Computational Modeling and Analysis of Truck Tire–Terrain Interaction

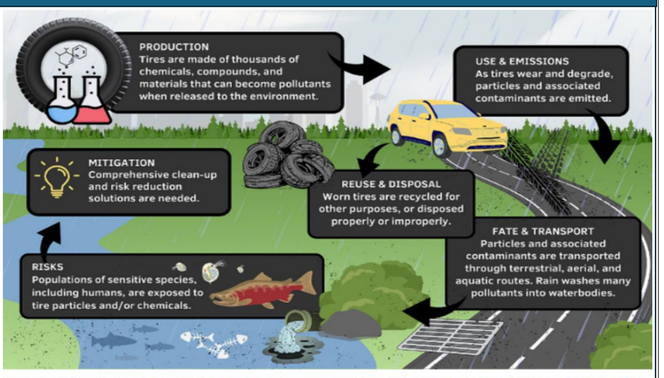
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Abstract

This research focuses on developing and validating computer models to predict truck tire behavior under different operating conditions. By comparing simulations with experimental data, the models are improved to accurately represent tire deformation, temperature changes, rolling resistance, and tread wear across dry, wet, and snowy conditions.

The goal is to better understand tire performance, durability, and efficiency while reducing the need for costly physical testing. Ultimately, improved tire modeling can support the development of more durable and efficient tires, reducing fuel consumption, material waste, and environmental impact.

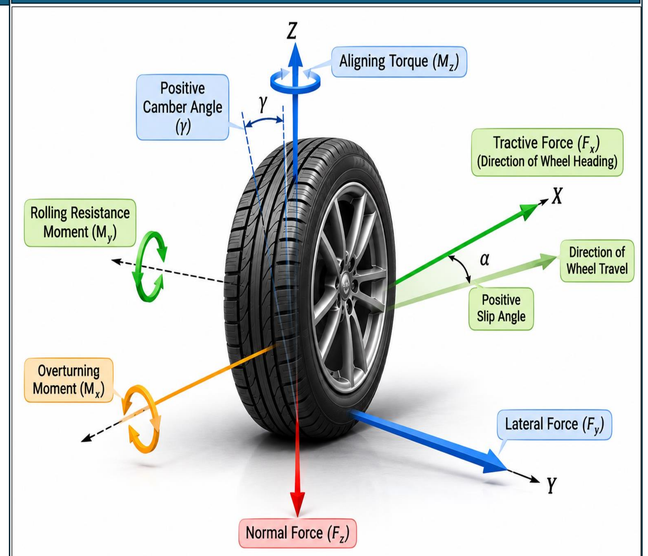
Better Tires, Greener Planet

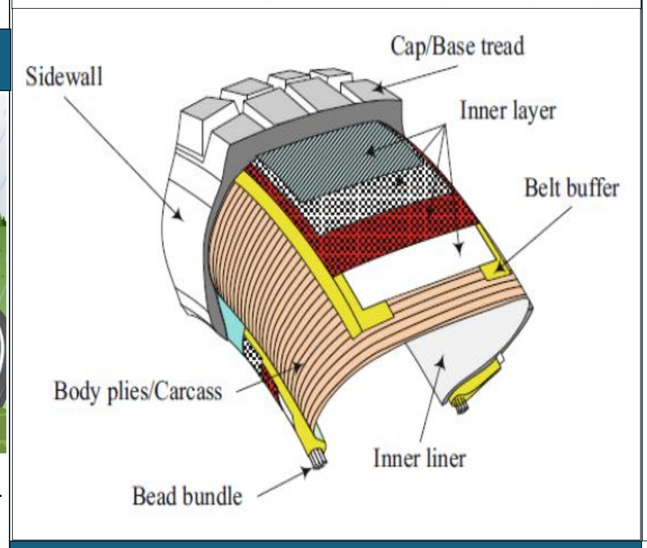


Graphic abstract from "Where the rubber meets the road: Emerging environmental impacts of tire wear particles and their chemical cocktails," 2024.

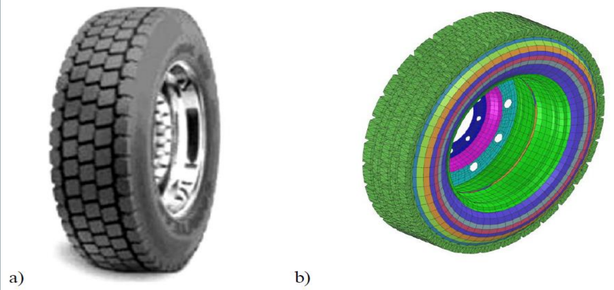
- **Environmental Impact of Tire Wear:** Normal tire–road interaction generates tire wear particles (TRWPs) as rubber gradually wears down. These particles can become airborne, accumulate in soil, or enter rivers and lakes through stormwater runoff, contributing to environmental pollution and potential ecosystem damage. *(Sources: U.S. EPA; U.S. Geological Survey)*
- **Harmful Tire Chemicals:** Certain chemicals used in tire manufacturing, particularly 6PPD, can react with atmospheric ozone to form 6PPD-quinone (6PPD-Q). Research has identified this chemical as highly toxic to certain aquatic organisms, including coho salmon. *(Source: Tian et al., 2021, Science)*
- **Role of Tire Material R&D:** Developing improved rubber compounds, material properties, and tire structures can enhance wear resistance, reduce tread degradation, and extend tire service life. Research into alternative chemical additives can also help minimize the environmental risks associated with tire materials.
- **Sustainability Benefits:** Reducing tire wear can minimize particle emissions, raw material consumption, replacement frequency, and waste. Additionally, optimizing tire compounds and structures can improve rolling resistance and vehicle energy efficiency.

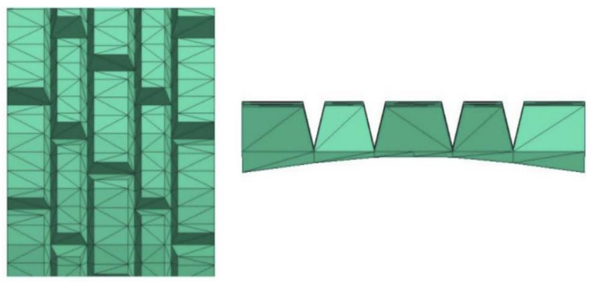
Tire Structure & Dynamics



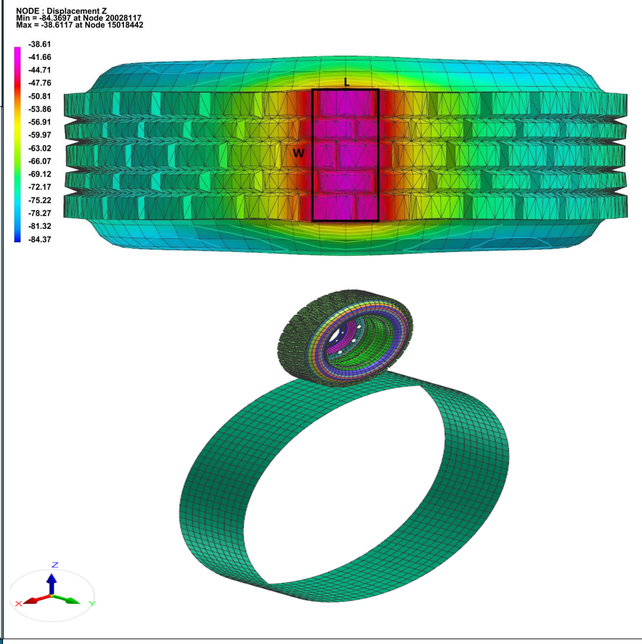


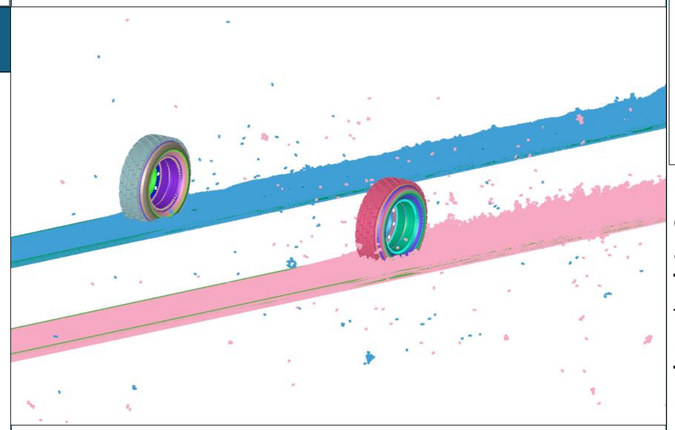
Tire-Terrain FEA Modeling





- **RHD Tire Model:** Based on a Goodyear 315/80R22.5 drive tire, previously developed and validated in PAM-CRASH to represent its real-world counterpart.
- **FEA Model Structure:** Consists of 13,280 elements, including shells, solids, layered membranes, and beams. The model incorporates rubber components, steel belts, and radial cords, with a simplified tread pattern to reduce computational time.
- **Static Footprint Analysis:** Evaluates how inflation pressure and vertical load affect tire deformation and contact patch area, helping understand tire–ground interaction under different loading conditions.
- **Drum-Cleat Test:** Investigates the tire's first vibration mode by analyzing vertical and horizontal responses during rotation. FFT analysis of reaction forces at the center of gravity identifies vibration frequencies and provides insight into vertical stiffness and its relationship with inflation pressure and material properties.

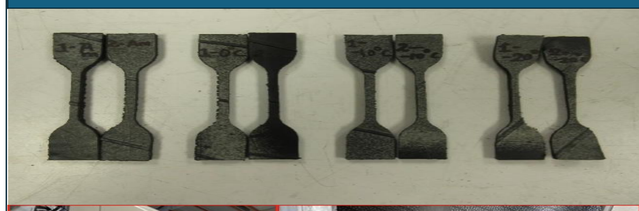


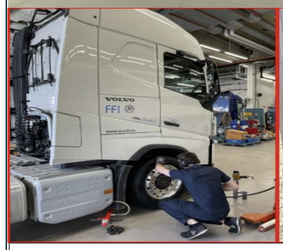


Snow Modeling Using SPH:

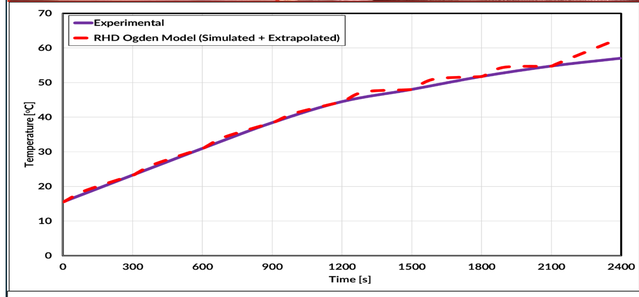
SPH simulations in PAM-CRASH are used to model snow as a highly deformable material and capture its interaction with the tire and ground. Simulations are performed under different tire speeds, vertical loads, temperatures, and snow depths. Contact forces are extracted and averaged to calculate the rolling resistance coefficient (RRC), allowing the effect of different operating conditions on tire performance in snowy environments to be evaluated.

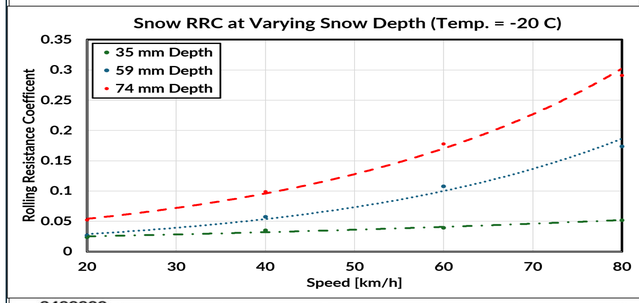
Simulation & Real-World Testing

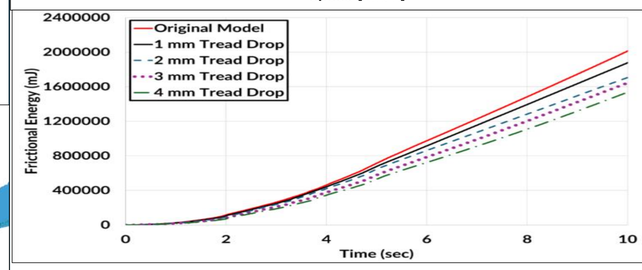












Material Testing: Evaluated material strength and deformation at different temperatures through tensile and compression tests.

Temperature Analysis: Used experimental data from four driven HCT tires to establish a reference for thermal model validation.

Thermal Modeling: Simulated tire heat generation and heat transfer to predict temperature distribution and behavior.

Thermal Model Validation: Compared simulation results with experimental data, identifying differences in predicted temperature rise and potential sources of error.

Snow Rolling Resistance: Analyzed how snow depth, temperature, speed, and vertical load affect tire rolling resistance and efficiency.

Tire Wear Analysis: Studied tread wear under different operating conditions to improve tire durability, performance, and lifespan.