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

- 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**

\[
\text{IFC} = f(P_{tr}, P_{acs} + P_{eng})
\]

\[
P_{tr} = f(F_a, F_g, F_c, F_r, F_i)
\]

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

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

\[F_a: \text{Aerodynamic forces}\]
\[F_g: \text{Gradient forces}\]
\[F_r: \text{Rolling resistance}\]
\[F_c: \text{Curvature forces}\]
\[F_i: \text{Inertial forces}\]
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

<table>
<thead>
<tr>
<th>Load (kN)</th>
<th>Pressure (kPa)</th>
<th>Speed (km/h)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.6</td>
<td>552</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>35.5</td>
<td>690</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td>44.4</td>
<td>758</td>
<td>115</td>
<td>65</td>
</tr>
</tbody>
</table>
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

![Graph showing rolling resistance at different pressures and speeds]
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

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

\[ k = 0.2740 \]
\[ \alpha = -0.6392 \]
\[ \beta = 1.3618 \]
\[ a = 10.68 \times 10^{-3} \]
\[ b = 26.23 \times 10^{-6} \]
\[ c = -129.1 \times 10^{-9} \]
Energy Per Tire Component

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

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</tr>
</thead>
<tbody>
<tr>
<td>$P_1=26.6$</td>
<td>$S_1=552$</td>
<td>$V_1=8$</td>
<td>$T_1=25$</td>
</tr>
<tr>
<td>$P_2=35.5$</td>
<td>$S_2=690$</td>
<td>$V_2=65$</td>
<td>$T_2=45$</td>
</tr>
<tr>
<td>$P_3=44.4$</td>
<td>$S_3=758$</td>
<td>$V_3=115$</td>
<td>$T_3=65$</td>
</tr>
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</table>

$T=45$ °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?