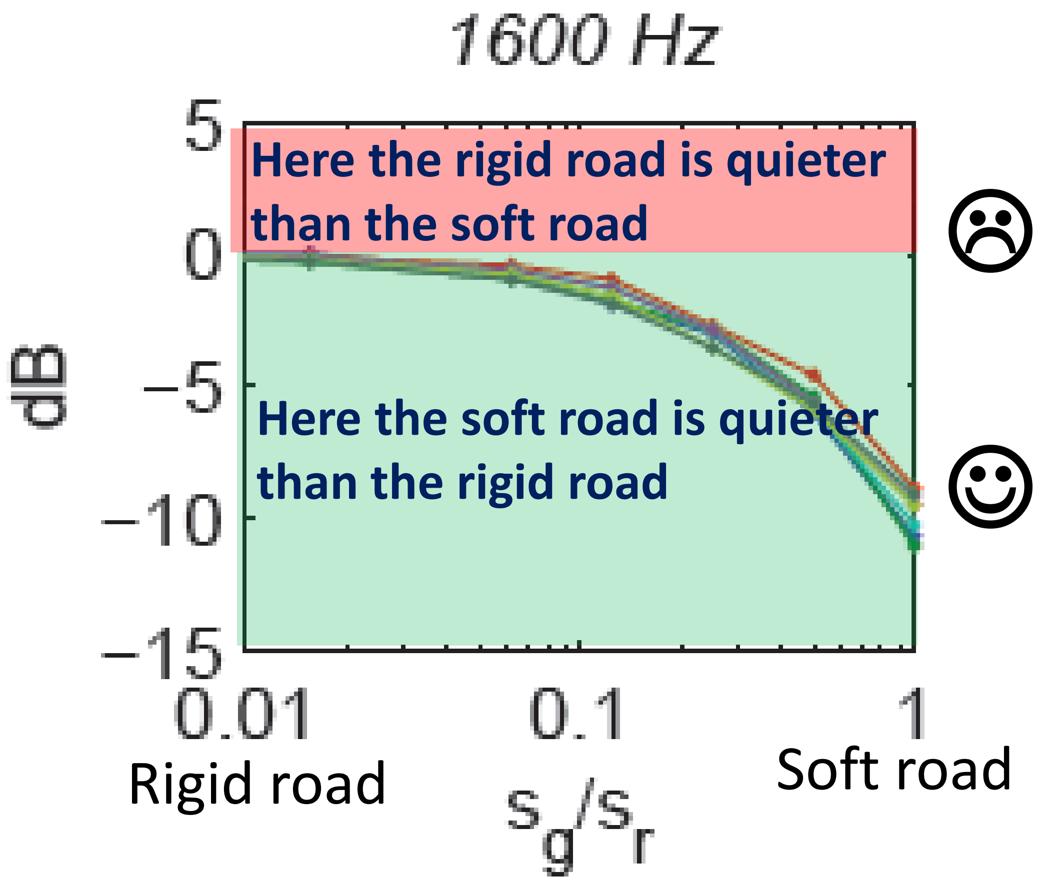
$$\Delta L_W = L_W(v, s_r, f) - L_W(v, \infty, f)$$





Road stiffness **impacts** the radiated noise: example at 1600Hz

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model☹☺



X-axis: stiffness of tire gum divided by stiffness of road.

Y-axis: Power noise spectra (1/3 octave spectra obtained at 50 km/h and 110 km/h): 6 curves per plot.

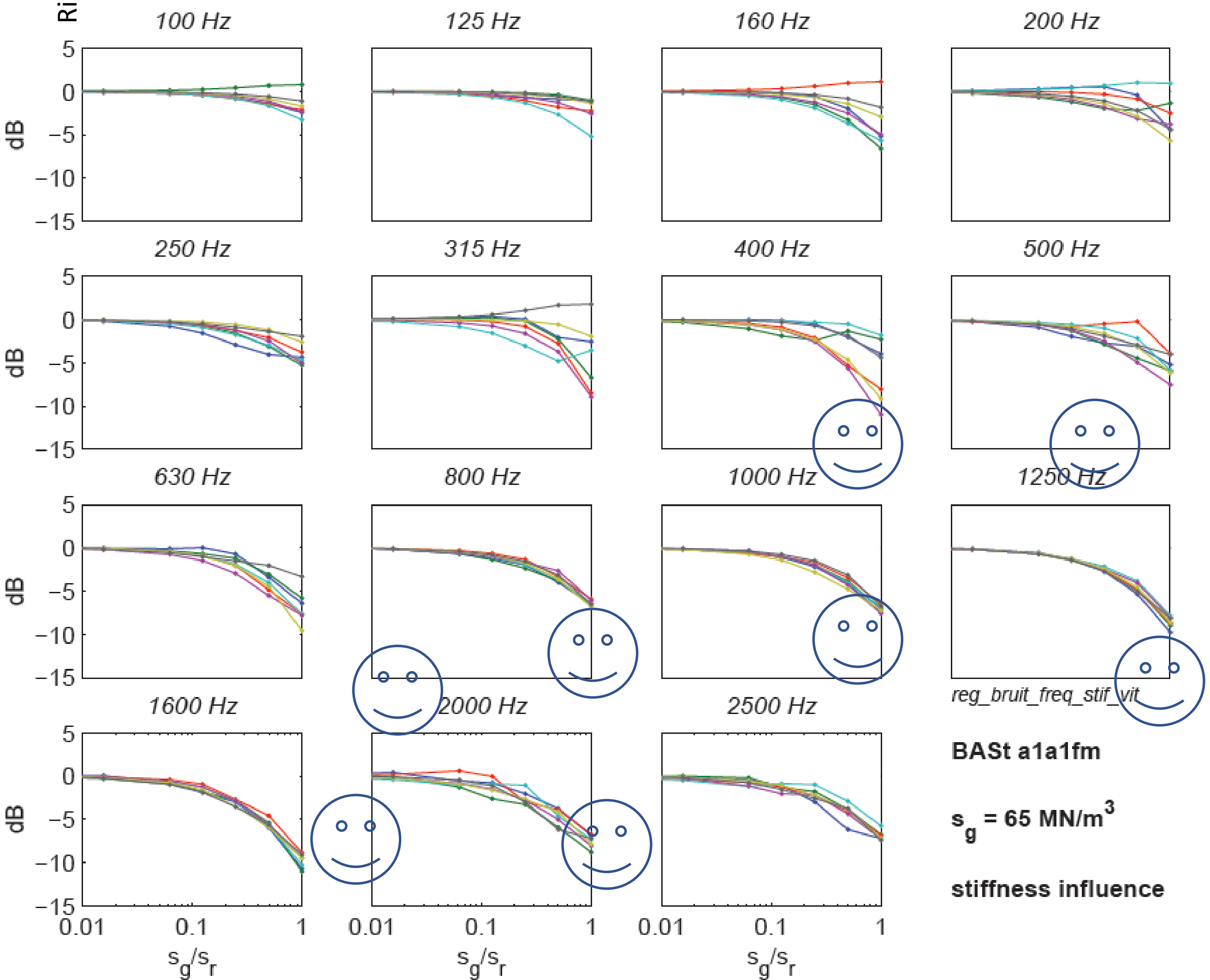
1600Hz: frequency of the simulation.

Curves: each curve corresponds to a given speed (30km/h, blue, to 150km/h)

Road stiffness **influences** the radiated noise:

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

Rigid road



Y-axis: Power noise spectra (1/3 octave spectra obtained at 50 km/h and 110 km/h): 6 curves per plot.

Road Stiffness influence: observations

- **<u>Vibration-induced noise might (or may?) be reduced if the road stiffness constant is decreased</u>** to the same order of magnitude than the tire stiffness constant.
- **<u>The reduction is rather independent of speed</u>** and may reach 5 dB(A). It is significant in the mid and high frequency range.
- Note that the vibration-induced noise ***is only a part of the tire noise*** (low and mid frequency range , up to about 1 kHz).
- According to several authors , decreasing the road stiffness also the air pumping noise decreases.

Road Stiffness influence: observations

Y-axis: Y/Ymax (i.e., *E* = *Ei*/ max *Ei*).
X-axis: Crumb rubber %.
An increase of percentage of CR (x-axis in Figure) and the corresponding variations in terms of air voids seems to imply:

1) The decrease of mechanical impedance (MI),
2) The decrease of the area under the impedance curve in 50-1250 Hz (Area MI);
3) The increase of the damping ratio (ζ);
4) The decrease of the modulus (*E*);
5) The decrease of the maximum acoustic response (maxAR)

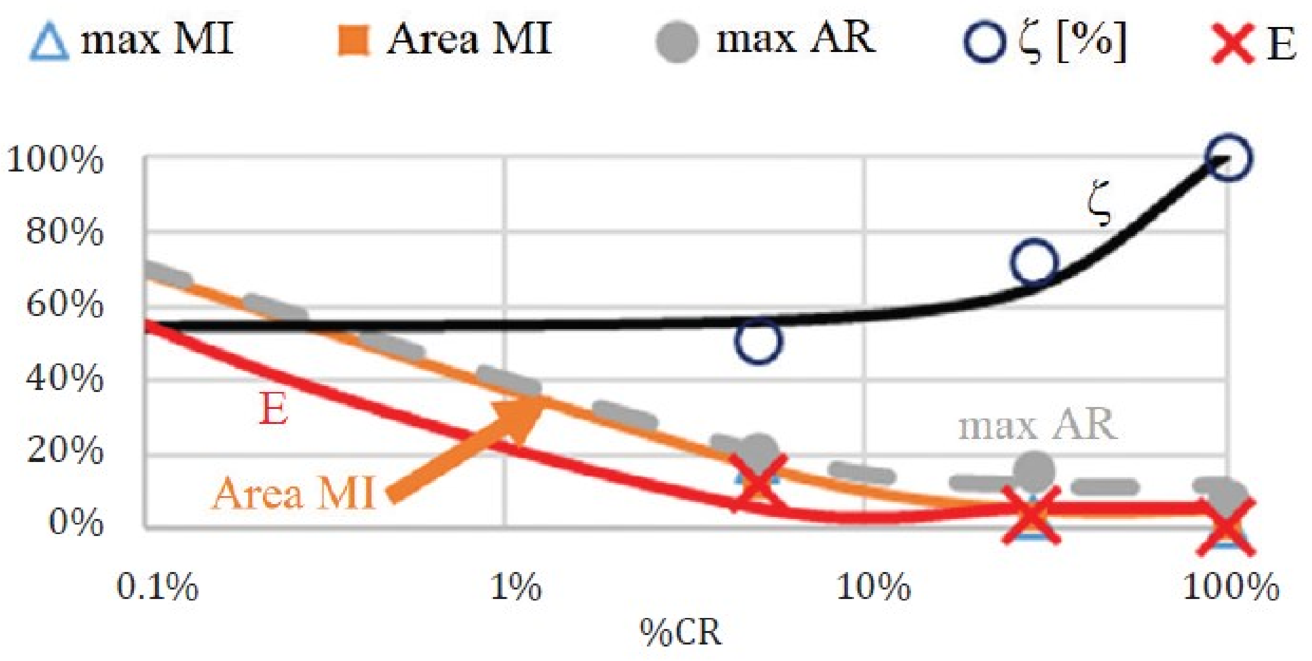


Figure 2. CR impact on noise (AR) and mechanistic response (MI, ζ, and *E*) elaborated from (Praticò et al., 2021b, 2021a)

RAR=road acoustic response

Praticò, F. G., Fedele, R., & Pellicano, G. (2021b). Pavement FRFs and noise: A theoretical and experimental investigation. *Construction and Building Materials*, *294*
PRATICO, FG, PELLICANO, G., BOLOGNESE, M., LICITRA, M., A STUDY ON FREQUENCY RESPONSE FUNCTIONS IN PAVEMENT ENGINEERING, Baltic JRE

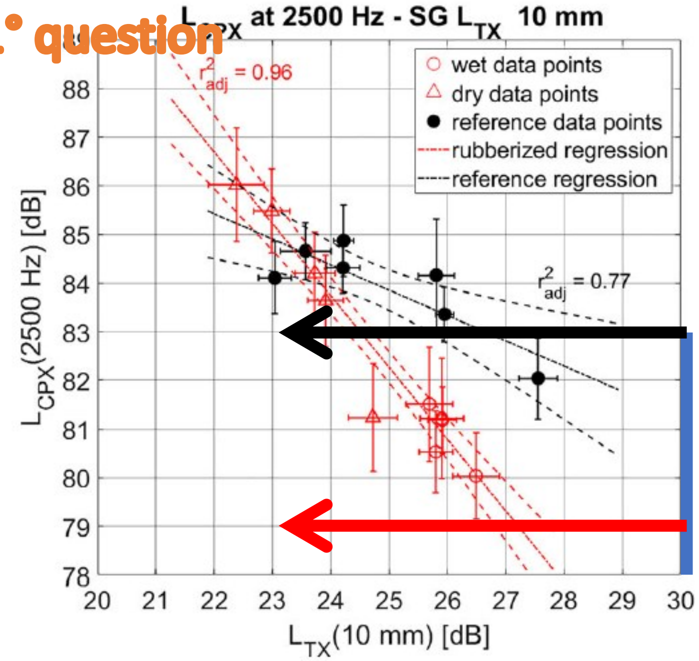
Road Stiffness influence: same grading, same texture level and different CPX level at 2500 Hz

1° question: Why does the same texture level correspond to a very different CPX level?

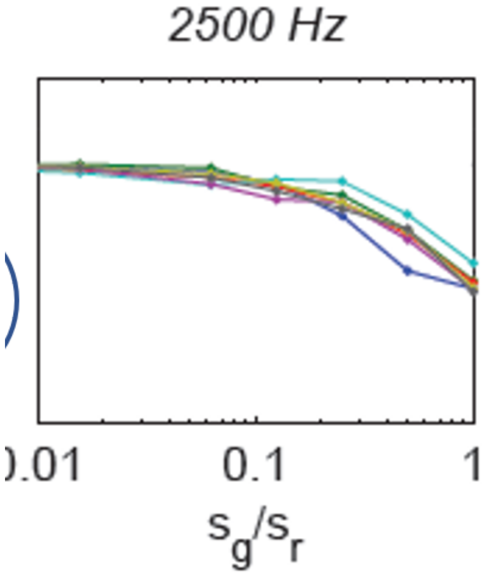
2° question: Is LCPX@2500Hz mostly impacted by airborn noise or/and by Radiated noise?

3rd question: are we talking about PERS?

1° question



2° question



3° question

Table 1 – Noise reductions for cars or car tyres at 50 km/h, obtained in some historic "full scale" trials with PERS

Country	Year	Manufacturer	Type of measurement	Noise reduction [dB(A)]	Remarks
Norway	1989	ViaNova A/S	CPB	7-9	On-site mix
Sweden	2004	VTI/Spentab	CPX	12	On-site mix
Sweden	2004	Rosehill	CPX	8	Prefab panels
Sweden	2004	Tokai	CPX	11	Prefab panels
Japan	2005	Tokai	SPB	7	Prefab panels
Japan	2005	Sumitomo	SPB	10	Prefab panels
Japan	2005	Yokohama Rubber Co.	SPB	10	On-site mix
Japan	2006-2009	Yokohama Rubber Co. & Nippon Road Co.	SPB	10	On-site mix

Gonzalo de León, Alessandro Del Pizzo, Luca Teti, Antonino Moro, Francesco Bianco, Luca Fredianelli & Gaetano Licitra (2020): Evaluation of tyre/road noise and texture interaction on rubberised and conventional pavements using CPX and profiling measurements, Road Materials and Pavement Design,

Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model

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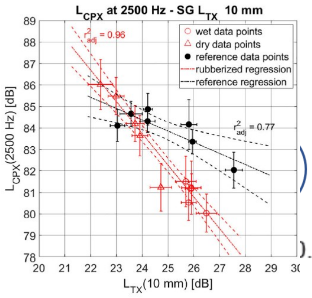
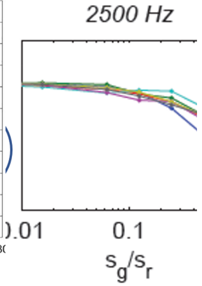
1° question 2° question 3° question





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Hamet and Klein (2010). Road stiffness influence on rolling noise - Parametric study using a rolling tire model
THE PORO-ELASTIC ROAD SURFACE (PERS): A POWERFUL TOOL FOR TRAFFIC NOISE REDUCTION L. Goubert U. Sandberg

List of DIIES experiences involving CR

- **Sulla buona strada project PIA CADI N. 3705 DEL 2010**
- SUS PAV (no rarx)-dry- lamezia terme CR plant – selant at the parco giochi ecolandia-red mixture and black mixtureTopic: Sustainable Pavements (SUSPAV). Funded by Regione Calabria (POR FESR Calabria 2007/2013 ASSE I RICERCA SCIENTIFICA, INNOVAZIONE TECNOLOGICA E SOCIETÀ DELL'INFORMAZIONE, **2013/14**-
- PERRI (Pavements that are self-Extinguishing, made of Recycled Rubber, and very Innovative) - Progetto "RETE REGIONALE DEI POLI DI INNOVAZIONE" - Polo Energie Rinnovabili, Efficienza energetica e Tecnologie per la gestione sostenibile delle risorse ambientali - POR FESR Calabria 2007/2013 ASSE I RICERCA SCIENTIFICA, INNOVAZIONE TECNOLOGICA E SOCIETÀ DELL'INFORMAZIONE-**2015**-
- Praticò, F.G., Moro, A., Noto, S., Colicchio, G. **(2016)**, Three-Year Investigation On Hot And Cold Mixes With Rubber, 8th International Conference on Maintenance and Rehabilitation of Pavements (MAIREPAV8), Singapore, 27 to 29 July 2016 (Research Publishing, Singapore).
- Praticò F.G., Moro, A., D'Agostino, P., An experimental investigation on innovative pavements for city logistics. In WIT Transactions on the Built Environment, volume 146, **2015**. ISSN: 1746-4498, Digital ISSN: 1743-3509. DOI: 10.2495/UT150261
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Thank you for your attention!