FFW 2026
Fracture Fatigue and Wear

Paper ID: FFW1511

Towards Sustainable Modular Tires: Experimental Validation of a Mechanically Interlocked Removable Tread System

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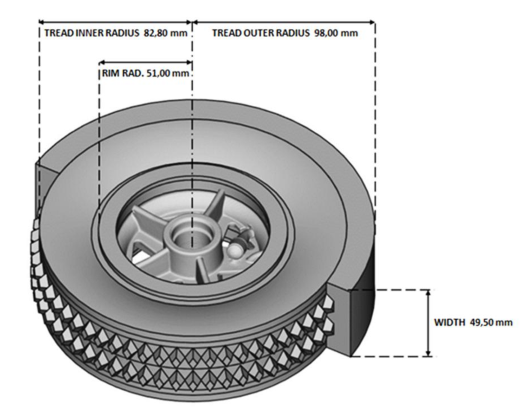
Introduction

Motivation → High environmental impact of conventional tires: *Tire–road wear is a major environmental concern, contributing up to 65% of airborne microplastics in urban areas.*

United Nations Sustainable Development Goals (SDGs) directly addressed by the ECOTIRE project, highlighting its contribution to resource efficiency, responsible production, and sustainable mobility.



Dimensional overview of the scaled ECOTIRE prototype design

Concept (ECOTIRE project)

→ Modular tire with removable and sustainable tread materials
→ Mechanical interlocking (no adhesives)
→ Reusable carcass
→ Improved recyclability & reduced rubber waste
→ Enhanced safety within an eco-friendly design
→ Extended lifetime

Objective

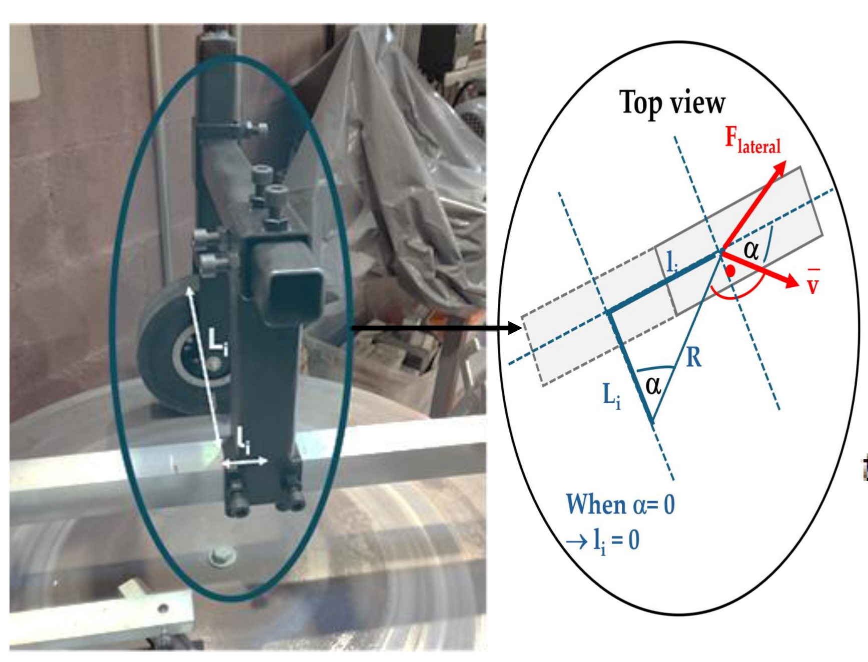
→ Evaluate manufacturability and assembly of the system

Experimental Procedure

Silicone compound (VMQ)

Assembled scaled ECOTIRE prototype

Test rig configuration



$$R^2 = L^2 + l^2 \rightarrow L = \sqrt{R^2 - l^2}$$

$$tg\alpha_i = \frac{l_i}{L_i} \rightarrow \alpha_i = arctg\left(\frac{l_i}{L_i}\right)$$

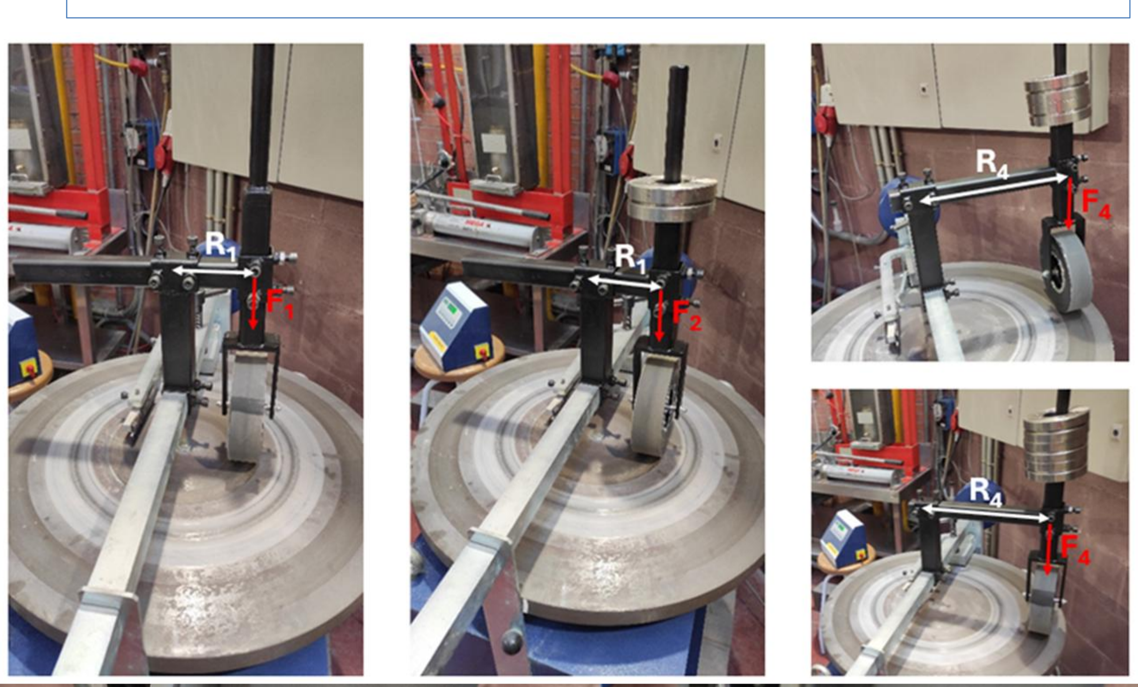
L = 2, 4 and 8 cm

- **Experimental setup**
  → Reduced-scale ECOTIRE prototype
  → Rolling rig (normal load, radius, slip and pressure)
- **Evaluation**
  → Interface stability
  → Direct observation (during and post-test inspection)

Normal force	Rolling radius
Fz_1 = 37.77 ± 0.01 N	R_1 = 12.5 ± 0.05 cm
Fz_2 = 71.22 ± 0.01 N	R_2 = 15.0 ± 0.05 cm
Fz_3 = 104.67 ± 0.01 N	R_3 = 29.0 ± 0.05 cm
Fz_4 = 138.12 ± 0.01 N	R_4 = 32.0 ± 0.05 cm

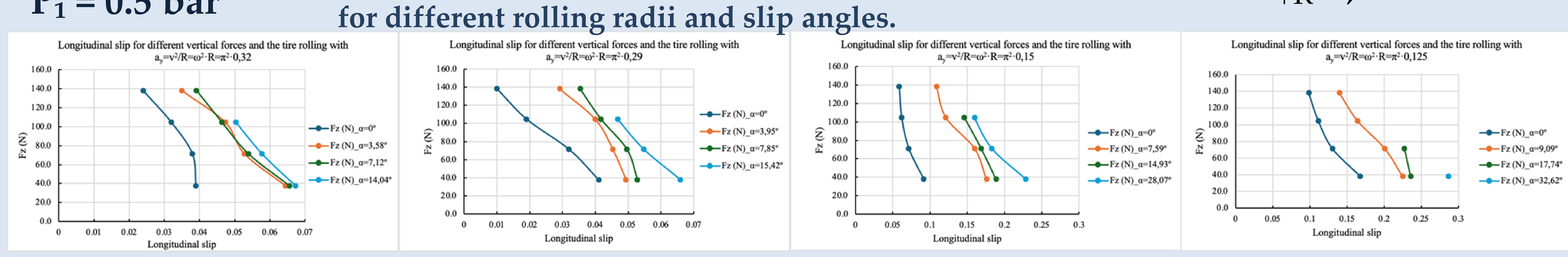
Inflation pressures: P_1 = 0.5 bar, P_2 = 1 bar. **Rotation speed:** Ω = 30 rpm = 3.1416±0.001 rad/s

Results

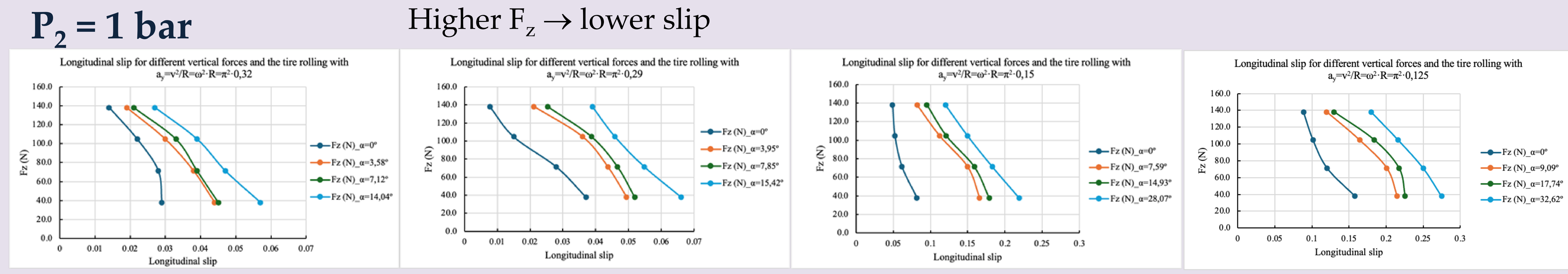


>10,000 cycles

P_1 = 0.5 bar — Longitudinal slip index as a function of applied normal force for different rolling radii and slip angles. ↑R →



P_2 = 1 bar — Higher F_z → lower slip



Conclusions

- Stable engagement of the interlocked tread–casing interface was maintained under rolling with slip under sufficient geometric confinement was provided.
- Under lateral stress, the stability of the mechanical connection between the tread and the casing is compromised.
- At 1 bar, no separation, wear, or permanent deformation was observed under all tested conditions.
- At 0.5 bar, increased compliance led to localized and reversible separation under high load, small radius, and slip angle, without full detachment.
- Post-test inspections, including extended rolling sequences (>10,000 cycles), confirmed the absence of material damage or measurable wear.
- Inflation pressure was identified as the key stabilizing parameter, defining the limits of stable operation.

This publication is part of the R+D+i project: TED2021-129604B-100, funded by MCIN/AEI/10.13039 501100011033 and by the European Union NextGeneration EU PRTR.