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Development of Baseline Rolling Resistance for Tires

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Outline

- Introduction
- Finite element model
- Numerical analysis matrix
- Rolling resistance approaches
- Effect of operating conditions on rolling resistance
- Regression analysis
- Tire’s internal energy per components
- Summary

Vehicle Operating Costs[1]

- License and insurance
- Tire wear
- Capital cost
- Oil consumption
- Repair and maintenance
- Fuel consumption

1. Chatti and Zaabar (2012)

Fuel Consumption

- **HDM-4 fuel consumption model**

$$IFC = f\left(P_{tr}, P_{acs} + P_{eng}\right)$$

$$P_{tr} = f(F_a, F_g, F_c, F_r, F_i)$$

F_a: Aerodynamic forces

F_g: Gradient forces

F_r: Rolling resistance

F_c: Curvature forces

F_i: Inertial forces

Rolling Resistance (RR): energy dissipated by tire per unit distance traveled

- Tire Deformation
- Pavement Surface Geometry (slope, texture, evenness)
- Pavement Structure

Rolling Resistance (RR)

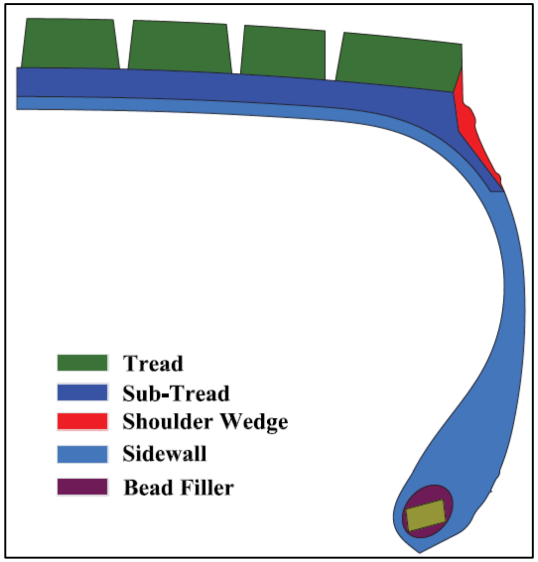
- Depending on conditions, **7-30% of fuel consumption** is caused by **rolling resistance**
- Longitudinal reaction force: **mechanical manifestation** of RR
- **Experimental and numerical approaches** have been used to study rolling resistance
  - Most numerical approaches have some degree of simplification

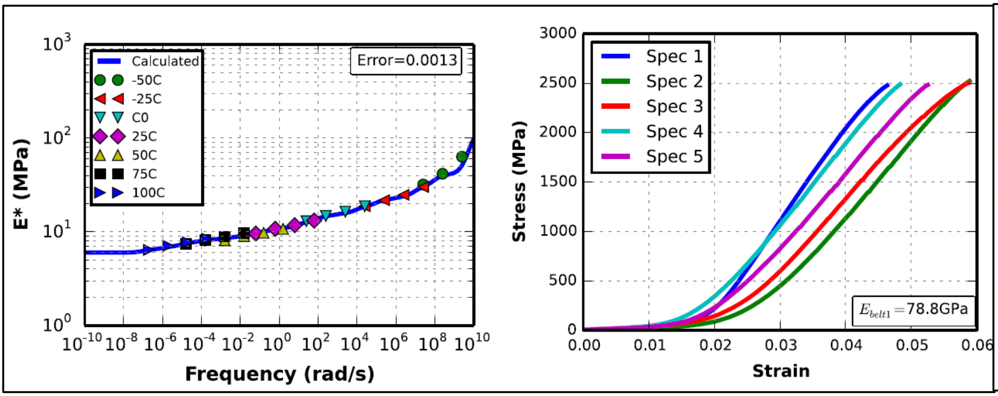
Objective

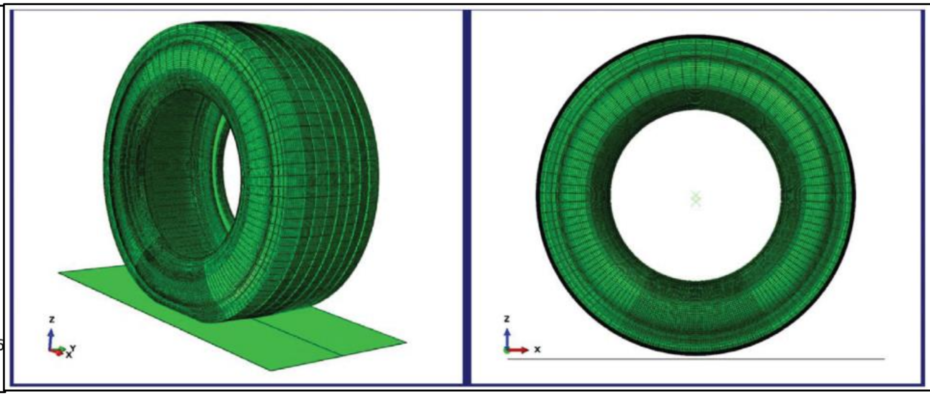
- Study the effect of **operating conditions** (i.e. load, tire-inflation pressure, speed, and temperature) on **rolling resistance** caused by **tire's deformation** using finite element method

Finite Element Model

- Accurate geometry
- Incompressible **Visco-hyperelastic rubber** and linear elastic reinforcement
- Combination of Cartesian, cylindrical, and rebar elements
- Sliding-velocity-dependent friction







Numerical Analysis Matrix

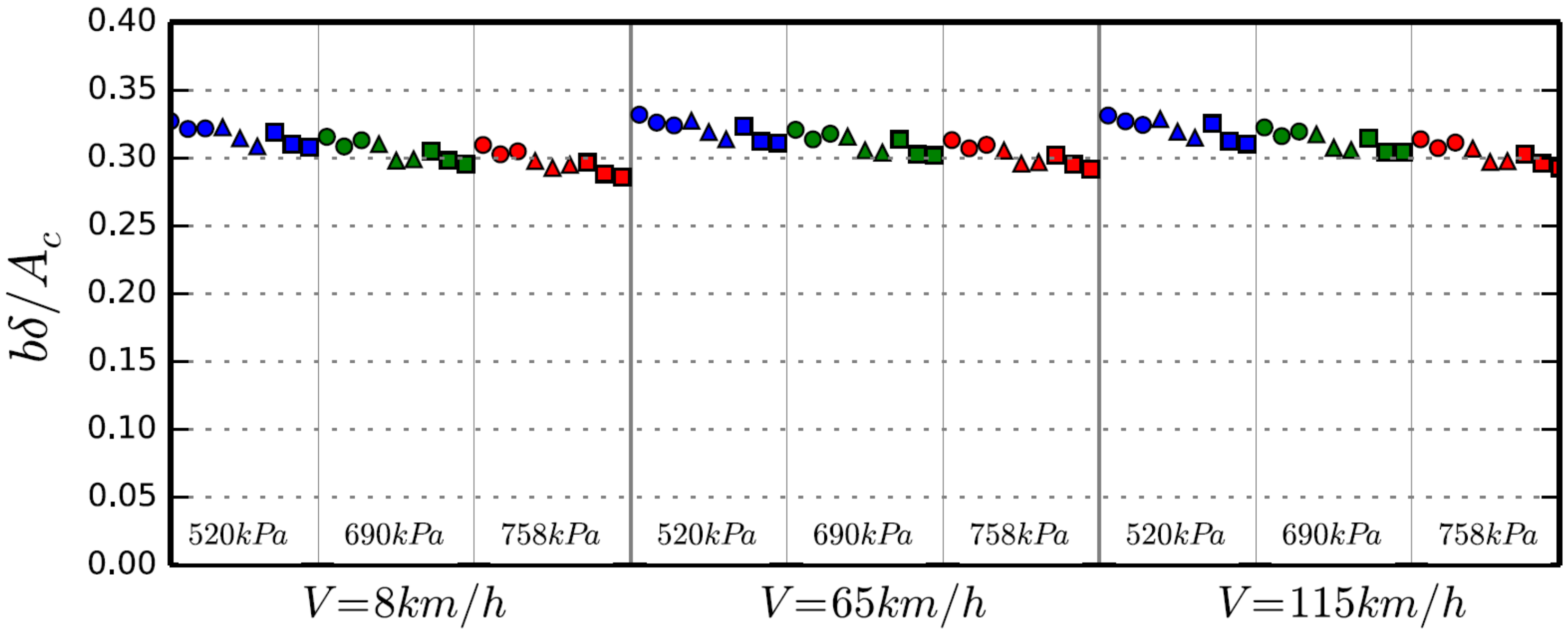
- Covers normal **operating conditions** of truck tires

Load (kN)	Pressure (kPa)	Speed (km/h)	Temperature (°C)
26.6	552	8	25
35.5	690	65	45
44.4	758	115	65

Rolling Resistance Approaches

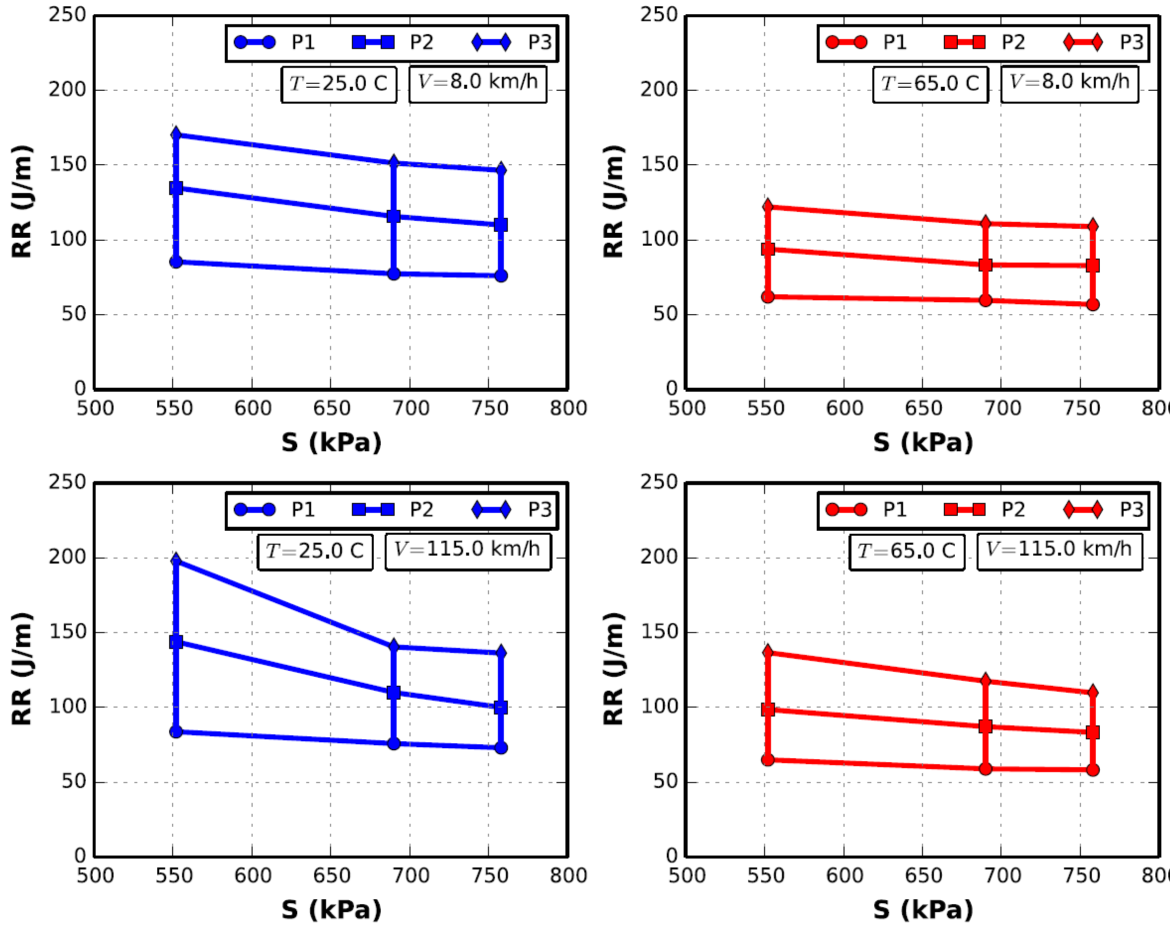
- RR_e: Rolling resistance from energy dissipation
- RR_f: Rolling resistance from reaction force
- $C_{rr} = \frac{RR_f}{P} = h\frac{\delta b}{A_c}$

h: energy lost/total energy input
C_{rr}: Coefficient of rolling resistance



Operating Conditions and *RR*

- *RR* decreases with *S* (between 8 and 30%)
- Effect of *P* is almost linear
- *T* changes slopes and decreased influence of load



Regression Analysis

$$RR = k\frac{S^{\alpha}P^{\beta}}{\sqrt{T}}\left(a + bV + cV^2\right)$$

$k = 0.2740$

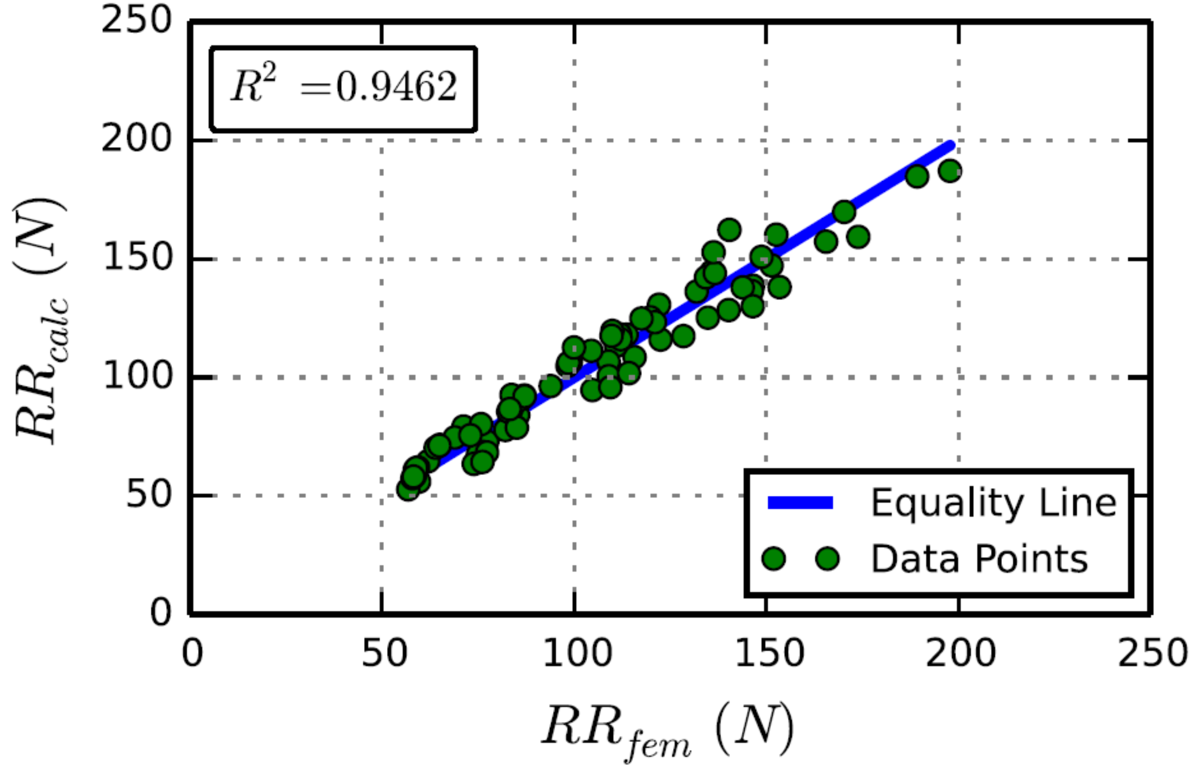
$\alpha = -0.6392$

$\beta = 1.3618$

$a = 10.68 \times 10^{-3}$

$b = 26.23 \times 10^{-6}$

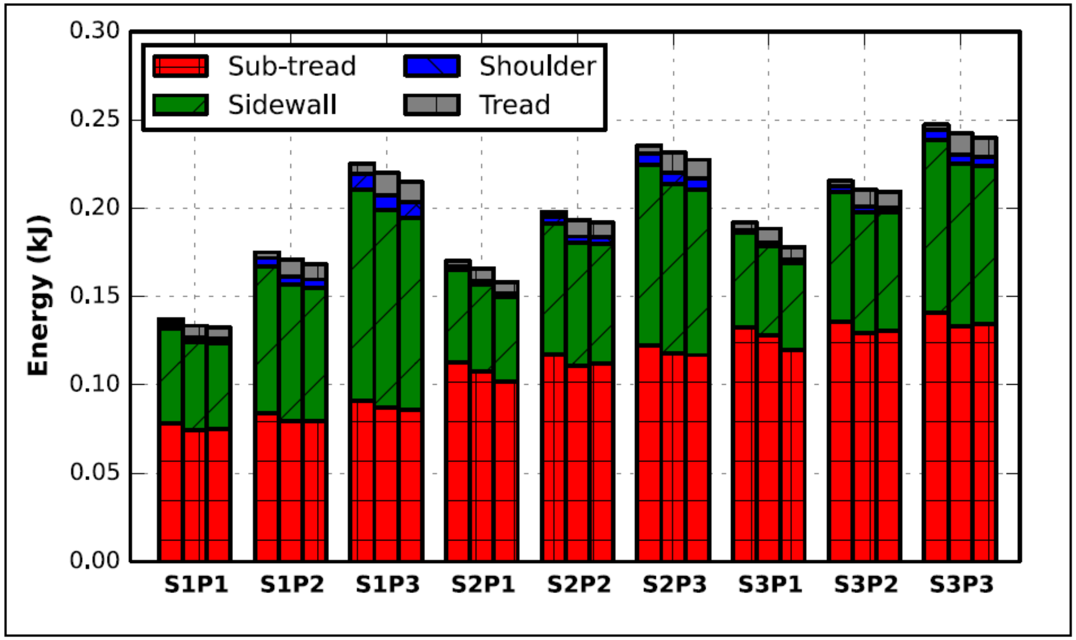
$c = -129.1 \times 10^{-9}$



Energy Per Tire Component

- Subtread and sidewall had the highest contribution
- High load and low pressure resulted into higher energy for sidewall

Load (kN)	Pressure (kPa)	Speed (km/h)	Temperature (°C)
*P*1=26.6	*S*1=552	*V*1=8	*T*1=25
*P*2=35.5	*S*2=690	*V*2=65	*T*2=45
*P*3=44.4	*S*3=758	*V*3=115	*T*3=65



T=45 °C

Summary

- **Visco-hyperelastic tire was modeled using finite element method to predict rolling resistance**
- **Temperature and load have significant effect on RR**
- **Existing equation (SAE J2425) to predict RR was modified to include temperature's effect**
- **Subtread and Sidewall's contribution to tire's internal energy is significant**

Questions?