39th Annual Business Meeting and Conference on Tire Science and Technology

Intelligent Transportation

Program and Abstracts

September 28th – October 2nd, 2020

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39th Annual Meeting and Conference on Tire Science and Technology

Day 1 – Monday, September 28, 2020

All sessions take place virtually

8:00 AM	Conference Opening		**Gerald Potts** *President of the Society*
8:15 AM	**Keynote Speaker**	*Intelligent Transportation - Smart Mobility Solutions from the Tire Industry*	**Chris Helsel,** *Chief Technical Officer* *Goodyear Tire & Rubber Company*
	Session 1: Simulations and Data Science		**Tim Davis,** *Goodyear Tire & Rubber*
9:30 AM	1.1	Voxel-based Finite Element Modeling to Predict Tread Stiffness Variation Around Tire Circumference	**Arnav Sanyal** *Cooper Tire & Rubber Company*
9:55 AM	1.2	Tire Curing Process Analysis through SIGMASOFT Virtual Molding	**Gabriel Geyne** *3dsigma*
10:20 AM	1.3	Off-the-Road Tire Performance Evaluation Using High Fidelity Simulations	**Biswanath Nandi** *Dassault Systems SIMULIA Corp*
10:40 AM	Break		
10:55 AM	1.4	A Study on Tire Ride Performance using Flexible Ring Models Generated by Virtual Methods	**Yaswanth Siramdasu** *Hankook Tire Co. Ltd.*
11:20 AM	1.5	Data-Driven Multiscale Science for Tire Compounding	**Craig Burkhart** *Goodyear Tire & Rubber Company*
11:45 AM	1.6	Development of Geometrically Accurate Finite Element Tire Models for Virtual Prototyping and Durability Investigations	**Emanuele Grossi** *Exponent*

Day 2 – Tuesday, September 29, 2020

8:15 AM	**Plenary Lecture**	*Enhancing Vehicle Fuel Economy through Connectivity and Automation – the NEXTCAR Program*	***Giorgio Rizzoni,*** *Director* *Center for Automotive Research* *The Ohio State University*
	Session 1: Tire Performance		**Eric Pierce,** *Smithers*
9:30 AM	2.1	Periodic Results Transfer Operations for the Analysis of Damage Accrual Under Steady / Transient Rolling	**William V. Mars** *Endurica LLC*
9:55 AM	2.2	Effect of Tyre Imperfection on Vehicle Response	**Niraj Kumar Jha** *Hari Shankar Singhania Elastomer & Tyre Research Institute*
10:20 AM	2.3	Road Induced Interior Noise: Use of OTPA to Determine Tire Contribution and Vehicle Sensitivity	**Guillaume Demaziere** *Michelin*
10:45 AM	2.4	Advantages of a Cross-Ply Carcass Tire Construction on Key Performances (Especially for Electrically Driven Vehicles)	**Francesco Calabrese** *Fraunhofer-Institute*
11:05 AM	Break		
	Session 2: Simulations and Data Science		**Jan Terziyski,** *Nexen Tire*
11:20 AM	2.5	Tire Conditions Needed to Maintain Contact Patch Shape	**Matthew Van Gennip** *A&D Technology*
11:45 AM	2.6	Wheel Speed Effect on Transient Lateral Force and its Characterization by Ramp-Steer Test Method	**Yi Li** *GCAPS*

Day 3 – Wednesday, September 30, 2020			
8:00 AM	Business Meeting		**Gerald Potts** *President of the Society*
	Session 1: Experimental Technologies		**Tan Li,** *Maxxis International*
9:00 AM	3.1	Measuring Strain Fields and Crack Advance in a Pre-cut Planar Tension Test Specimen during Slow, Medium and High-Speed Straining	**Aron Dodger** *Axel Products Inc*
9:25 AM	3.2	A Validated Test Methodology to Evaluate Radial Ply Tire Road Hazard Impact Failures	**David R. Southwell** *Tyrexperts Pty Ltd*
9:50 AM	3.3	Influence of Tire Force and Moment Properties on Sine with Dwell Maneuver Test Metric Variability	**Cedric (Ric) Mousseau** *General Motors*
10:10 AM	Break		
10:25 AM	3.4	Tire Mode Identification, Distribution Chart, and Correlation with Vehicle NVH	**Tan Li** *Maxxis International*
10:50 AM	3.5	Self-Excited Full Vehicle Oscillations Caused by Tire-Road-Interaction – Virtual and Real-World Experimental Investigation	**Dirk Engel** *Haw Hamburg*
11:15 AM	3.6	Elimination of Stray Forces from Tire Dynamics Measurements	**Gerald Potts** *GRP Dynamics LLC*

Day 4 – Thursday, October 1, 2020			
	Session 1: Student Papers		**Yusheng Chen,** *Eastman*
8:00 AM	4.1	Research on the Contradiction Mechanism of Tire Rolling Resistance and Grip Performance	**Chen Liang** *Jiangsu University*
8:25 AM	4.2	Application of Steady State and Transient Acceleration Signals in Intelligent Tire	**Tong Zhao** *Tsinghua University*
8:50 AM	4.3	How to Test Snow Tread Block Traction in Lab: Effect of Snow Density	**Matthias Wangenheim** *Leibniz University Hannover*
9:10 AM	Break		
9:20 AM	4.4	A Predictive Modeling of the Viscoelastic Response of Styrene Butadiene Rubber due to Aging	**Waleed Alkandari** *Virginia Tech*
9:45 AM	4.5	Isogeometric Analysis for Tire Simulations: From Mesh Generation to High Precision Results	**Alina Israfilova** *Technische Universität Dresden*
10:15 AM	**Invited Lecture**	*Future Tire Requirements for Battery Electric Vehicle Tunnel Transportation Systems*	**Ross Tessien,** *Principal at Electricwaze LLC*

Day 5 – Friday, October 2, 2020			
	Special Talk		**Meysam Khaleghian,** *TX State Univ.*
8:00 AM	5.1	40 Years and More of Tire Science and Technology - A History of the Tire Society	**Jim McIntyre** *Bridgestone*
	Session 1: Emerging Technologies		**Corissa Lee,** *Exponent*
8:25 AM	5.2	A 3D-Textile-Rubber Composite: Description and Multiscale Modeling	**D. Aranda-Iglesias** *Goodyear Tire & Rubber Company*
8:50 AM	5.3	A Comprehensive Constitutive Equation and the Prediction of Tire Temperature and Rolling Resistance	**Mahmoud Assaad** *Goodyear Tire & Rubber Company*
9:10 AM	Break		
9:20 AM	5.4	Speed Dependent Maxxis-Savkoor Friction Model for Rubber Compound	**Jonathan Watson** *Maxxis International*
9:45 AM	5.5	Improved Vehicle Longitudinal Velocity Estimation Using Accelerometer Based Intelligent Tire	**Rajvardhan Nalawade** *Virginia Tech*
10:15 AM	**Panel Discussion**		
11:30 AM	Close of Conference		**Meysam Khaleghian** *Program Chairman*

About The Tire Society

The Tire Society was established to disseminate knowledge and to stimulate development in the science and technology of tires. This is pursued through technical meetings and publication of the journal, Tire Science and Technology. The Society is a not-for-profit Ohio corporation managed by a duly elected Executive Board of tire industry professionals who serve on a volunteer basis.

Many members volunteered their time to put together the 2020 conference.

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Co-Chair:	Gobi Gobinath	*The Goodyear Tire & Rubber Company*
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Corissa Lee	*Exponent*
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In addition to the Journal Editor, the associate editors volunteer time to contribute to the peer review process associated with publishing manuscripts in the Tire Science & Technology Journal:

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The 40th Annual Meeting and Conference
August 31st & September 1st, 2021

at The Hilton Akron Fairlawn Hotel

Program Chair:	Matthew J. Schroeder	*Cooper Tire & Rubber Company*
Co-Chair:	Gobi Gobinath	*The Goodyear Tire & Rubber Company*

Conference Theme: The Virtual Tire

The conference committee would appreciate your assistance and suggestions.

A call for papers will be issued to attendees of the conference and will be available online.

Visit www.tiresociety.org for updates.

Keynote Address

Chris Helsel
Senior Vice President and Chief Technology Officer, The Goodyear Tire & Rubber Company

Chris Helsel is Senior Vice President and Chief Technology Officer for The Goodyear Tire & Rubber Company. As traditional tire innovation and design become increasingly complex, Goodyear's products and services also are becoming an integral part of the connected car, which operates in an emerging mobility ecosystem. In that environment, Chris's deep tire industry experience, his track record of driving change and delivering results in challenging assignments, along with his curiosity and passion to win are a perfect combination to drive Goodyear's innovation.

He joined Goodyear in 1996 and spent the early years of his career working in computer modeling, tire design and technology for consumer, commercial and racing tires. In 2010, he was named a global director, overseeing development of technology for consumer and commercial truck tires, before relocating to Goodyear's Innovation Center in Luxembourg as director of technology programs. He went on to lead the company's commercial truck tire retread business in North America prior to assuming a role as director, North America commercial and global off-highway technology at Goodyear.

Helsel earned his undergraduate degree in mechanical engineering from Cleveland State University and his Master's in the same discipline from The University of Akron.

Title of Talk:
Intelligent Transportation - Smart Mobility Solutions from the Tire Industry

Plenary Lecture

Dr. Giorgio Rizzoni
Professor at The Ohio State University and Ford Motor Company Chair in Electromechanical Systems

Giorgio Rizzoni, the Ford Motor Company Chair in ElectroMechanical Systems, is a Professor of Mechanical and Aerospace Engineering and of Electrical and Computer Engineering at The Ohio State University (OSU). He received his B.S. (ECE) in 1980, his M.S. (ECE) in 1982, his Ph.D. (ECE) in 1986, all from the University of Michigan.

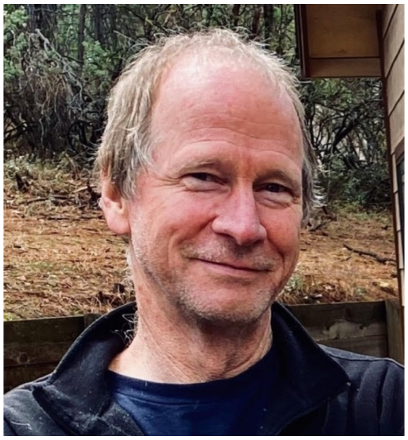
Since 1999 he has been the director of the Ohio State University Center for Automotive Research (CAR), an interdisciplinary university research center in the OSU College of Engineering. His research activities are related to modeling, control and diagnosis of advanced propulsion systems, vehicle fault diagnosis and prognosis, electrified powertrains and energy storage systems, vehicle safety and intelligence, and sustainable mobility. He has contributed to the development of graduate curricula in these areas and has served as the director of three U.S. Department of Energy Graduate Automotive Technology Education Centers of Excellence: Hybrid Drivetrains and Control Systems (1998-2004), Advanced Propulsion Systems (2005-2011, and Energy Efficient Vehicles for Sustainable Mobility (2011-2016). Between 2011 and 2016 he served as the OSU Site Director for the U.S. Department of Energy China-USA Clean Energy Research Center - Clean Vehicles.

He is currently leading an ARPA-E project in the NEXTCAR program. During his career at Ohio State, Prof. Rizzoni has directed externally sponsored research projects funded by major government agencies and by the automotive industry in approximately equal proportion. Prof. Rizzoni is a Fellow of SAE (2005), a Fellow of IEEE (2004), a recipient of the 1991 National Science Foundation Presidential Young Investigator Award, and of many other technical and teaching awards

Title of Talk:

Enhancing Vehicle Fuel Economy through Connectivity and Automation – the NEXTCAR Program

Invited Speaker



Ross Tessien
Principal at Electricwaze LLC

Ross Tessien is a Mechanical Engineer, Writer, Inventor and Futurist with 46 issued US patents for products including high speed electronic cable connectors, chimney charcoal starters, cavitation fusion reactor technologies and high-speed electric vehicle transportation tunnel systems similar to those being developed and built by The Boring Company founded by Elon Musk who also founded Tesla and SpaceX.

Title of Talk:

Future Tire Requirements for Battery Electric Vehicle Tunnel Transportation Systems

The Boring Company is building a first commercial tunnel for electric vehicles at the Las Vegas Convention Center where patrons will be able to travel below ground from one end of the convention center to the other (~1-mile distance) in battery electric vehicles built by Tesla.

Tessien will discuss the future of electric vehicle tunnel transportation systems with a focus on the new types of tires that will be required for these new transportation systems. Tessien expects future tunnels to be installed beneath all of the 44,000 miles of US Interstate Freeways. Vehicles built to use these tunnels will require new tires for several technical reasons, vehicle weight due to batteries being just one. Tessien will address some of these new requirements in his talk.

Panel Discussion
Intelligent Transportation

Evolving technologies around intelligent transportation impacts on the tire industry and require realignment of what features a tire should be equipped with and how tires are engineered, manufactured, and sold. The realignment will be driven by changes in road condition, vehicle configurations, requirements, cost, and also by environmental concerns. OEM's are compressing development vehicle development schedules, driving increased use of simulation to support virtual tire modeling. Environmental issues to address sustainability and tire recycling are also a concern. The list goes on. Representatives from the tire industry, vehicle OEM's, Futurist and academia will provide their perspectives on these issues.

Moderator: Mohammad Behroozi, Sr. Vehicle Dynamicist, General Motors.
Dr. Behroozi received his PhD/PostDoc from the University of Birmingham, UK, on FE Analysis of tires. He worked as research scientist at TNO Automotive, Netherlands, within Delft Tire group and Pratt & Miller Engineering, Michigan, on areas such as F&M characterization, tire testing, modelling, simulation technologies and smart tire development. He is currently Vehicle Dynamicist at General Motors on next-gen Full-size trucks and EV platforms. Dr. Behroozi instructs workshops on the tire mathematical modeling and collaborates in several research projects with universities. He has also undertaken roles as editor, session chair, award committee, panelist and reviewer to several tire and vehicle dynamics journals and conferences.

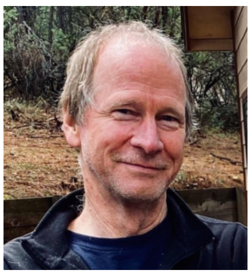
Panelist: Ric Mousseau, Lead Tire Modeling Engineer, General Motors.
Dr. Mousseau received his PhD in Mechanical Engineering from the University of Michigan. He served in the Mechanical Engineering departments at the universities of Michigan and Toledo and has worked in the automotive and tire industries and for the US Army TACOM. Dr. Mousseau has volunteered in many roles with the Tire Society, including, President, Vice President, Secretary, XCOM Member at Large, Program Chair, and Associate Editor. He has authored over 30 publications on tire mechanics and vehicle dynamics. In his free time, he enjoys being with his family, running, hiking, golf, and photography.

Panelist: Chris Queen, Director of Innovation Technology, Goodyear, USA
Leading the beyond tire technology development for Tire Intelligence & Mobility. Mr Queen began with Goodyear in their student co-op program. He received his BS in Mechanical Engineering from the University of Akron. In his 19 years with Goodyear he has held a variety of roles in Tire Engineering in both Akron and Luxembourg, managed the Texas Proving Grounds and most recently was on the NA Commercial business team as Category Manager.

Panelist: Giorgio Rizzoni, Professor at The Ohio State University and Ford Motor Company Chair in Electromechanical Systems
Dr. Rizzoni received his B.S., M.S., and Ph.D. degrees from the University of Michigan. Since 1999 he has been the director of the Ohio State University Center for Automotive Research (CAR), an interdisciplinary university research center in the OSU College of Engineering. He is currently leading an ARPA-E project in the NEXTCAR program. Professor Rizzoni is a Fellow of SAE, a Fellow of IEEE, a recipient of the 1991 National Science Foundation Presidential Young Investigator Award, and of many other technical and teaching awards.

Panelist: Saied Taheri, Professor at Virginia Tech

Dr. Saied Taheri received his B.S., M.S., and Ph.D. degrees in Mechanical Engineering from Clemson University. He is a Professor of Mechanical Engineering at Virginia Polytechnic Institute and State University, known as Virginia Tech (VT). He has been the founding director of the NSF I/UCRC Center for Tire Research (CenTiRe) since 2012 and the director of the Intelligent Transportation Laboratory since 2008. He was also the co-founder of the National Tire Research Center in 2009. He has 30 years of academic and industrial experience in automotive engineering (tire and vehicle dynamic modeling and design), dynamics and control, and intelligent systems, with applications in intelligent tires and vehicles, vehicle dynamics and control, automotive and transportation safety, and railroads. Dr. Taheri has published 161 refereed (journal and conference) articles, delivered 76 abstracts in presentations, seminars, and invited talks, and is currently finishing a book on Vehicle Dynamics.



Panelist: Ross Tessien, Futurist & writer, Principal at Electricwaze LLC

Ross Tessien is a Mechanical Engineer, Writer, Inventor and Futurist with 46 issued US patents for products including high speed electronic cable connectors, chimney charcoal starters, cavitation fusion reactor technologies and high-speed electric vehicle transportation tunnel systems similar to those being developed and built by The Boring Company founded by Elon Musk who also founded Tesla and SpaceX.

Voxel-based Finite Element Modeling to Predict Tread Stiffness Variation Around Tire Circumference

Arnav Sanyal[1]

Email: axsanyal@coopertire.com

The tread pattern of a tire is typically designed with a particular pitch sequence of tread blocks around the tire's circumference. While the variable tread pitch is primarily intended to reduce the overall tire noise, it also introduces a variation in the tread stiffness as the tire rolls over the contact patch. This variation in tread stiffness adds a non-uniformity in the tire which can interact with other existing non-uniformities present in the tire.

In this study, we developed a process to calculate the tread stiffness variation around the tire circumference using laser scan measurement data. A new unworn tire was scanned using a CTWIST machine to get a complete topographical map of the tread pattern. The raw data from the scan was used to develop an image of the full tread pattern containing all the major tread blocks that define the pitch sequence. The image was used to generate a voxel-based finite element model of the tread pattern. Voxel (the 3D generalization of a 2D pixel) based mesh generation has been extensively used in biomechanics research for generating computer models from CT/MRI scans and we used a similar approach for generating the finite element mesh of the tread pattern.

Finite element analysis of circumferentially spaced sub-models of the tread pattern was performed to compute the tread stiffness and its variation around the tire's circumference. The process developed in this study can be used to quantify the non-uniformity of tread stiffness variation in a tire due to pitch sequencing.

[1] Cooper Tire & Rubber Company, Findlay, OH 45840

Tire Curing Process Analysis through SIGMASOFT Virtual Molding

Gabriel Geyne[1]

Email: g.geyne@3dsigma.com

Cycle time is at the top of the list of factors that define the cost of a product from design to production. In tire manufacturing, the curing process is one of the more difficult processes to optimize due to the complexity of the elastomer materials. The chemistry of the elastomers is inconsistent and varies depending on the formulation, typically composed of dozens of different ingredients. Thus, developing a sustainable process that yields consistent quality is difficult with high levels of uncertainty predicting potential issues prior to production. The curing process is not only time and energy consuming, but it also has a large effect on final shape, quality and characteristics.

In order to gain more control over such a pivotal process, tire manufacturers can use process simulation to accurately model the curing of the elastomer materials through SIGMASOFT® Virtual Molding. Virtual Molding gives an “inside the tire” analysis by providing insight into the evolution of temperature and curing degree throughout the curing process. Additionally, Virtual Molding provides the ability to dissect and investigate individual components (i.e., bead wire, rubber coated cords, carcass ply, etc.) and determine regions that cure faster and understand how properties change from uncured to cured.

Having the capability to look at the behavior of individual components during the curing process means more informed decisions can be made to define, operate and monitor the manufacturing process. Adjustments can be made prior to manufacturing leading to a more robust solution. In that same regard, through simulation different rubber compounds can be trialed in order to meet specific design and process objectives. Through virtual molding, tire manufacturers can not only optimize their cycle time, but also minimize resources, reduce energy consumption, decrease time in trials, avoid defects, and improve part quality.

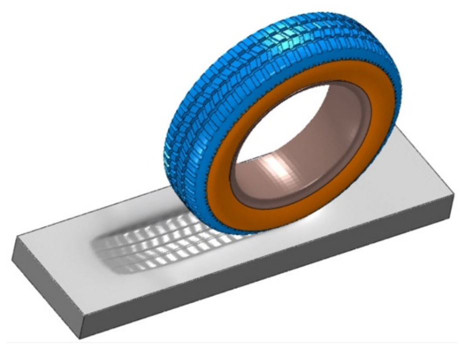
[1] SIGMA Plastic Services, Inc., 10 N. Martingale Road, Suite 620, Schaumburg, IL. 60173

Off-the-Road Tire Performance Evaluation Using High Fidelity Simulations

Biswanath Nandi[1] and John Lewis[1]

Email: biswanath.nandi@3ds.com

Agricultural, mining, military and construction vehicles operate on unpaved roads most of the time. Therefore, capturing tire-terrain interactions such as tire-soil, tire-sand and tire-gravel is a critical aspect of designing these vehicles. Because of the complexity of the problem, a 2D empirical method is often used for evaluating the tire-terrain interactions. In addition, physical tests are very expensive and time consuming to evaluate the performance of an Off-The-Road (OTR) tire. A predictive simulation tool can be very useful for this purpose. This paper focuses on a full 3D finite element analysis approach for both aspects of OTR tire modeling and the soil modeling to obtain meaningful simulation results.



The tire-soil interaction modeling involves simulating an extreme deformation problem since the soil deforms significantly, when an OTR vehicle operates on it. Therefore, a typical Lagrangian finite element technique fails due to excessive deformation of the elements. However, tire-soil interactions can be modeled successfully employing the Coupled Eulerian-Lagrangian (CEL) technique, in which the soil is modeled in the Eulerian framework and the tire is modeled in the Lagrangian framework, and a robust contact capability available within Abaqus/Explicit allows capturing the contact behavior between the tire and the soil.

In addition, this paper also discusses briefly how to characterize soil and select an appropriate Abaqus material model and how to compute rolling resistance based on the plastic deformation in the soil and viscoelastic energy dissipation in the rubber.

[1] Dassault Systems SIMULIA Corp., Johnston, RI, USA

A Study on Tire Ride Performance using Flexible Ring Models Generated by Virtual Methods

Yaswanth Siramdasu[1], Kejing Li[1], Jonghyuk Lim[1], and Robert Wheeler[1]

Email: siramdasu.yaswanth@hankooktech.com

Abstract
The objective of this study is to quantify the contributions to ride performance of the tread, belt, sidewall and carcass using a flexible ring tire model generated from finite element (FE) model simulations. Firstly, FE models are generated, and basic performances predicted to provide the virtual data for the flexible ring models. Secondly, dynamic cleat tests on a fixed spindle are simulated with the flexible ring models and spindle forces are documented. The virtual method is first validated using measured data for a tire with multiple tread depths. Then the observations on changes in longitudinal and vertical spindle force responses for different tread depth, belt, sidewall and carcass features are reported and relationships to ride performance are discussed. The methods for development of the flexible ring models based on virtual data from FE models [1] are also discussed. The techniques are applied using commercial products ABAQUS for the FE simulations and FTire for the flexible ring models.

[1] Hankook Tire and Technology - America Technical Center

[1] Siramdasu, Y., Li, K., and Wheeler, R., "Generation of Flexible Ring Tire Models Virtually using FEA: Application to Dynamic Cleat Simulations," presented at Tire Society Conference 2019

Data-Driven Multiscale Science for Tire Compounding

Hongyi Xu[1], Richard J. Sheridan[2], L. Catherine Brinson[2], Wei Chen[3], Bing Jiang[4], George Papakonstantopoulos[4], **Craig Burkhart**[4], Patrycja Polinska[5]

Email: craig.burkhart@goodyear.com

Modern tire compound design is confronted with the simultaneous optimization of multiple performance properties, most of which have tradeoffs between the properties. In order to uncover new design principles to overcome these historical tradeoffs, multiscale compound experiment, physics, and simulation are being developed and integrated into next-generation design platforms across the tire industry. This presentation describes the efforts in our laboratories to quantify compound structures and properties at multiple scales—from nanometers to microns—and their application in compound simulations. This integration of experiment and simulation has been found to be critical to highlighting the levers in data-driven multiscale compound design.

[1] *The University of Connecticut*, Storrs, CT
[2] *Duke University*, Durham, NC
[3] *Northwestern University*, Evanston, IL
[4] *Goodyear Innovation Center*, Akron, OH
[5] *Goodyear Innovation Center*, Colmar-Berg, LUXEMBOURG

Development of Geometrically Accurate Finite Element Tire Models for Virtual Prototyping and Durability Investigations

Emanuele Grossi[1], Edoardo Samarini[2], and Ahmed A. Shabana[2]

Email: egrossi@exponent.com

In this paper, new finite element (FE) tire models are developed using an approach based on the integration of computer-aided design and analysis (I-CAD-A). This approach allows for modeling multibody vehicle systems (MBVS) using unified geometry/analysis meshes in order to eliminate the costly and time-consuming process of converting solid models to analysis meshes. The tire geometry is defined using the FE *absolute nodal coordinate formulation* (ANCF), which is related to B-splines and nonuniform rational B-spline (NURBS) geometries by a linear mapping.

In the case of large deformation analyses, the ANCF geometry can be used directly as the analysis mesh. On the other hand, in case of small deformation analyses which require the calculation of the tire natural frequencies and mode shapes, the ANCF position vector gradients can be written in terms of rotation parameters to define geometrically accurate *floating frame of reference* (FFR) finite elements (referred to as ANCF/FFR elements). Both small and large deformation problems are investigated to demonstrate the feasibility of the mechanics-based approach used in this paper. A small deformation ANCF/FFR pneumatic tire model is developed to solve the linear eigenvalue problem required for the calculation of the tire frequencies and mode shapes and the results of the modal analysis are verified against the results of the commercial FE software Ansys. Regarding the large deformation analysis approach, an ANCF non-pneumatic tire model is developed and systematically integrated with a multibody system (MBS) planetary rover model for Mars explorations. Several simulation scenarios are investigated to analyze the performance of ANCF non-pneumatic tire models experiencing large deformations and rotations.

[1] Exponent, 525 W Monroe St, Chicago, IL 60661
[2] University of Illinois at Chicago, 1200 W Harrison St, Chicago, IL 60607

Periodic Results Transfer Operations for the Analysis of Damage Accrual Under Steady / Transient Rolling

William V. Mars[1], Govind Paudel[2], Jesse D. Suter[1]

Email: wvmars@endurica.com

Tires sometimes encounter road hazards, and it is an open question whether such events are damaging enough to influence long-term durability. Although the problem is difficult to study experimentally, Endurica DT's incremental critical plane fatigue analysis procedures open the opportunity to study such events using numerical simulation. In order to apply these procedures in the most efficient possible manner, a periodic results transfer procedure has been developed to enable damage to be accrued across a series of simulations including both an Abaqus/Explicit Lagrangian rolling impact analysis and an Abaqus/Standard steady state rolling analysis. The procedures allow for uniform damage accrual on a 2D or sector mesh associated with steady state rolling to be transferred to a 3D mesh as an initial condition for a Lagrangian rolling simulation. They allow for accrual of nonuniform damage around the circumference to be accrued. They also allow for worst case results along a streamline with nonuniform damage to be collected and presented on a 2D or sector mesh. The procedures are applied here to study the damage accrued during a transient impact in terms of remaining life for later steady state operation. Damage done by sidewall curbing and cleat impact events are evaluated.

[1] Endurica LLC, 1219 West Main Cross, Suite 201, Findlay, Ohio 45840, USA,
[2] Dassault Systemes, 6105 Parkland Blvd, Mayfield Heights, Ohio 44124

Effect of Tyre Imperfection on Vehicle Response

N. K. Jha[1], L. Madhav[1], P. Ghosh[1] and R. Mukhopadhyay[1]

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A tyre acts as an interface between road & vehicle and plays an important role in terms of vehicle dynamics. Any imperfections in tyre manufacturing processes may cause unwanted noise, vibration and ride quality. In the present study, we analyze the effect of belt off-center on tyre characteristics. As a part of quality check, x-ray images detail the amount of belt offset in a particular side of the tyre. Due to imperfect belt alignment during building process results in tyre conicity which causes variation in important uniformity parameters e.g. lateral and radial force variation. The amplitude of the first harmonic of these force variations contributes to vehicle shake.

Experimental results showing the effects of belt off-center on drum test rig which allows the reproducible measurements of tyre road noise & vibration on real road surfaces at speeds up to 120 km/h. To analyze the vibration levels of a passenger car tyre, at first, the acceleration/vibration data of perfect tyre is measured and then compared it against the imperfect tyres. The time-series waveform of acceleration at the leading, center and trailing edge region is then extracted to the frequency domain by using the well-known Fast Fourier Transform (FFT) technique whereas the vibration data is analyzed using power spectral density (PSD). Finally, the effect of manufacturing defect is assessed in terms of vehicle response.

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Road Induced Interior Noise: Use of OTPA to Determine Tire Contribution and Vehicle Sensitivity

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Customers' expectations concerning noise and comfort inside a vehicle are getting higher, as an image of the quality of the vehicle. Because of optimization of engine noise during the past years, the contribution of road noise to interior noise has increased. The road noise performance is mainly due to the vibrations coming from the wheels and going inside the car through the frame. Thus, it depends on the good coupling between the tire and the vehicle, to avoid bad filtering or mode resonance. The OTPA (Operational Transfer Path Analysis) is a powerful tool to investigate quickly the sound inside the cabin of the vehicle, and to determine the contributions of the main sources of it. Then it is possible to find the link between a disturbance inside the cabin and its origin. One of the uses of this tool for Michelin is to investigate specific claims of customers concerning the interior noise of the car. For road noise, it makes it possible to find the wheel responsible for the disturbance, and to separate the input (wheel accelerations) from the path (car transmissibility). The cause of the sound can be determined: high source level from the wheel, or low filtering from the car on the specific disturbance. An example of study showing how the method is implemented in the case of road noise is presented.

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Advantages of a Cross-Ply Carcass Tire Construction on Key Performances (Especially for Electrically Driven Vehicles)

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As electrification becomes mainstream, there are a number of ground-breaking changes happening simultaneously. These changes are not only trying to replace internal combustion engines, but are also affecting all many other vehicle components, tires included. An EV (Electric Vehicle) tire is designed to work at high traction torques because of the electrical engine, they need to carry greater weight due to the battery packs, produce minimal noise - and they should be lighter to compensate (at least in part) for the vehicle's increased weight.

We observed that the introduction of a cross-ply carcass is an important tire design change, performed to balance the increase of load index with the simultaneous reduction of weight of the new EV tires. In this paper the authors will explain how a cross-ply carcass layer has been mathematically modelled in the 3D shell-based tire model CDTire.

Simulation results will show that the model can predict the change of all the tire key performance indicators due to the cross-ply carcass. This variation affects the tire's static characteristics, its handling characteristics and as well as the behavior in frequency domain up to 250Hz. This model improvement allows for the usage of the tire model in the multi-body-dynamics co-simulation context of full EV virtual design

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Tire Conditions Needed to Maintain Contact Patch Shape

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The tire contact patch is the only interaction between a vehicle and the road. The forces generated in this patch dictate the movement of the vehicle. During many maneuvers the contact patch will change shape and size. During straight driving the contact patch is generally rectangular in shape, but during cornering maneuvers it may change due to changes in slip angle, camber angle, normal load, etc. This usually causes the contact patch to become more triangular in shape. However, there are combinations of slip angle and camber angle that maintain a similar contact patch shape (Figure 1). This is named the equivalent shape line, and it is primarily dependent on normal load (Figure 2)
.

This study will investigate the necessary conditions for maintaining a rectangular contact patch shape. This could include changes in speed, pressure, load, slip angle, and camber angle. This investigation may help to identify ideal vehicle alignment properties, so that the tire is always operating in the ideal range of contact patch shapes during various maneuvers. With vehicles becoming more intelligent, it may become possible to further control these parameters while driving, leading to increased efficiency.

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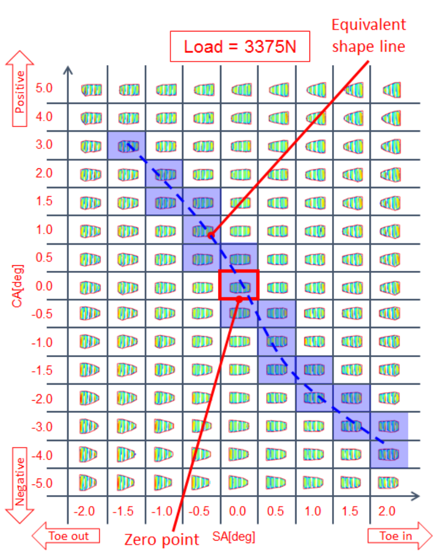

Figure 1: Example of Equivalent Shape Line

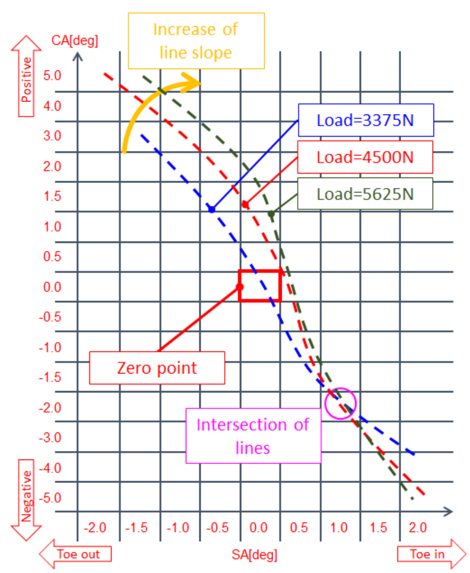

Figure 2: Example of Load Dependency of Equivalent Shape

Wheel Speed Effect on Transient Lateral Force and Its Characterization by Ramp-Step Steer Test Method

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The concept ‘relaxation length’ serves as one of several ways to characterize the transient lateral response for a rolling tire. Most test methods developed to identify relaxation length tightly link to Pacejka's single-contact-point linear transient model. Its underlying assumption is that the traveled distance during the transition interval is always a constant regardless of wheels’ linear rolling speed. The current research provides physical data against this strong assumption. The data is acquired through a newly developed test method named ‘ramp-step steer method’.

The ramp-step steer method features a non-stop, high rolling speed, and fast-changing slip angle procedure that cannot be fulfilled by the conventional `start-stop-resume' step steer method. Thanks to the high dynamic capability of the equipment in GCAPS corp, the proposed test method becomes feasible. A novel data post-processing scheme comes along with the test method as well. The ramp-step steer method is independent of any specific models and, to the most extent, replicates the scenario of a rolling tire subjected to a sudden slip angle change from on-vehicle to an indoor environment.

The wheel speed effect on tires' transient lateral response is reflected through a proposed quantity, Ly, which is a more general descriptor and can downscale to relaxation length under specific circumstance. Ly itself does not associate with any model. The remaining study is to explain the speed effect through an updated model.

The present research aims at providing a better way of characterizing tires’ lateral transient behavior, not an alternative to identify the key parameter ‘relaxation length’ in Pacejka's model. Another contribution of the research is categorizing and separating hierarchy of various transient tire models.

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Measuring Strain Fields and Crack Advance in a Pre-cut Planar Tension Test Specimen during Slow, Medium and High Speed Straining

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In a physical testing laboratory, a tension test involving a pre-cut planar tension test specimen is often used to evaluate the stress and energy required to advance a crack. It is desirable to know the surface strain field in the specimen overall and near the tip of the crack. As the crack begins to grow, it is also desirable to capture and characterize the advancing crack.

The presents difficult measuring challenges. In this work, low-speed and high-speed imaging are combined with Digital Image Correlation (DIC) to observe and calculate surface strains. High resolution imaging is needed near the crack tip and a large field of view is needed to capture specimen translation and large strains in the far field. Due to limitations in the capabilities of the high-speed imagining systems required to capture the crack event, these requirements contradict each other and serve as the functional limitation of the measurements.

In addition, during slow straining experiments a crack tip may remain stationary for a long time followed by high speed crack tip advancement. It is difficult to capture both events, and the resulting analysis requires merging the two data sources to create an accurate picture of the strains throughout the specimen.

This presentation describes the challenges and approaches attempted using low- and high-speed imaging with DIC to provide useful experimental data.

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A Validated Test Methodology to Evaluate Radial Ply Tire Road Hazard Impact Failures

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In-service tire failures are a critical road safety issue. Tire malfunctions were reported to have contributed to seven hundred and thirty-three 2016 US traffic fatalities [1], and a similar number in 2017 [2]; it is therefore important to identify the predominant root causes. For decades tire manufacturers have warned that substantial in-service impacts can cause subsequent tire failure, even in the absence of immediate inflation pressure loss. Such impacts (e.g., with a curb) are not uncommon, yet the vast majority of affected tires proceed safely to end-of-tread-life removal. A threshold impact magnitude, beyond which precautionary tire removal or close inspection for damage is recommended, appears not to have yet been established. A diversity of approaches has been used in attempting to do so, and in the present work those approaches have been reviewed in the light of measurements of road wheel impact force vectors, which have been validated herein. It was established that static laboratory tests published to date result in tire impact forces which differ very substantially from those confirmed on vehicles in operation, and that postimpact durability testing results in contact and other tire forces which similarly differ. No association between these tests and on-vehicle operating conditions has yet been determined. A suitable alternative test methodology and equipment design has been developed and validated, and a DOE proposed that will enable the determination of a set of impact and operating circumstances comprising a threshold at which damage that compromises the long-term structural durability of the test tire is expected.

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Influence of Tire Force and Moment Properties on Sine with Dwell Maneuver Test Metric Variability

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The Sine with Dwell (SWD) maneuver is the basis for the NHTSA FMVSS-126 regulation. All vehicles under 10,000 lbs. GVWR need to pass this test. Understanding the variability in the yaw rate ratio and lateral displacement test metrics is important for vehicle development. Anything that influences vehicle handling can affect test metric variability. Vehicle handling performance depends largely on vertical tire patch loads, tire force and moment behavior, on slip angle, and camber angle. Tire force and moment relationships have distinct shapes, but they all commonly rise to a peak value at a given slip angle value and then fall off with increasing slip angle. Severe handling maneuvers, like the SWD operate at slip angles that are at, or above, the peak lateral force. This paper examines how changes in shape of the lateral force and aligning moment curves, affect the sine with dwell test maneuver variability.

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Tire Mode Identification, Distribution Chart, and Correlation with Vehicle NVH

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Tire modes have a major effect on vehicle ride, vibration, and noise performance. Modal testing and analysis is usually conducted to determine the modal parameters of the structure, including natural frequencies, damping ratios, and mode shapes. However, tire modal identification is usually difficult due to its high damping and double curvature geometry.

Using a single proprietary experimental setup in this study, the series of tire balloon mode (W1), drift mode (W2), sidewall bouncing mode (W3), lateral bending mode (W4), crown bending mode (W5), and sidewall shear mode (W6) are identified. Some special modes can also be detected, including cavity mode, bead mode, etc. Under loaded condition, the tire mode is generally bifurcated into two corresponding modes, namely, anti-node and node modes. This modal analysis procedure is capable of identifying at least 28 tire modes for unloaded condition and 40 tire modes for loaded condition below 400 Hz.

A unified naming convention (C*n*W*m*) for the tire modes is developed, and the tire mode distribution chart is established to provide insights into how these modes interact with each other. Besides the cavity mode and low-frequency structural modes, vehicle NVH testing shows that the sidewall steer mode (C1W6) may also have significant influence on the vehicle interior noise and vibration. To improve tire NVH performance, it is good practice to identify modes/frequencies that have issues and modify corresponding tire constructions (mass/stiffness/damping) to shift frequency or reduce amplitude.

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Self-Excited Full Vehicle Oscillations Caused by Tire-Road-Interaction – Virtual and Real-World Experimental Investigation

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In this paper self-excited full vehicle oscillations - in this context referred to as “Power-Hop” - will be described and discussed. These self-excited oscillations are mainly caused by tire-road-interaction. First engineering models to analyze self-excited oscillations will be discussed followed by results of full-vehicle measurements.

For validating full-vehicle measurement results and further investigations a specially built test rig will be presented. This “longitudinal dynamics test rig (LDP)” has been drafted and designed at the Institute for Automotive and Powertrain Engineering (IFAS) of Helmut-Schmidt-Universität (HSU) in Hamburg. Measurement results at different conditions (tarmac, concrete, dry, wet) concerning Power-Hop will be shown before a new transparent surface setup is introduced which allows to gain deeper insight into tire-contact patch. Furthermore, virtual investigation by an mbs full-vehicle model will be shown.

Tire-road interaction is evaluated by a quasi-static tire model which returns overall tangential forces by evaluating the state of every discretized element in contact patch. Concluding, an outlook for further of testing and modelling of the different disciplines will be given. Keywords: self-excited oscillations, Power-Hop, tire-road interaction, full-vehicle measurement, test rig development, multibody simulation, tire modelling

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“Elimination of Stray Forces from Tire Dynamics Measurements”

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The forces that enter the mounted-tire spindle of laboratory-based tire dynamics test machines include:

1. Direct tire-generated forces, tire nonuniformities and tread pattern vibrations
2. Direct tire transmitted rough road surface or cleat impact forces
3. Machine frame back-path transmitted versions of the above
4. Machine resonance amplified versions of the above
5. Dynamic load cell cross-talk
6. External noise from foundation vibrations
7. Adjacent load station criss-cross vibrations traveling through the machine frame

While Items 1 and 2 above are sought in spindle vibration measurements, Items 3 – 7 also appear and confound the measurement, confusing the analyst into thinking that machine properties are tire properties. Not only do Items 3 – 6 not exist in vehicle operation but comparing results from one test machine to another can be an exercise in comparing machine to machine, not tire to tire. Tire dynamics measurements should simulate tires in operation, not create a whole new set of problems that do not exist in vehicles. Elimination of Item 7 paved the way to the development of a tire failure warning system [1] that operates on tire endurance test machines and can be adapted for operation on passenger vehicles to warn the driver of tire trouble.

This paper develops the theory of stray force measurement, describes a method for eliminating them from experimental tire dynamics data, and provides experimental verification of the effectiveness of these methods.

Test tires not machines!

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[1] U.S. Patent No. 7,272,536 “Failure Warning for a Tire Among a Plurality of Tires”

Research on a Synergistic Method of Improving Tire Rolling Resistance and Grip Performance”

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In order to clarify the contradictory mechanism between tire rolling resistance and grip performance, ten (10) 205/55 R16 radial tires with different tread patterns were selected as the research object. Using VIC-3D non-contact strain measurement system, the pattern deformation in the contact area under vertical load was tested and the relevant deformation parameters of the contact area were extracted. Correlation analysis was used to establish the relationship between the identified deformation parameters and tire performance indicators. Then the contradiction mechanism between tire rolling resistance and grip performance was identified.

The mechanism is such that, in order to improve the grip performance of the tire, it is necessary to reduce the transverse tensile strain of the tread in the contact area and increase the longitudinal tensile strain of the tread, but with the increase of the longitudinal tensile strain, the rolling resistance of the tire will also increase, which leads to the contradiction between tire rolling resistance and grip performance. In order to better understand and solve this contradiction, a finite element model of 205/55R16 tire with complex pattern was established. The influence of the number and width of transverse grooves in the outer shoulder area on tire rolling resistance and grip performance was analyzed by numerical simulation, where it was identified that, the longitudinal tensile deformation of the tread is the main cause of contradiction between the two performances.

An optimized design of concave transverse groove with narrow groove in the middle and wide groove at both ends was proposed in the outer shoulder area to resolve the contradiction. Compared with the original scheme, the rolling resistance of the optimized scheme was reduced by 2.112N, and the grip force saw an increase of 10.196N, and thus delivering a cooperative improvement of tire rolling resistance and grip performance.

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Application of Steady State and Transient Acceleration Signals in Intelligent Tire

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Intelligent tire senses its working states with sensors, thus enhancing performance and safety of vehicles. Accelerometer is widely adopted in intelligent tires for its ability to obtain both kinematics and dynamics-related information. However, the lack of tire rolling acceleration theory restraints its further development.

In this paper, a hardware prototype of accelerometer-based intelligent tire is constructed, and then a rolling kinematics model based on mixed Euler-Lagrange method is proposed to reveal the formation of the three-dimensional tire acceleration in both steady and transient domain. It is analytically demonstrated that tire body acceleration originates from the coupling effect of rigid body motion and elastic deformation, and can be presented as the addition of steady-state and transient-state component.

Under this mechanism, many essential information related to tire acceleration could be inferred to help improving driving safety and performance. Tire vertical and lateral forces are estimated from the steady-state features of acceleration waveform along with force models, and the estimation methods are validated to be widely applicable. Transient-state acceleration component is hard to split from the measured signals for complex external excitations, thus learning-based algorithms are developed to automatically extract discriminative features without any physical models.

As the application, tire wear is identified at a high accuracy with machine learning and deep learning based on complete acceleration signals. The proposed acceleration-based intelligent tire system and mechanism are proved to be effective in acquiring vital information about tire to improve vehicle safety and performance.

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How to Test Snow Tread Block Traction in Lab: Effect of Snow Density

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While in nature snow properties change from day to day or even minute-by-minute, one of the great advantages of lab tests is the stability and reproducibility of testing conditions. In our labs at IDS, Leibniz University of Hannover we currently run 3 test rigs being able to conduct tests on snow and ice tracks [1,2] with tire tread blocks: HiLiTe (High Speed Linear Tester)[3], PFT (Portable Friction Tester), RepTiL (Reproducible Tread Block Mechanics in Lab). In the past years, we have utilized them in a project on the influence of snow track properties on friction and traction test results. In this paper, we will present a first excerpt of the results.

On the RepTiL test rig, we executed a test campaign with variations in tread material hardness, number of sipes, slip ratio, while evaluating the penetration into the snow, slip length, max. longitudinal force level, longitudinal force gradient. On the other hand, we varied snow density during preparation of our tracks. We have accompanied our experiments with DEM simulations to better visualize and understand the physics behind the interaction of snow and tread block. Both, tests and simulations show a strong influence of snow density resulting even in reversal of the ranking of the tread blocks' performance.

We derive several best-practice rules for snow test in lab incl snow properties and corresponding testing conditions. Furthermore, we transfer this know-how into proposals how to characterize outdoor snow test tracks and under which conditions the clearest test results (with widest spread) can be expected.

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[1] S. Ripka et al. "Investigation of Friction Mechanisms of Siped Tire Tread Blocks on Snowy and Icy Surfaces", Tire Science and Technology, 40 (1), 2012, 1–24.
[2] T Linke et al. "Investigation of Snow Milling Mechanics to Optimize Winter Tire Traction", Tire Science And Technology 45 (3), 2017, 162-174
[3] S Ripka et al., „Tread block mechanics on ice–snow surfaces studied with a new high speed linear friction test rig", VDI BERICHT 2086, 2009, 239-254

A Predictive Modeling of the Viscoelastic Response of Styrene Butadiene Rubber due to Aging

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Styrene Butadiene Rubber (SBR) degrades under its service conditions when exposed to environmental factors such as oxygen, humidity, and temperatures. The mechanical properties of the rubber evolve via the change of its chemical characteristics. This phenomenon is referred to as ‘rubber aging.’

According to the study conducted by NHTSA, thousands of car crashes and hundreds of fatalities were caused due to accidents occurring because of tire aging. Although research has been conducted in the field of rubber degradation and accelerated ageing, the prediction of rubber ageing using different optimization techniques and the formulation of a mathematical model remain unexplored.

This work focuses on developing a continuum damage mathematical model using an integrated testing/modeling framework to predict the aging of SBR when exposed to the atmosphere for a prolonged period. The obtained model can be used to predict the degradation of rubber over time and can be used to improve tire performance like durability and wear.

In this study, accelerated aging is conducted on SBR at a particular temperature and varying aging time. The change in mechanical properties is characterized by Dynamic Mechanical Analysis (DMA). A master curve for each aging condition is obtained after performing time-temperature superposition (TTS) using the Williams-Landel-Ferry (WLF) equation. The Prony series parameters of the viscoelastic model, such as characteristic time and relaxation modulus, are investigated by using different algorithms such as a genetic algorithm and trust region method.

An aging evolution function is defined based on the change in the Prony series coefficients, which occurs due to crosslinking in the SBR. Fourier Transform Infrared Spectroscopy (FTIR) is used to investigate the chemical changes, and to verify that the mechanical changes are due to crosslinking. Thus, this study will help establish a correlation between the mechanical and chemical properties of SBR rubber.

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Isogeometric Analysis for Tire Simulations: From Mesh Generation to High Precision Results

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Isogeometric Analysis (IGA) has become an alternative to the standard Finite Element Method (FEM) in many areas of engineering. Its powerful tools for model generation and flexibility of basis functions makes this relatively new approach attractive for the tire analysis and its computational challenges.

The contribution at hand is aimed to summarize the benefits of IGA for complex tire simulations starting from the step of model generation and the following transition to the environment of numerical analysis without losing accuracy at the parameterizing stage. The numerical issues which arise in IGA under the enforcement of contact and the application of inelastic materials with inclusions of reinforcing layers are studied. Moreover, the important advantages of the possibility to use higher-order functions for simulations of tire maneuvers are addressed within the steady-state framework.

Numerical examples are provided to illustrate the capabilities of IGA. The precision of the contact formulation at hand plays a significant role in the engineering simulations. Dramatic deformations and complex geometries of bodies in contact become a complex task for virtual tests in FEM. An approximation of the curved edges with standard FEM functions leads to discontinuity of the normal vectors followed by the inevitable appeal to various complex mathematical algorithms for smoothing. NURBS and NURBS-enriched FEM contact implementations allow more precise contact detection and definition of the contact penalty forces. The latter fact makes NURBS based contact formulations beneficial for simulations of complex industrial processes such as molding. Concluding remarks on the obtained results close the presentation.

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40 years and more of Tire Science and Technology - A History of the Tire Society

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In the late 1960s in the U.S. public interest in motor vehicle safety was at an all-time high, resulting in The National Traffic and Motor Vehicle Safety Act, The Highway Safety Act, and the creation of the National Highway Traffic Safety Administration (NHTSA). Around 1970 a group of industry scientists saw the need for a forum for creation of useful tire standards and dissemination of scientific knowledge about tires. This led to the formation of ASTM committee F-09 on tires in 1971. In 1972, the committee began publication of the journal Tire Science & Technology (TSTCA), the first peer-reviewed journal dedicated exclusively to scientific articles on tires. In 1979, ASTM ceased publication of the journal and in 1980 members of F-09 incorporated The Tire Society to continue publication. In 1982, The Tire Society held its first annual Conference on Tire Science and Technology. Forty years later, The Society has been through many changes, but the journal, the annual conference, and the core mission of encouraging and disseminating knowledge about tire science and technology remain.

Through a review of documents and interviews with members of the society, this paper seeks to comprehensively document the history of The Tire Society.

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A 3D-Textile-Rubber Composite: Description and Multiscale Modeling

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This work focuses on the mechanical behavior of a new class of textile-reinforced rubber composites which are made up of a 3D-fabric core enclosed by two rubber layers. The manufacturing versatility of the 3D-textiles offers encouraging possibilities to tailor these composites for specific engineering applications. However, mechanical testing of these sandwich structures considering different topologies of the reinforcement textile is expensive and time-consuming. Therefore, it is of interest to develop mechanical models that provide: (1) a better understanding of the interaction between the constituents; and (2) some insight on the role played by the different length scales of the composite microstructure.

To this end, a multiscale modeling approach has been developed based on a full-field finite element homogenization conducted at each microstructural level. The relevant scales and their related material features have been identified by means of micro-tomography imaging. The homogenized mechanical response at each level has been fitted by an appropriate (isotropic or anisotropic) hyperelastic material model and used in the upper level. Thus, the information has been connected through the scales using a staggered approach. Furthermore, a new compressible, orthotropic and hyperelastic constitutive model has been specifically developed in this work to capture the behavior of the material at the macroscopic scale. The multiscale modeling presented in this work sheds light on the complex mechanics of the textile-rubber microstructure. Moreover, our study may support the development of these new 3D-fabric-rubber materials by enabling the optimization of the different constituents to obtain specific mechanical properties.

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A Comprehensive Constitutive Equation and the Prediction of Tire Temperature and Rolling Resistance

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Cooler running tires with reduced rolling resistance is a primary consideration for both tire makers and automotive OEMs. To investigate the mechanics of energy loss and temperature rise, a nonlinear viscoelastic model suitable for numerical analysis of rolling tires is developed and demonstrated.

The rubber compounds are represented as nonlinear viscoelastic materials with temperature/frequency, strain and strain history dependent response. Several applications to different tire designs are provided to demonstrate the impact of this new material constitutive law in improving the quality of the numerical predictions over other methods. One application is a rolling tire model that was used to delineate the tire temperature distribution and the resultant rolling resistance for different 3D tread patterns.

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Speed Dependent Maxxis-Savkoor Friction Model for Rubber Compound

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Tire modeling using finite element analysis (FEA) to predict tire rolling performances requires friction characteristics of tread rubber compound under dynamic rolling conditions. A modified version of Savkoor's friction model, Maxxis-Savkoor model, has been developed for capturing the friction properties of rubber compound under dynamic rolling conditions, including contact pressure, traveling speed, and slip velocity effects.

Obtaining consistent and reproducible dynamic friction data for rubber compound was a challenge. As the rubber sample wheel, sandpaper surface, and surface temperature are continuously changing during the test; therefore, the friction coefficient measured can be inconsistent. A proprietary testing method and procedure have been developed at Maxxis to generate consistent and reproducible data to allow the better fit of Maxxis-Savkoor Model.

A friction testing machine is used to capture the friction properties of cured rubber wheel. The machine uses a large drum wrapped in sandpaper as the road surface. The small rubber wheel is run on top of the road surface at a pre-determined vertical load, speed, and slip rate. The output data includes the slip rate and the friction coefficient. The contact pressure is determined by capturing the area of the footprint of the rubber wheel using pressure paper. Initially, the data has been used to fit Savkoor's model of sliding friction. However, Savkoor's model does not include a speed dependent variable. By analyzing the fit of the model at various speeds, a speed dependent factor was added to the model. A single model can now be used to analyze the compound at multiple loading conditions and various speeds.

In order to verify the Maxxis-Savkoor Model, an ABAQUS FEA simulation of the friction testing machine was utilized. The simulations in ABAQUS were conducted over the same range of vertical loads, speeds and slip rates as the testing. The Maxxis-Savkoor Model was utilized at the interface between the rubber wheel and drum in the FEA simulations. The FEA predictions showed good agreement with measured results.

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Improved Vehicle Longitudinal Velocity Estimation Using Accelerometer Based Intelligent Tire

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An intelligent tire-based algorithm was developed to reinforce the vehicle longitudinal velocity estimation, from the vehicle IMU. A tire was instrumented using a tri-axis accelerometer (intelligent tire) in an instrumented vehicle with an IMU, and a VBOX as the ground truth for vehicle velocity. A testing matrix was developed, including two tire inflation pressures, two normal loads, and variable speed between 15-40 kph. A signal processing algorithm was developed to analyze the data from the accelerometer. Variational mode decomposition and Hilbert spectrum analysis were used for extracting features from each tire revolution. Later, a machine learning algorithm was trained to estimate the velocity using the acceleration data from the intelligent tire. Since the sampling rates of the IMU data and the intelligent tire data were different, sensor fusion was implemented. This calculated velocity was then used to correct the IMU-based estimated velocity. This new velocity can be used to enhance the performance of all advanced chassis control systems, such as ABS and ESP.

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