



Influencing parameters on force transmission of tires on snow tracks

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Introduction

Motivation – Outdoor and Indoor snow tests

Outdoor vehicle tests



strengths:

- real life conditions
- customer relevant
- high efficiency

constraints:

- just during winter periods
- interaction with vehicle
- no controlled test conditions

Indoor laboratory tests



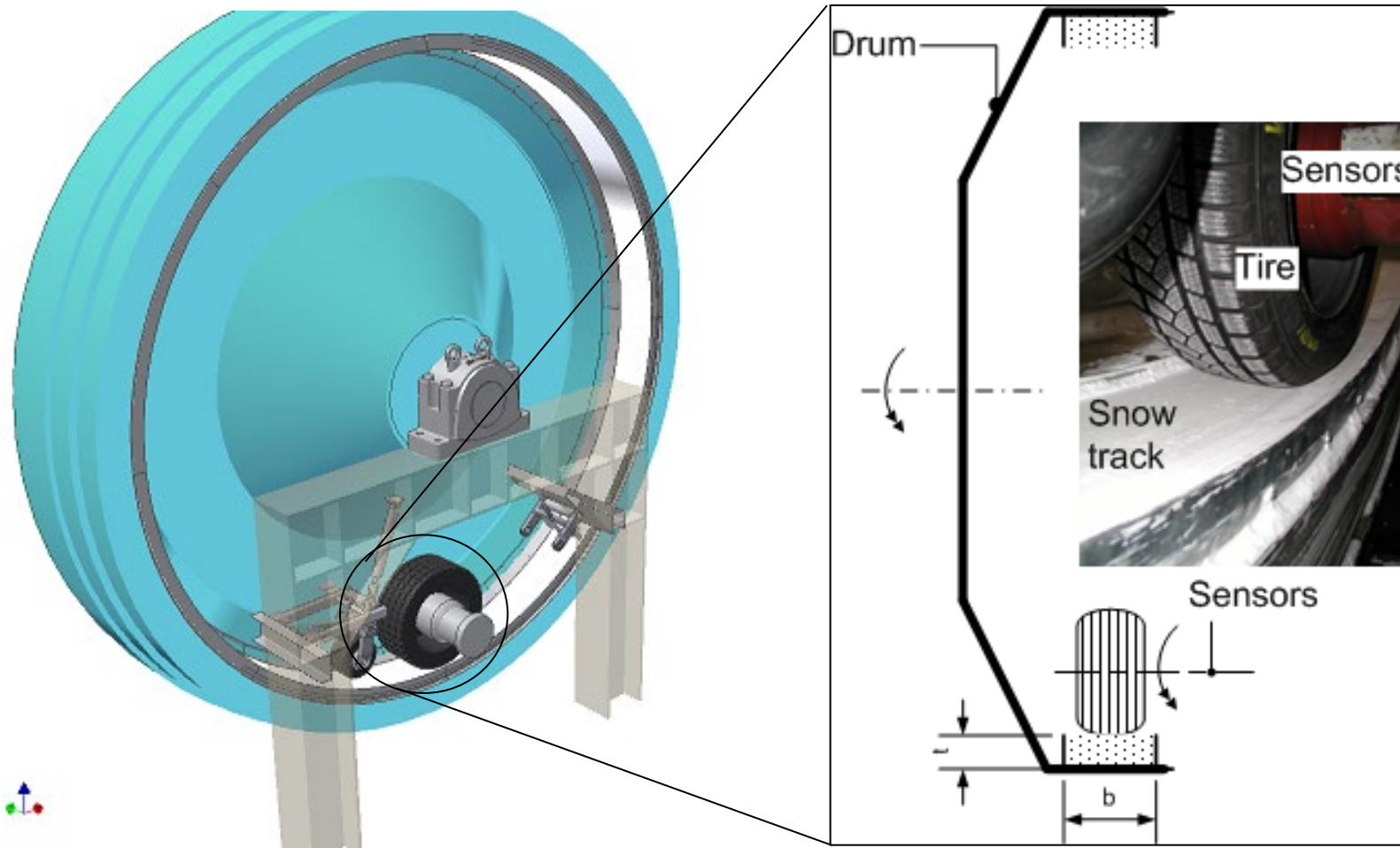
strengths:

- all year around winter testing
- just tire properties – no interaction
- controlled test conditions

The enrichment of Outdoor by Indoor lab testing is an ideal instrument to achieve all year around winter testing under highly controlled conditions.

Introduction

Indoor drum test rig for snow tests - technical data



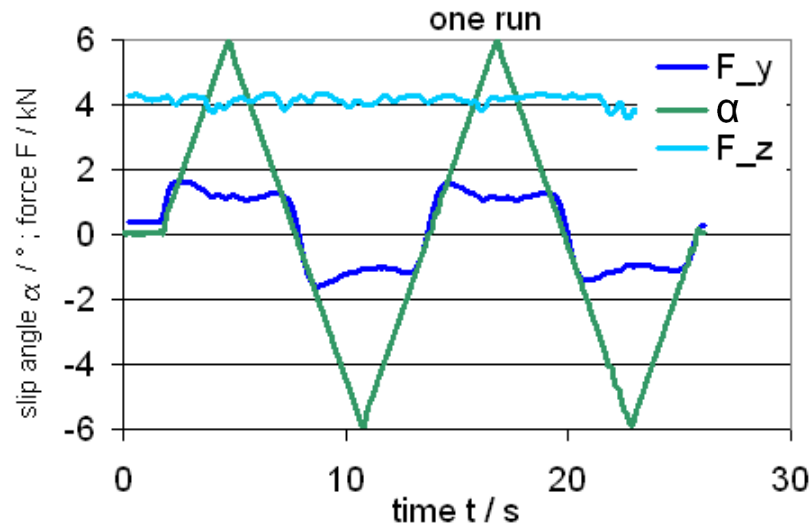
further tests:



- asphalt, concrete
- iced and wet tracks
- dynamic response at run over obstacle

Indoor tests

Procedure for side force measurement on snow

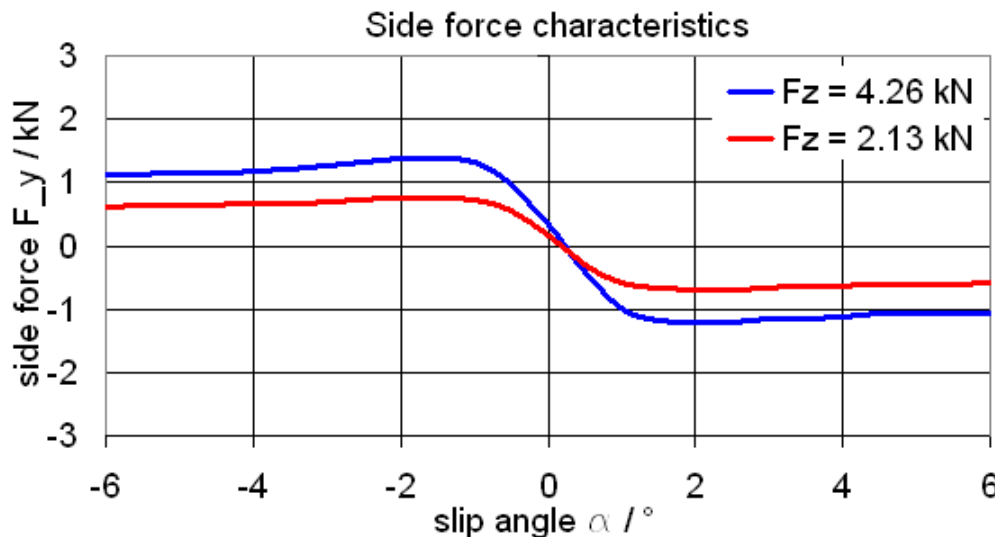
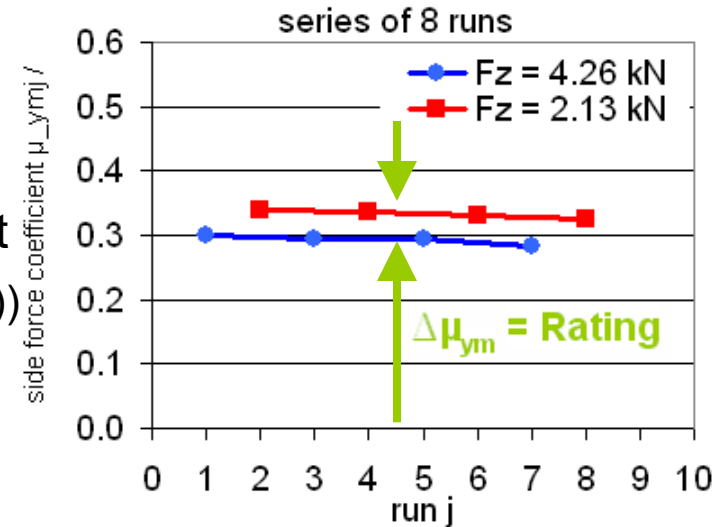


force coefficient

$$\mu_{y,i} = \frac{F_{y,i}}{F_{z,i}}$$

average force coefficient

$$\mu_{y,m} = \frac{1}{n} \sum_{i=1}^n (\mu_{y,i} (1^\circ \leq |\alpha_i| \leq 5^\circ))$$

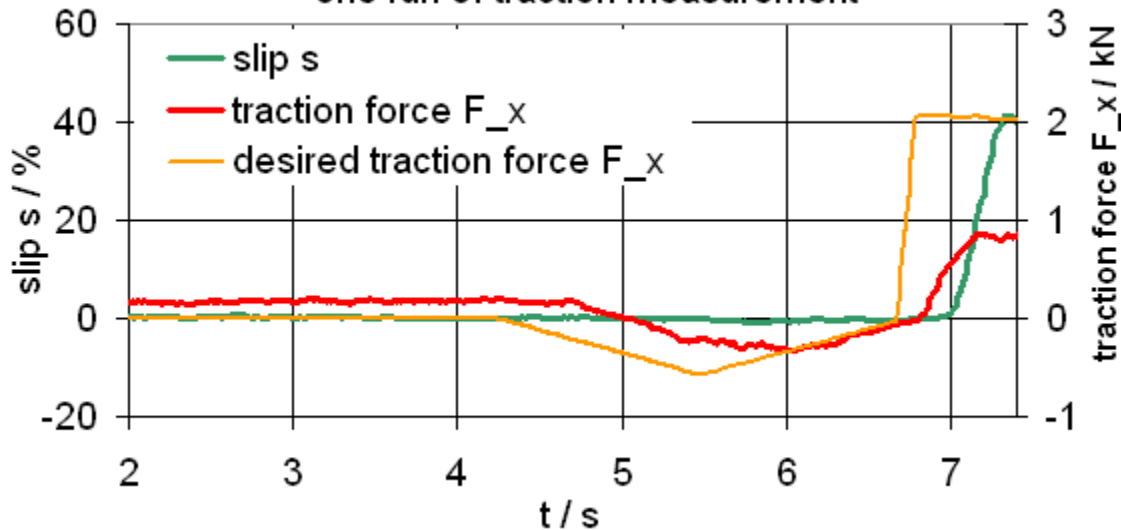


Tire's side force performance determined in 4 single alternated runs and compared to one reference tire.

Indoor tests

Procedure for traction force measurement on snow

one run of traction measurement



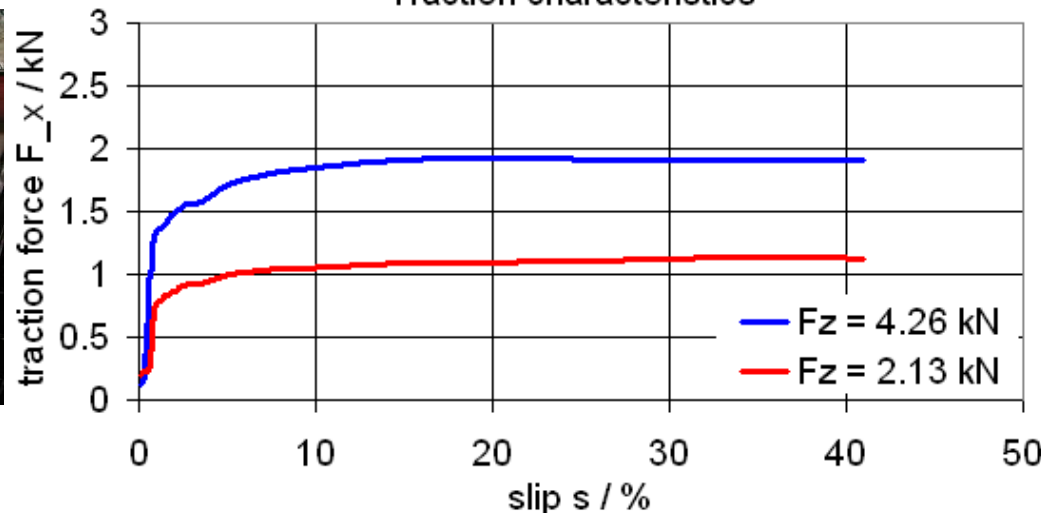
force coefficient

$$\mu_{x_i} = \frac{F_{x_i}}{F_{z_i}}$$

average force coefficient

$$\mu_{x_m} = \frac{1}{n} \sum_{i=1}^n (\mu_{x_i} (10\% \leq |s_i| \leq 40\%))$$

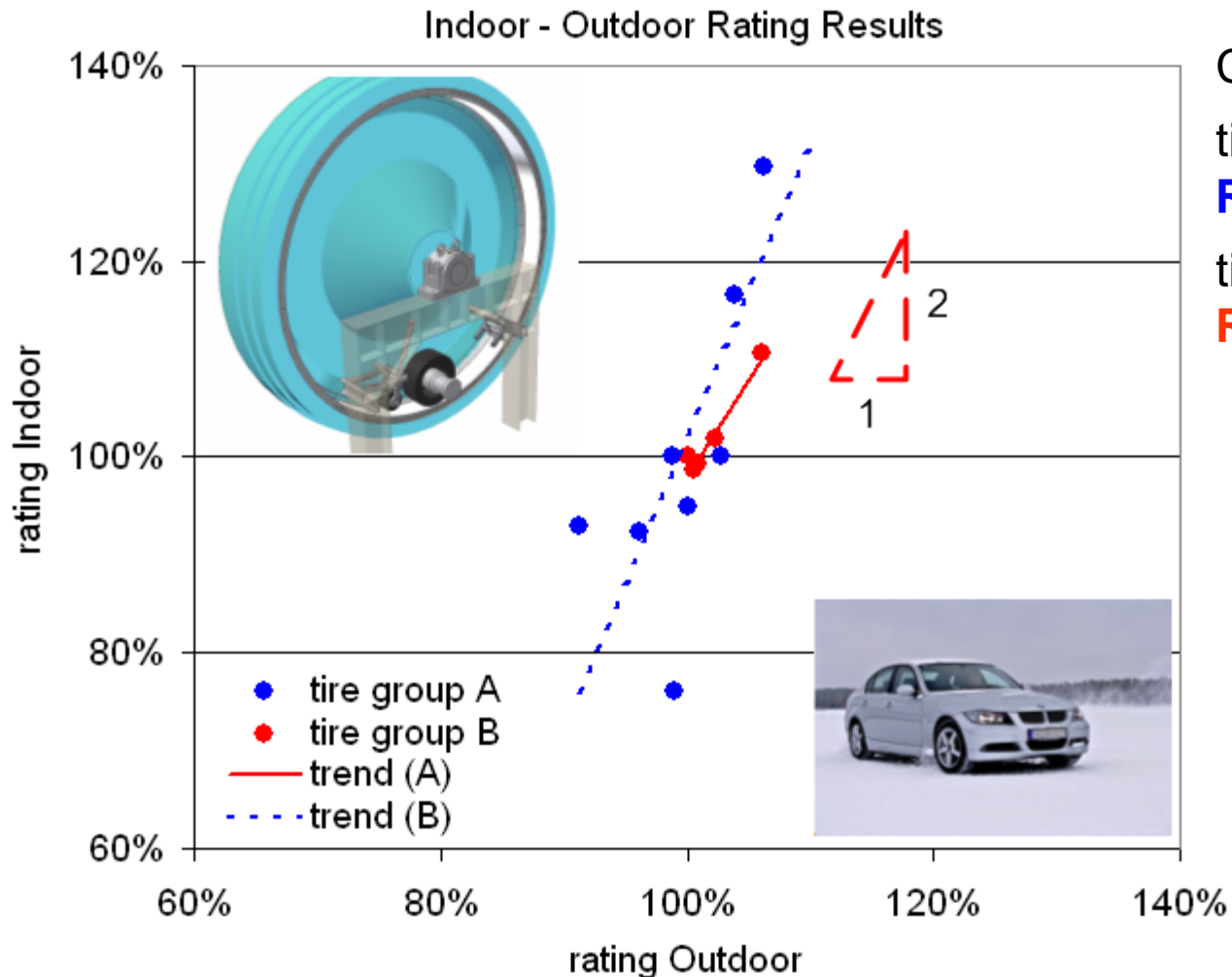
Traction characteristics



Tire's traction performance is again compared with one reference tire.

Indoor tests

Correlation Outdoor – Indoor for driving traction results



Correlation:

tire group A (-14 ... -8°C):

$R^2 = 80\%$

tire group B (-12 °C):

$R^2 = 95\%$

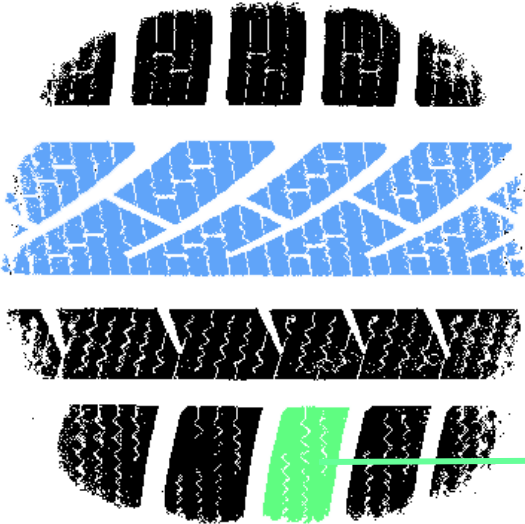
- Excellent correlation at same boundary conditions.
- Higher spread of results.

Parameter Studies

Tested tires

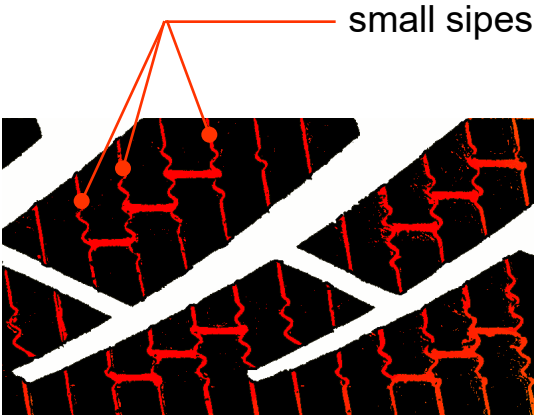
Name	size	Load Index	Speed Index	ETRTO max. load	shore (A)	tread pattern
All Season	205/55 R16	91	H	5.4 kN	> 65	ripped, less small sipes
Winter Sport		94	V	6.5 kN	60 – 65	band-shaped and many small sipes
Winter		91	H	5.4 kN	60 – 65	less band-shaped, thicker sipes and many small sipes
Nordic		91	Q	5.4 kN	< 60	high structured, blocks and high sipe density

tire “winter”:



band

block



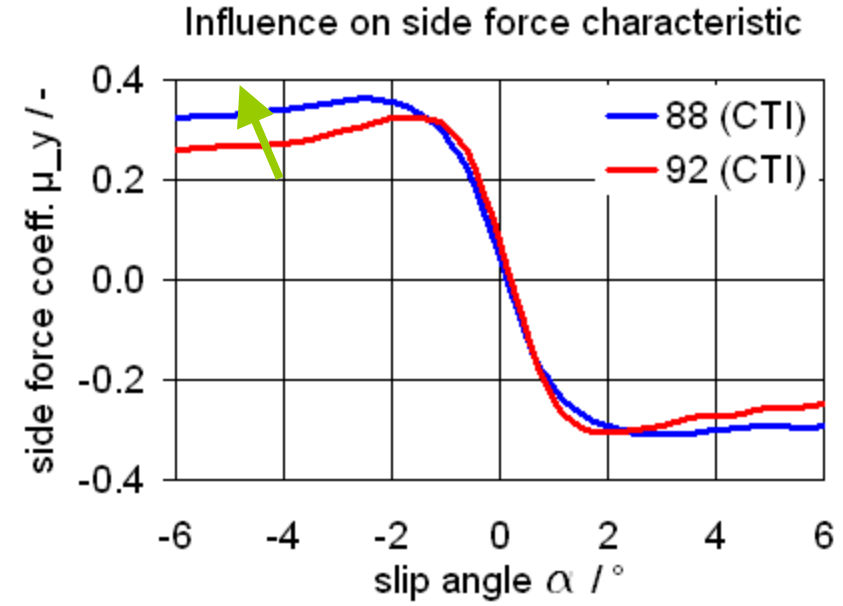
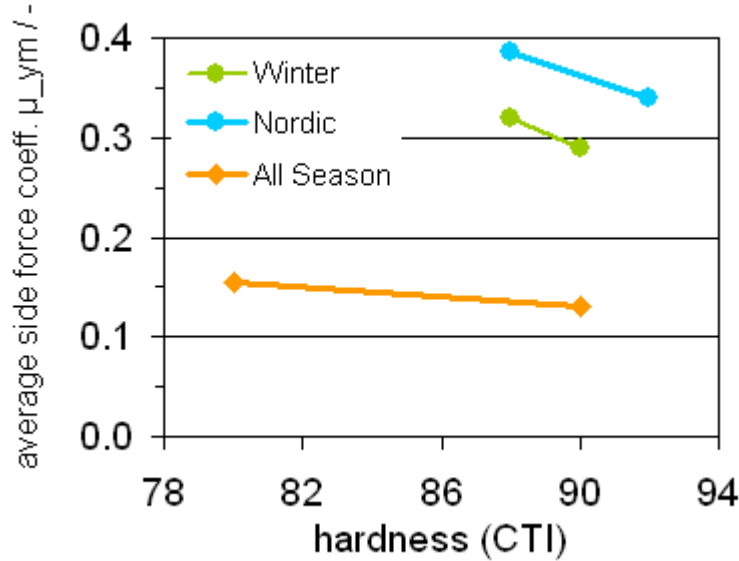
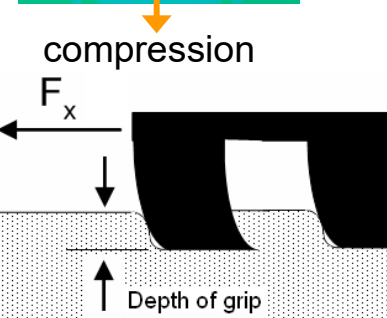
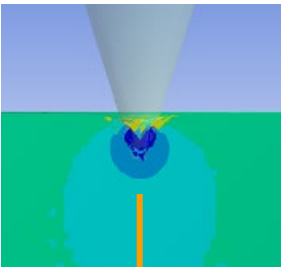
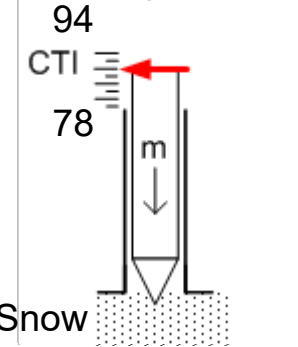
small sipes

- Typical winter tires tested within parameter studies.

Parameter Studies

Track characteristic – Influence of track hardness

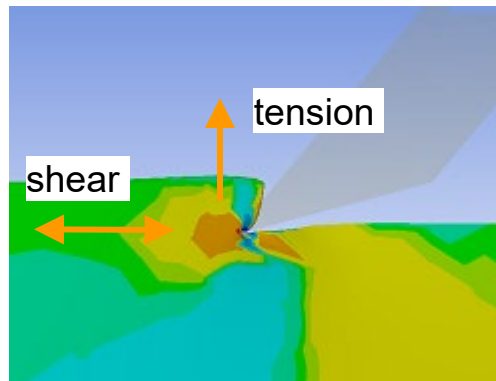
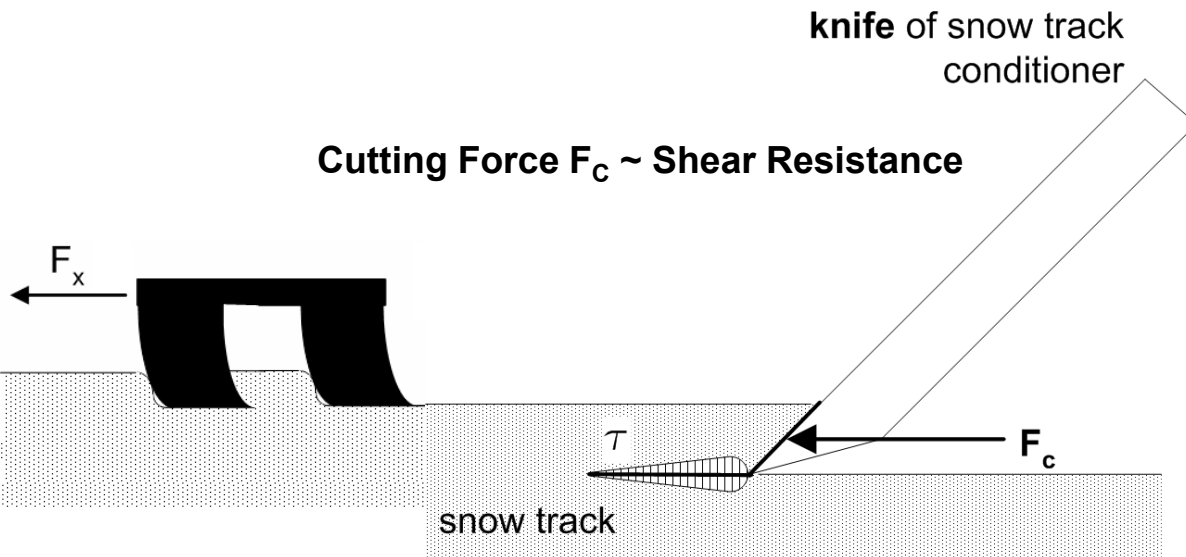
Penetrometer
mass $m = 0.218 \text{ kg}$
drop height = 0.22 m



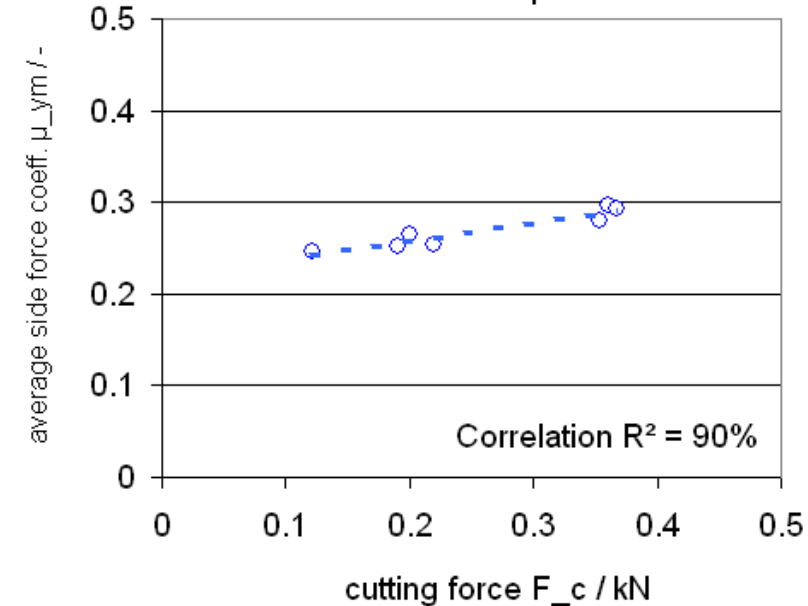
- **Penetrometer - Determination of local track hardness and compressibility.**
- **sipes filled with snow at low hard tracks**
→ increase of snow/snow friction.

Parameter Studies

Track characteristic – Influence of snow shear resistance



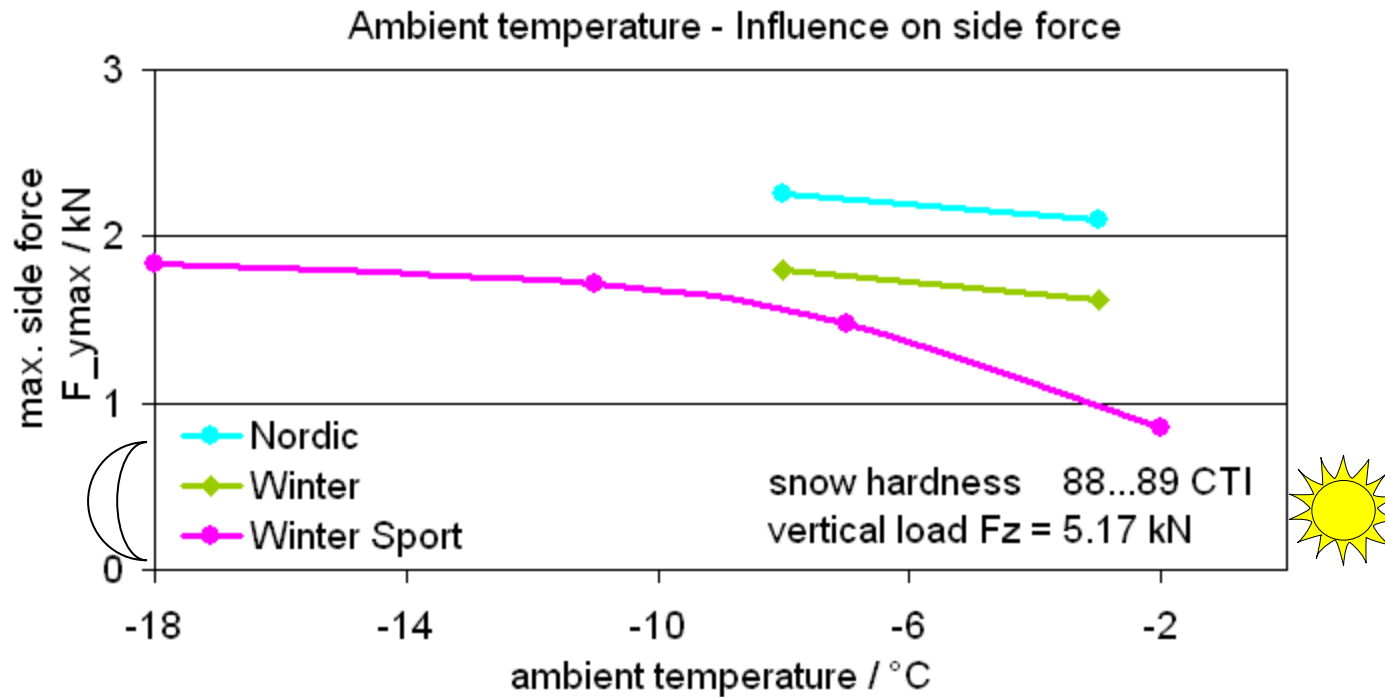
Correlation Cutting force - Side force coeff. of tire "Winter Sport"



- Shear resistance of snow = 2nd major mechanical property.
- Cutting force determine shear resistance along big snow fields.
- Interlocked snow block submits high forces, when shear resistance is high.

Parameter Studies

Ambient temperature



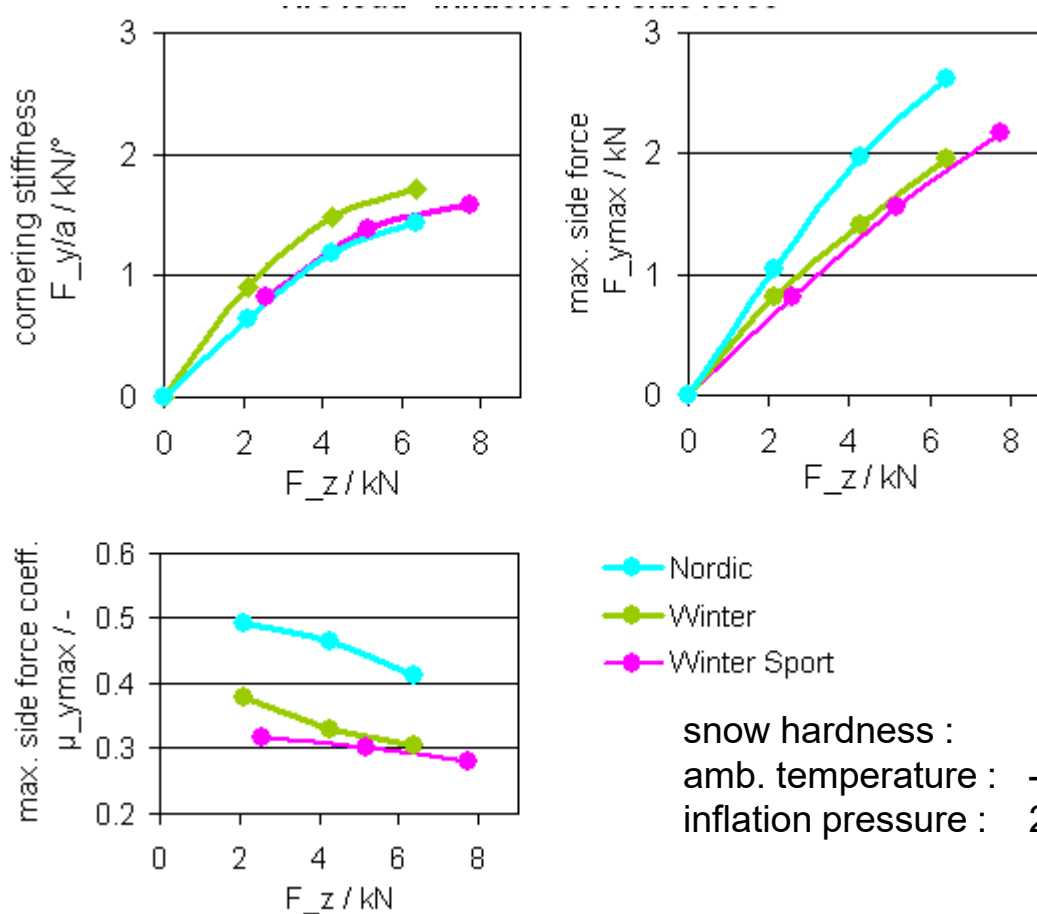
Friction heat → water film which depends on

- ambient temperature;
- tire's specific heat transfer

Force performance higher at low ambient temperature.

Parameter Studies

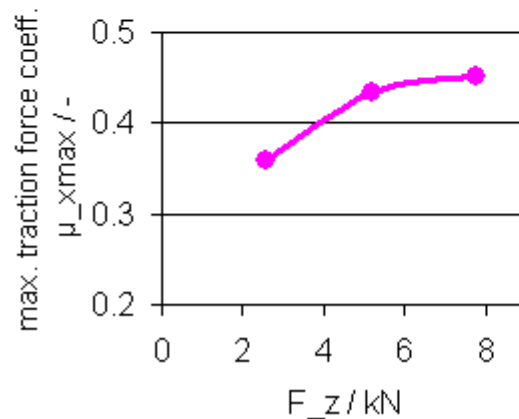
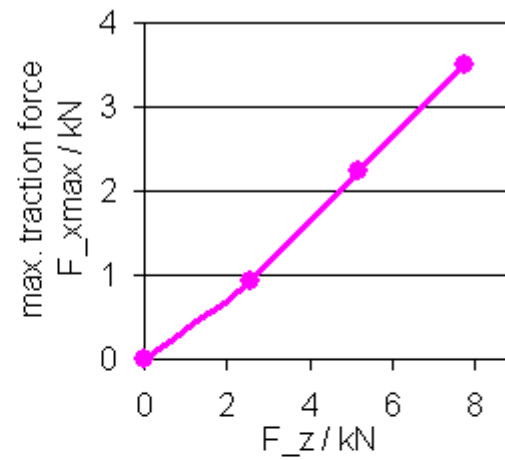
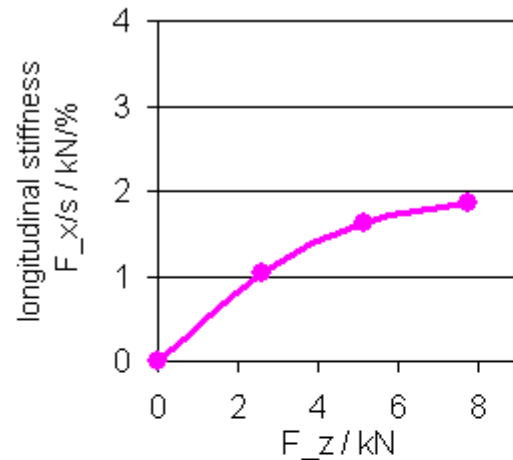
Vertical tire load – side force



- digressive character for cornering stiffness;
 - increasing side force maximum;
 - decreasing side force coefficient.
- Tires shouldn't be overloaded.

Parameter Studies

Vertical tire load - Traction



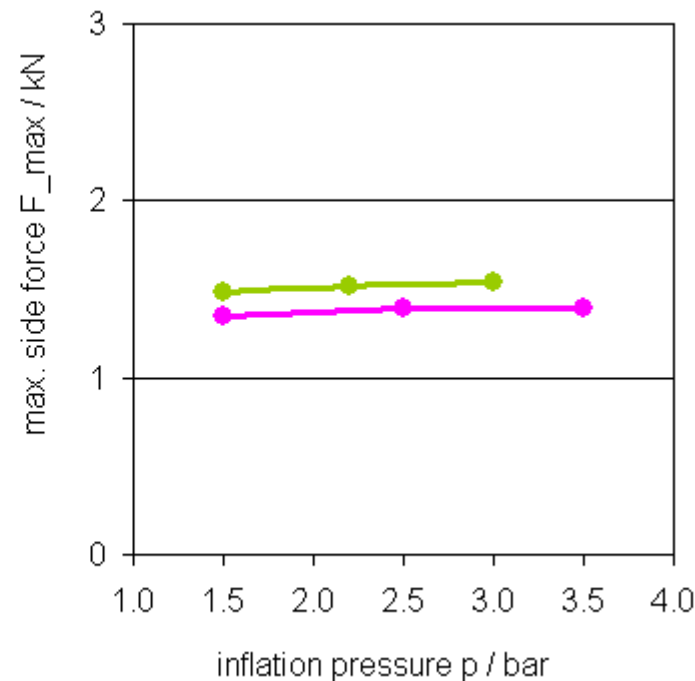
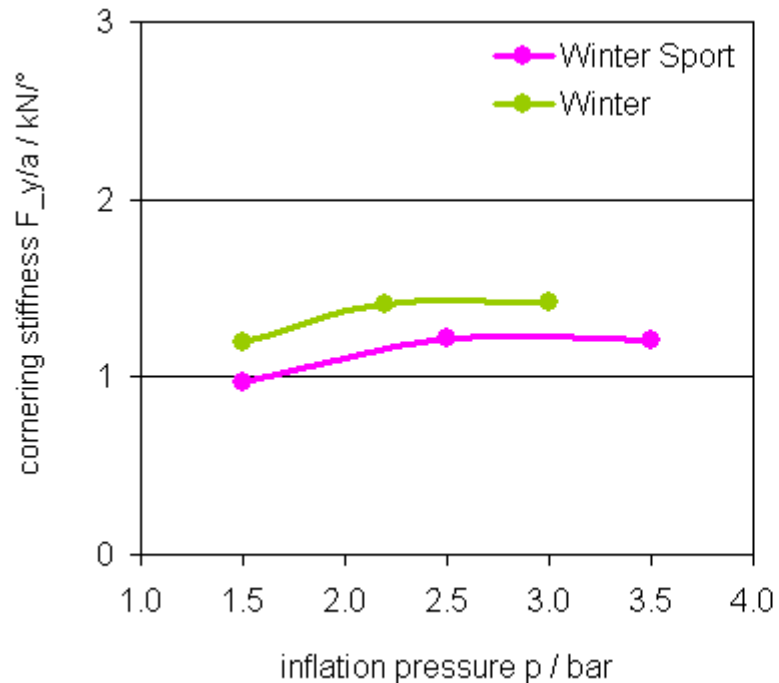
—●— Winter Sport

snow hardness : 88...90 CTI
amb. temperature : -9...-8 °C
inflation pressure : 2.5 bar

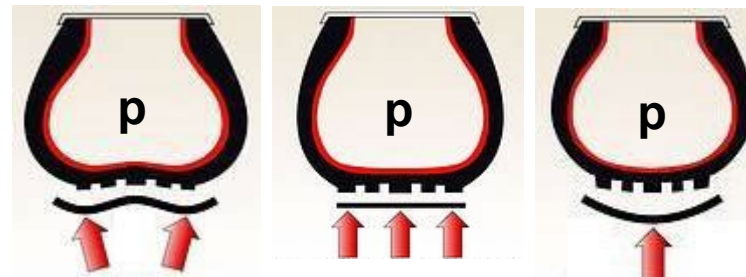
- **digressive character for longitudinal stiffness;**
- **increasing traction force maximum;**
- **decreasing traction force coefficient.**

Parameter Studies

Inflation pressure – Side force



snow hardness : 88...90 CTI
amb. temperature : -9...-8 °C
tire vertical load : 5.25 kN



inflation pressure p :

low

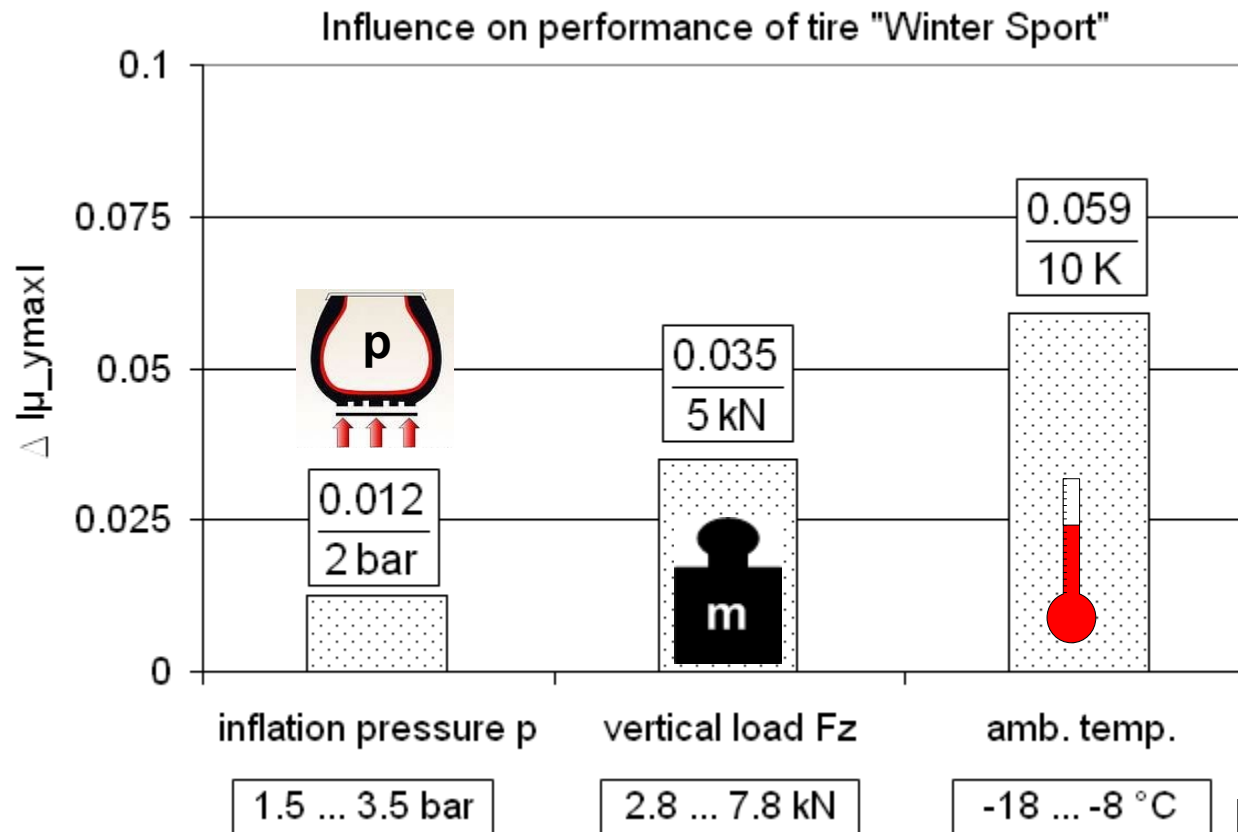
medium

high

- digressive character for cornering stiffness;
- slight increase of side force maximum and side force coefficient.

Parameter Studies

Comparison – Influencing factors on side force



Ambient temperature has highest influence on side force performance.

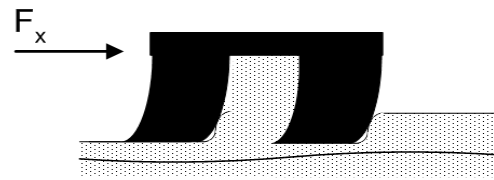
Theory – Hypothesis of force transmission

Force transmission mechanisms



Interlocking Tread / Snow

- Slip low
- Contact pressure high
- Cohesion of snow high
- High tread blocks with fine sipes



Sliding friction - snow

- Slip high
- Contact pressure high
- Adhesion higher than cohesion of snow



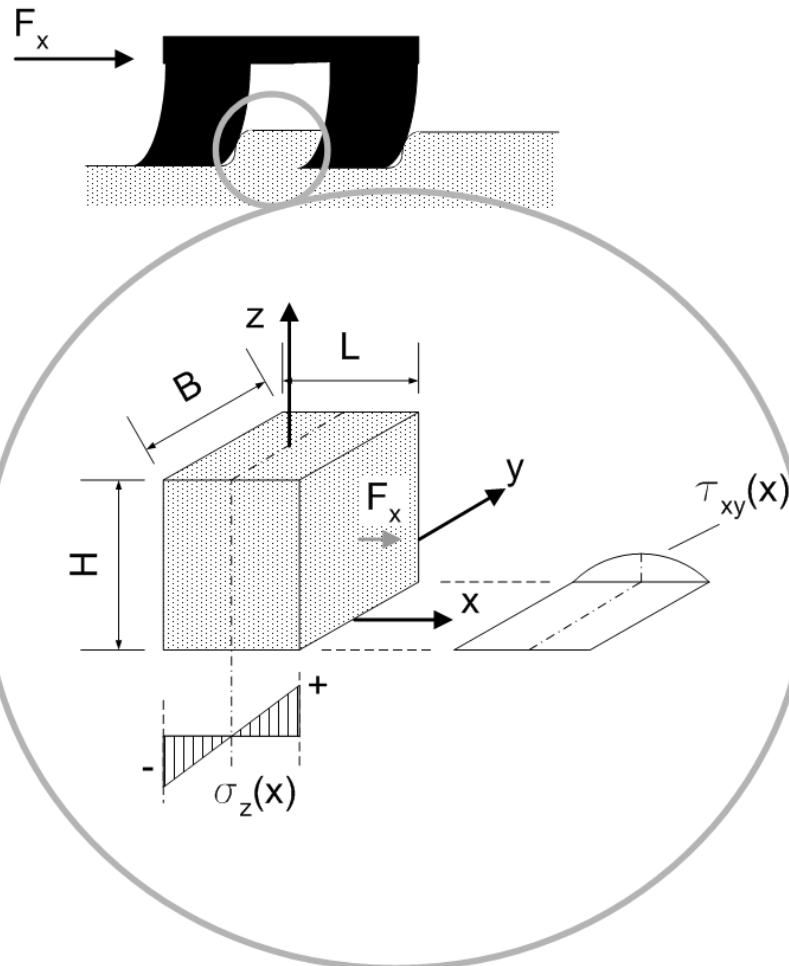
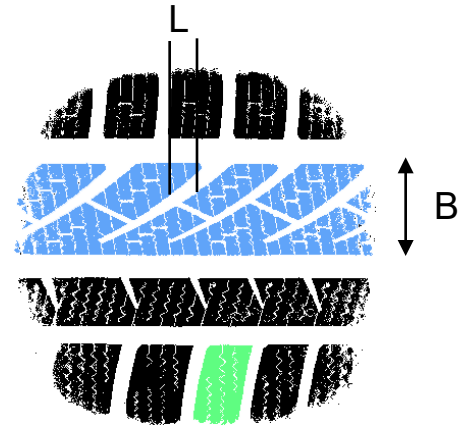
Sliding friction - Rubber and Snow

- Slip high
- Contact pressure high
- Less deformation of snow

Force transmission on snow tracks involves 3 mechanisms.

Theory – Hypothesis of force transmission

Physical Model – Interlocking between tread and snow



Bending stress:

$$|\sigma_z(x)| = \frac{M_b}{I_y} \cdot x$$

$$\left| \sigma_{z_max} \left(x = \frac{L}{2} \right) \right| = 3 \cdot F_x \cdot \frac{H}{B \cdot L^2}$$

$$\lim_{L \rightarrow \infty} \sigma_{z_max} = 0$$

Shear stress:

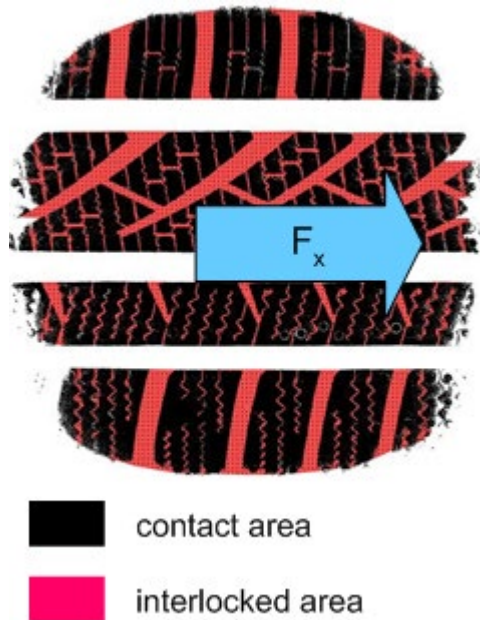
$$\tau_{xy_max}(x) = \frac{3}{2} \cdot \frac{F_x}{B \cdot L} \cdot \left[1 - \left(\frac{x}{B/2} \right)^2 \right]$$

$$\tau_{xy_max}(x=0) = \frac{3}{2} \cdot \frac{F_x}{B \cdot L}$$

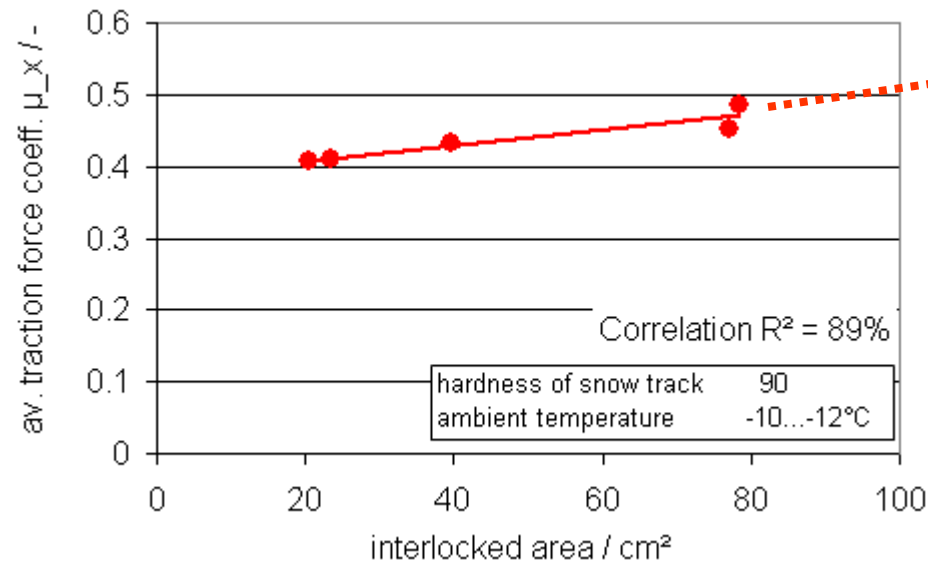
**As bigger the interlocked area,
as lower the transmitted stress.**

Theory – Hypothesis of force transmission

Physical Model – Interlocking between tread and snow

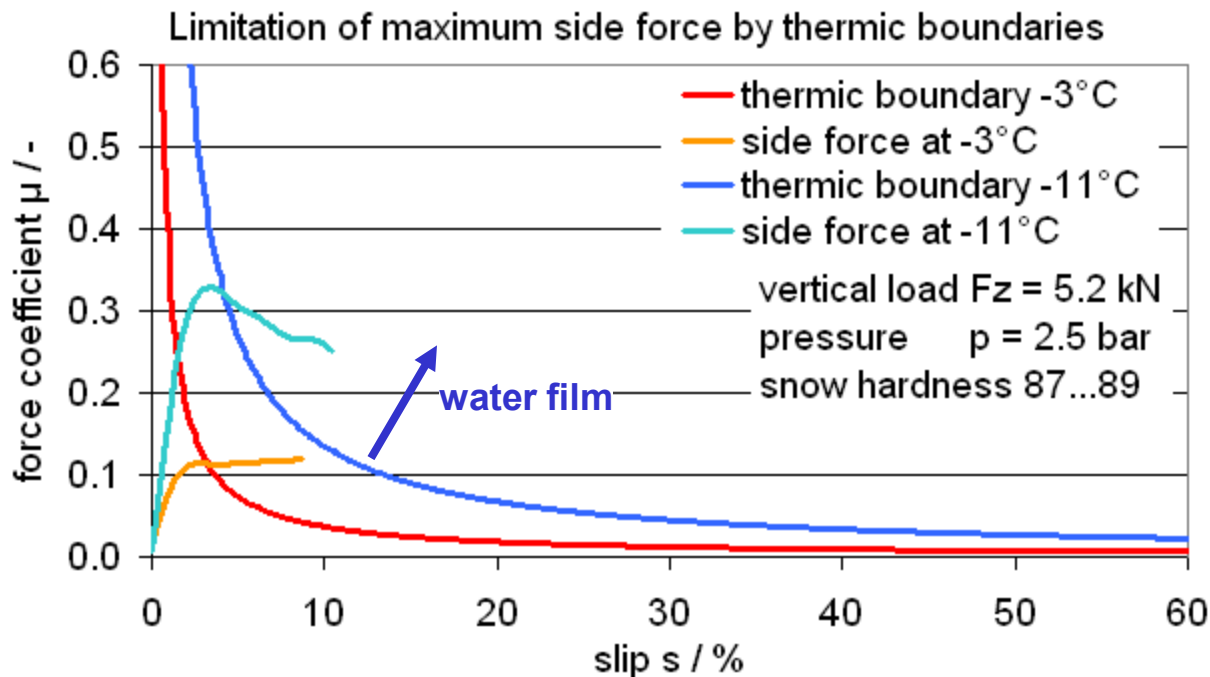
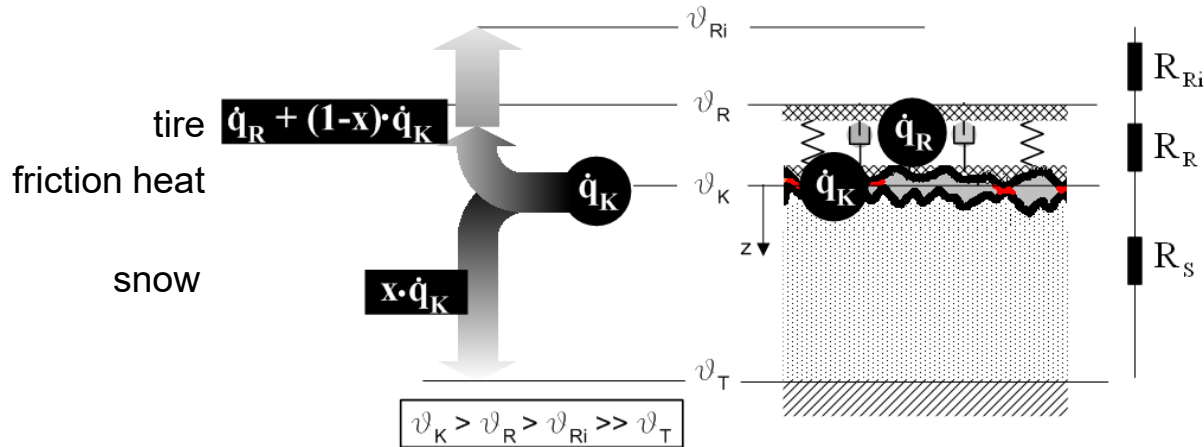


Traction performance of different tested tires correlate to interlocked area of their tire pattern.



Traction performance increases, if interlocked area is enlarged by adding more sipes.

Hypothesis of force transmission on snow



Friction heat leads to water film.
Physical formula is found to
calculate thermic boundary.

Conclusion

- **Tire force transmission tests on snow tracks at the internal test bench all year around.**
- **High Correlation between Outdoor and Indoor results.**
- **Influence of ambient temperature is very high and tire dependent.**
- **At hard tracks distinctive force maximum can be found.**
- **Higher side force performance at low load and high inflation pressure.**
- **Force transmission is limited by thermal and mechanical properties of the track.**

Thank you for your attention!

