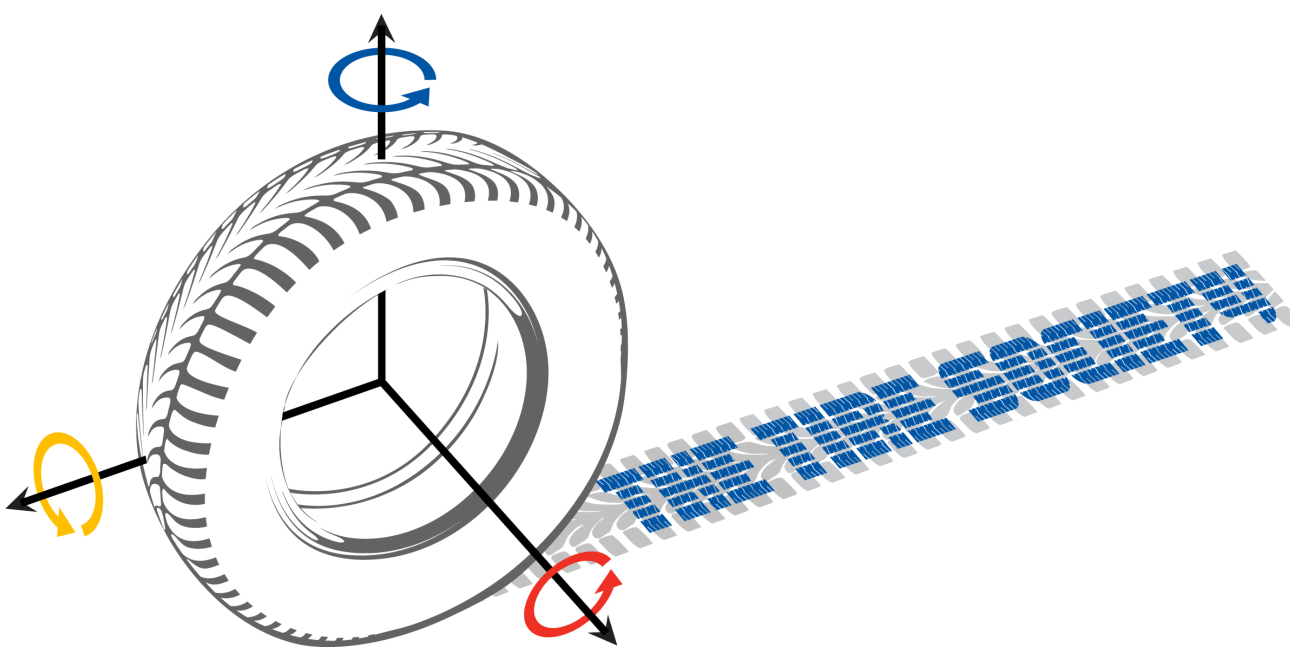
26th Annual Meeting and Conference on Tire Science and Technology

Program and Abstracts



September 25-26, 2007
Radisson Hotel, Akron City Centre
Akron, Ohio

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The Tire Society, Inc.

26th Annual Meeting and Conference on Tire Science and Technology

September 25-26, 2007
Radisson Hotel, Akron City Centre, Akron, Ohio

Overview

Day 1 – Monday, September 25

7:15 Registration

8:15 Opening: *Hans Dorfi*,
President of The Tire Society

8:30 **Keynote Address**:
Mr. Tadanohu Nagumo,
President of the Yokohama Rubber co., Ltd.

9:15 Program Opening: *Mahmoud Assaad*,
2007 Tire Society Program Chair

9:20 **Session 1**
Tire Durability
4 presentations

11:00 Break (10 minutes)

11:10 **Plenary Lecture**
Speaker: Dr. Bruce Engelmann
SIMULIA: Vice President & Chief Technology Officer

12:00 Lunch (1 hour)

1:00 **Session 2**
Tire Temperature
4 presentations

2:40 Break (20 minutes)

3:00 **Session 3**
Student Papers
3 presentations

4:15 Break (20 minutes)

4:35 **Session 4**
Tire / Vehicle Dynamics
3 presentations

7:00 **Dinner**
Speaker: *Jim Maloney,*
Goodyear: Manager Airship Operations

Day 2 – Tuesday, September 26

7:30 Registration

8:15 **Opening/Announcements**

8:20 **Session 5**
Tire NVH
3 presentations

9:35 Break (20 minutes)

9:55 **Session 6**
Tire Wear / Friction
4 presentations

11:35 **State of the Society**

11:55 Lunch (1 hour)

12:55 **Plenary Lecture**
Speaker: *Mr. Douglas Milliken*,
Milliken Research Associates Inc.

1:45 Break (10 minutes)

1 1:55 **Session 7**
Materials
4 presentations

3:35 Break (20 minutes)

3:55 **Session 8**
Tire Structural Performance
4 presentations

5:35 **End of Program**

26th Annual Meeting and Conference on Tire Science and Technology

Day 1 – Tuesday, September 25

7:15 AM		**Registration**	
8:15 AM		**Conference Opening**	Hans Dorfi President of The Tire Society
8:30 AM		**Keynote Address**	Mr. Tadanohu Nagumo President of the Yokohama Rubber co., Ltd.
9:15 AM		**Technical Program Opening**	Mahmoud Assaad, Program Chair
9:20 AM		**Session 1: Tire Durability**	Kevin Ellwood / Donald Amos, Session Chairs
9:20 AM	1.1	Overview of Roadwheel Test Development for an Aged Tire Durability Standard	Greg Altman, James Popio, David Stalnaker
9:45 AM	1.2	Study on Oxygen and Nitrogen Permeation through Tires	Donald D. Amos
10:10 AM	1.3	Evaluation of New and Aged Tires by Accelerated Service Life Tests: Comparison Using a Stepped-Up-Load and a Stepped-Up-Speed Roadwheel Test	Larry R. Evans, James D. MacIssac Jr. Sebastian Feve
10:35 AM	1.4	Yokohama Advanced Liner Technology	Tomohiko Kogure, Kinya Kawakami, Hirohisa Hazama, Yasuo Hatano, Yoshiaki Hashimura
11:00 AM		**Break**	
11:10 AM		**Plenary Lecture:** A Look at Trends in Tire Design Simulation	Dr. Bruce Engelmann – Dassault Systemes Simulia Corp.
12:00 AM		**Lunch**	
1:00 PM		**Session 2: Tire Temperature**	Mohammed Sobhanie, Session Chair
1:00 PM	2.1	Flat vs. Curved Contact Surfaces Effect on Consumer, P-Metric-LT Tire Operating Temperatures	Leighton Spadone, Jason Bokar
1:25 PM	2.2	Temperature Correction for Rolling Resistance Testing	Jason Bokar
1:50 PM	2.3	ASTM Radial Medium Truck Tire Operating Temperatures – Flat vs. Curved Surfaces	Terrence M. Ruip
2:15 PM	2.4	Thin Film Heat Flux Sensor for Measuring Film Coefficient of Rubber Components of a Rolling Tire	M. C. Assaad, G. C. Fralick, J. D. Wrbanek, J. M. Gonzalez
2:40 PM		**Break**	
3:00 PM		**Session 3: Student Papers**	Ric Mousseau, Session Chair
3:00 PM	3.1	Prediction of Tire Profile Wear by Steady State FEM	Kory R. Smith, Ronald H. Kennedy, Samuel B. Knisley
3:25 PM	3.2	Prediction of Tread Block Forces for Free-Rolling Tyres	Feiyang Liu, Michael P. F. Sutcliffe, Will R. Graham
3:50 PM	3.3	Study of Materials Properties of Tread Rubbers; Experiments and FEA Verification	Hiroshi Yokohama, Stephen D. Hall, Robert B. Randall
4:15 PM		**Break**	

Day 1 (Continued)

4:35 PM		**Session 4: Tire/Vehicle Dynamics**	Zhen-Zhong Du, Session Chair
4:35 PM	4.1	Tire-Suspension-Chassis Dynamics in Rolling over Obstacles for Ride and Harshness Analysis	Vladimir Kerchman
5:00 PM	4.2	Vehicle Suspension Measurements: Evaluation of the Benefits of Dynamic over Quasistatic Kinematics and Compliance Testing	Terence E. Wei, Hans R. Dorfi
5:25 PM	4.3	Effect of Tire Stiffness on the Articulated Vehicles Understeer Gradient	Mohamed Kamel Salaani
5:50 PM		**End of Technical Session**	
7:00 PM		**Dinner**	Jim Maloney Goodyear Airship Operations

Day 2 – Wednesday, September 26

8:15 AM		**Opening/Announcements**	
8:20 AM		**Session 5: Tire NVH**	Lin Kung, Session Chair
8:20 AM	5.1	Finite Element Modeling of Rolling Tire Dynamics for Noise Prediction	Maik Brinkmeier, Udo Nackenhorst
8:45 AM	5.2	Engineering Solution of Rolling Tire Vibration Model	Dong Zheng
9:10 AM	5.3	Validation of a Belt Model for Prediction of Hub Forces from a Rolling Tire	Christophe Lecomte, Will R. Graham, Dan J. O'Boy
9:35 AM		**Break**	
9:55 AM		**Session 6: Tire Wear/Friction**	Barry Yavari, Session Chair
9:55 AM	6.1	The Evaluation Method of One-Sided Wear by Frictional Energy	Youngsam Choi, Yuseong-gu Daejeon, Sangju Lee, Bumjin Ko
10:20 AM	6.2	Experimental Validation of the Brush Tire Model	Jacob Svendenius, Fredrik Bruzelius, Magnus Gafvert, Johan Hulten
10:45 AM	6.3	New Design Concept of Friction Rig; Fundamentals to Predict Tire Forces	Hiroshi Yokohama, Stephen D. Hall, Robert B. Randall
11:10 AM	6.4	A Study on the Frictional Energy of the Rubber Block According to the Effectiveness Factors	Hyun-Seung Yoo, Doo-Man Kim, Sang-Ju Lee, Bum-Jin Ko
11:35 AM		**State of the Society**	
11:55 AM		**Lunch**	
12:55 PM		**Plenary Lecture:** Tire Requirements for New Vehicle Architectures	Doug Milliken, MRA
1:45 PM		**Break**	
1:55 PM		**Session 7: Materials**	Cigdem Gurer, Session Chair
1:55 PM	7.1	Novel Coupling Agents for Silica-filled Rubber with Superior Processing Safety and Improved Hysteresis of the Vulcanizates	M. Gerster, E. Peregi, C. Fagouri
2:20 PM	7.2	Damping Characterization using Hysteresis on Static Non-rolling and Dynamic Rolling Behavior of Farm Tires	Guiyong Song, Brett Conard, S.K.R. Iyengar
2:45 PM	7.3	Non-Pneumatic Bicycle Tire: Design Concepts and Virtual Product Development	Kundan Kumar, Gerhard Scharr
3:10 PM	7.4	Rubber Hyperelastic Behaviours Study With Application to TBR FEA	K.J. Gong, J.X. Ye, T.T. Wei, Y. W. Luo, Y. Liu, Y. M. Miao, D. L. Chai
3:35 PM		**Break**	
3:55 PM		**Session 8: Tire Structural Performance**	Abraham Pannikottu / Bill Rockwell, Session Chair
3:55 PM	8.1	Analytical Solution for the Stresses Arising in +/- Angle Ply Belts of Radial Tires	Robert McGinty, Timothy B.Rhyne, Steven M. Cron
4:20 PM	8.2	Effect of Normal Pressure Distributions on the Analytical Solutions to Tire Forces	Mohamed Kamel Salaani
4:45 PM	8.3	Simulation and Measurement of Steel Cords Forces in Typical Truck Radial Tire	Y. Liu, Y Luo, Y. Miao, D. Chai, Y. Wei, K. Gong, Y. Ye
5:10 PM	8.4	A Case in Evaluating a Finite Element Tire Model: Measurements on Real Tire Configuration and Improved Computational Contact Pressure	LI Bing, Xia Yuanming, Li Wei
5:35 PM		**End of Conference**	

About The Tire Society…

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

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Paper Number 1.1

Overview of Road wheel Test Development for an Aged Tire Durability Standard

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ASTM F09.30 Aged Tire Durability Task Group was formed in 2002 with members from 20 organizations with the objective of developing a scientifically valid, short duration, aged durability test which correlates to conditions that can occur in service and avoids conditions which are by-products exclusive of roadwheel testing. This research program is still on-going but will be overviewed with particular emphasis on the second phase which includes the roadwheel test development effort. (The first phase involved the development of accelerated laboratory aging conditions applied to tires prior to roadwheel testing). Three different tire types were subjected to different durations of thermal-oxidative oven aging and then a variety of stepped-up load and steady state roadwheel test conditions were applied. The stepped-up tests were modeled after the FMVSS 139 endurance test but examined different speeds and load step durations. The steady state testing was conducted based on a designed experiment varying deflection, speed, and inflation pressure. Speed and deflection framing experiments were used to develop appropriate ranges for the test conditions of the DOE which was also based on tire temperatures. Particular emphasis has been placed on achieving realistic internal temperatures, end-of-test conditions of interest, and reasonable durations. Belt edge is the primary region of interest. A catalog of over 35 possible end-of-test conditions was divided into categories of target, non-target, and non-representative of in-service conditions. Tire analysis involved shearography, extensive cutting and photographing, and classification into one or more of the end-of-test conditions, coupled with test duration. Based on this testing and analysis, an aged tire durability test protocol has been proposed for further study and validation testing.

[1] Presenting author

Paper Number 1.2

Study on Oxygen and Nitrogen Permeation through Tires

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Pneumatic tires are inflated structures that depend on inflation pressure to operate at standardized levels of performance. Compressed air is now, and historically has been, the most common inflation medium; it is plentiful, generally very satisfactory, and cheap. Composed of roughly 78% nitrogen, 21% oxygen, and 1% other gasses, use of air does impose some considerations on tire designers and tire users. Gradual loss of inflation pressure is commonly known. This pressure loss is due to permeation through the tire, to leakage past the bead-rim seal and the valve, and to any puncture through the tire or damage to the rim. Tires are built with an innerliner that retards, but doesn't eliminate, such losses of inflation. Further, it has been recognized that primarily oxygen in the tire body is involved in changes of the tire materials' mechanical and chemical properties. It is less widely known and understood that the nitrogen and oxygen permeate at differing rates based on chemical properties of the gas and the tire, temperature, and on the gas partial pressure of the particular gas, and that this permeation takes place in both directions: from the inflated tire cavity to the outside and vice versa.

When high concentration nitrogen is billed as an ideal inflation medium, it has been stated on occasion that the pressure of the nitrogen will exclude oxygen from the tire. This statement is incorrect as atmospheric oxygen will permeate into a tire cavity devoid of oxygen. Atmospheric oxygen will pass through the body of the tire under all operational circumstances, until, eventually, the partial pressure is in equilibrium with atmospheric. The direction of oxygen flow will depend on existing partial pressures of oxygen in the tire cavity and atmosphere.

Measurements done on real world tires confirm these basic principles. Tires in long service typically have the inflation pressure more or less regularly checked and topped off. Since the oxygen is consumed in chemical reactions and permeates faster than the nitrogen, the tire inflation partial pressure of oxygen eventually trends significantly lower. Moreover, tires with high concentration nitrogen as an inflation medium show a gradual increase of oxygen within the tire's cavity. This oxygen originates from atmospheric oxygen permeating in a reverse direction into the tire.

Paper Number 1.3

Evaluation of New and Aged Tires by Accelerated Service Life Tests: Comparison Using a Stepped-Up-Load and a Stepped-Up-Speed Roadwheel Test

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As part of NHTSA's Tire Aging Test Development Project, tires were collected from service on privately owned vehicles in the Phoenix, Arizona area. These tires displayed significant degradation in material properties and whole tire performance that continued throughout the service life of the tire. Six different tire models collected from Phoenix were evaluated versus new tires of the same model for physical properties and time to removal in two roadwheel tests. This paper presents the results for the Phoenix tires, and new tires of the same model, tested on a 1.7 meter (67 in.) roadwheel using one of two laboratory roadwheel tests: a stepped-up-load (SUL) test, based on the FMVSS 139 Endurance test, and a stepped-up-speed (SUS) test, based on the FMVSS 139 High Speed test. The dataset consists of 154 individual roadwheel tests. The effects of previous tire service life on time to removal and the end of test condition of the tires tested were examined. A variety of transformations were investigated for the Phoenix retrieved tires to account for the time and mileage of the tire in service and to attempt to correlate the failure time to a measure of total energy input. All data are publicly available for download in the "NHTSA Phoenix Tire Dataset" at http://www-nrd.nhtsa.dot.gov/vrtc/ca/tires.htm.

[2] Presenting author

Paper Number 1.4

Yokohama Advanced Liner Technology

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In summer, 2007 Yokohama launched a new series Decibel super E-spec into the Japanese domestic market. Besides many sophisticated new technologies, super E-spec adopted a quite unique new tire innerliner material, a DVA film with an adhesive layer. The air permeability of this DVA film is ten times less than that of an ordinary BrIIR layer. It contributes environmental protection by using less raw material and providing lower rolling resistance. Lower air permeability requires less tire maintenance effort. Other tire performance is not affected, but endurance performance is improved. The adoption of the cylindrical blown film innerliner should be an initiation of jointless tires. We will try to further improve Yokohama Advanced Liner Technology and start to use in other tire applications.

[3] Presenting author

Paper Number 2.1

Flat vs. Curved Contact Surfaces Effect on Consumer, P-Metric - LT Tire Operating Temperatures

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The operating stress and resultant temperature is critical to the endurance of a tire. There are fundamental differences between the tire stresses when operating on a flat surface, as experienced in normal highway use, and on a cylindrical laboratory test wheel. Even though there are substantially higher tire stresses and temperatures on a curved test wheel, government mandated laboratory durability testing of tires is performed on cylindrical test wheels. Therefore, it is important to consider the severity of test conditions intended for a flat surface and the equivalent severity on the curved surface in order to avoid subjecting the tire to unrealistic stresses and temperatures. In this study, temperature measurements were made at the tire belt edge and center-line, for both flat and curved surfaces, under designed ranges of load, pressure and speed conditions. Statistical regression models that predict the temperatures at the tire center-line and belt edge locations are developed and discussed. Finally, a simple yet consistent conversion from flat to curved conditions is provided so that equivalent tire temperatures are obtained.

[4] Presenting author

Paper Number 2.2

Temperature Correction for Rolling Resistance Testing

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The current Society of Automotive Engineers (SAE) Rolling Resistance (RR) procedures (SAE J1269/J2452) specify that ambient temperature shall be controlled between 20°C and 28°C. To compensate for this allowed temperature difference a temperature correction equation is provided in both of these standards, yet the equations are different. Using measured rolling resistance values at various temperatures, the value for the temperature correction coefficient is investigated and a change to the temperature correction equation of SAE J1269 is proposed. However, further work is needed to determine whether a different temperature correction that includes speed dependence, in support of the coast-down method in SAE J2452, is required, although the value and equation currently used matches the newly proposed SAE J1269 value.

[5] Presenting author

Paper Number 2.3

ASTM Radial Medium Truck Tire Operating Temperatures – Flat vs. Curved Surfaces

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This paper reports the results of an extensive design of experiment (DOE) conducted on radial medium truck tires by the ASTM Committee F09.30 task group on Truck/Bus Tire Test Development. These results are from the part of the task group's work to benchmark "real world" (operational) tire temperatures.

DOE variables were tire inflation, load, and speed. Response temperatures were measured in the apex at the ply ending, at the #2 / #3 belt ending, and in the shoulder and centerline ribs via embedded thermocouples. Steady state temperatures for steer, drive, and trailer tires from three different test venues are compared; (i.e. flat belt lab machine, road/track, and 1.7m. dia. lab roadwheel). Results from temperature regression modeling are discussed. Examples of the effects of a curved test surface on tire operating temperatures and strain levels are provided. Model predictions are used to compare temperatures and strains of tires running the current Federal Motor Vehicle Safety Standard (FMVSS) 119 test vs. running both "max" and "severe service" truck operating conditions. The concept of "Highway Speed Equivalency" for laboratory endurance testing is introduced.

Paper Number 2.4

Thin Film Heat Flux Sensor for Measuring Film Coefficient of Rubber Components of a Rolling Tire

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Heat flux is one of a number of parameters, together with pressure, temperature, flow, etc., of interest to engine designers and fluid dynamicists. The ability to measure heat flux magnitude and direction was incorporated into a resistance bridge design fabricated using the thin film techniques to allow fast response. The result is a sensor that does not need the large area and stiff packaging required for the thermopile design nor that has its low output, but has nearly as fast response. The development of this sensor offers a new laboratory procedure to establish heat transfer coefficients for different regions of a tire. Testing generated heat transfer coefficients that were within the range reported in the literature, and the numerically predicted temperatures from these data agree well with the experimentally generated values.

[6] Presenting author

Paper Number 3.1

Prediction of Tire Profile Wear by Steady State FEM

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Much research is being done in the tire industry in order to reduce tire development time as well as cost. One such field of particular importance is that of tread wear, where testing time for indoor tests is measured in days, compared to weeks for outdoor tests. Development time could be further reduced if a "virtual wear test" could be performed using a finite element approach to predict friction energy. The purpose of this study is to investigate the link between indoor tread wear profile and steady state finite element prediction of friction energy. Blank grooved tires of a common construction with three different tread compounds are run through indoor wear tests of different severities to study severity vs. compound interaction. The drive files provide a mix of low speed cornering maneuvers that simulate city driving as well as highway speed steady-state rolling with acceleration and braking events. One drive file places more emphasis on the city maneuvers while the other places emphasis on the highway driving. Using the steady state finite element model, a composite friction energy is calculated from friction energy predictions at selected loading conditions taken from the drive file events. The composite friction energy profile is finally compared to laser measurements of the worn tire profile to examine the feasibility of a "virtual wear test."

[7] Presenting author

Paper Number 3.2

Prediction of Tread Block Forces for Free-rolling Tyres

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In the effort to understand the dynamic hub forces on road vehicles, an advanced free-rolling tyre model has been developed in which the tread blocks and tyre belt are modeled separately. The finite element code ABAQUS/Explicit is used to predict the normal and tangential forces on the tread blocks of various shapes in contact with both smooth and rough road surfaces. A pressure and slip rate dependent frictional law is applied in the analysis. Special attention is paid to investigating the impact and snap-out mechanisms. An analytical model is also proposed where the tread blocks are discretised into linear viscoelastic spring elements. The results from both models are validated via experiments in a high-speed rolling test rig and found to be in good agreement.

[8] Presenting author

Paper Number 3.3

Study of Material Properties of Tread Rubbers; Experiments and FEA Verification

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Rubber material constants were calculated with four distinctive deformation modes; uni-axial tensile, pure shear, simple shear, and volumetric compression. Each experimental result was verified by FEA. Then, joint material constants, which were calculated by computation with all four test results, were verified by comparison between experimental and FEA results. Since it has been demonstrated that the rubber tests are applicable to any rubber-like materials, tyre tread rubber sheet was used.

The tread rubber properties are significant to prediction of tyre forces. Elastomeric behavior or rubber in contact with rough surface is extremely complex. Sufficient analysis requires accurate appropriate material properties. Therefore, tyre tread should be evaluated accurately prior to theoretical predictions. In the past publications, four deformation modes in rubber tests were examined to three types of commercial rubber sheets and Dunlop SL1. In this paper Dunlop SL1 and SL6 Go-kart slicks were newly tested. Each experimental result was verified by FEA and the material properties derived with all deformation modes were demonstrated through experiments and FEA.

[9] Presenting author

Paper Number 4.1

Tire-Suspension-Chassis Dynamics in Rolling over Obstacles for Ride and Harshness Analysis

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The importance of improving dynamic properties is growing in the vehicle development. In particular, accurate analysis of tire and suspension dynamics in rolling over road irregularities is needed for predictive evaluation of ride comfort and harshness in realistic driving conditions. Severity of loading from impact against bigger obstacles, such as a speed bump, deep pothole, or a curb also helps to assess extreme conditions for suspension and body joints damage and durability.

In this study, a detailed tire-wheel FE model is combined with suspension and attached to a simplified vehicle model with bicycle-type body and rear half. Transient simulations in ABAQUS of straight rolling over a bump or pothole of various geometries reveal rich dynamics of tire impact deformations and the post-impact tire, hub, and vehicle vibrations. Their relation to the tire resonant modes and rolling-impact load variations at different velocities is elucidated. Modeling of curb impact and rolling over a long pothole is conducted for conditions similar to the suspension abuse test. In addition to very strong amplification of tire and suspension loads, such events produce severe local tire strains and stresses that indicate tire endurance and performance post-impact effects.

Paper Number 4.2

Vehicle Suspension Measurements: Evaluation of the Benefits of Dynamic over Quasistatic Kinematics and Compliance Testing

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Empirical vehicle simulation environments, such as CarSim®, can be used to simulate handling or braking maneuvers that would otherwise need to be performed outdoors. Many of the parameters for these types of vehicle models are determined through Kinematics and Compliance (K&C) measurements. Machines that perform these measurements apply various forces or moments and measure the response of the vehicle. The rate that these forces or moments are applied can be quasistatic or dynamic. Many K&C machines are only capable of performing quasistatic tests. Machines that are capable of performing dynamic tests are more expensive, due to the need for inertia compensation, sensors that can acquire data at higher rates, and larger actuators or hydraulic power supplies. However, it is possible that measurements of dynamic vehicle response may increase the fidelity of parameter identification, compared to the sole use of quasistatic tests. One reason that parameter identification may be more accurate is the rate of force and moment application in dynamic tests is more similar to those in the actual maneuvers that are desirable to simulate.

A study was performed to determine where the advantages of performing dynamic K&C testing lie. Quasistatic K&C tests, along with dynamic tests performed at several frequencies up to 3.0 Hz, were performed on the front axle of a FWD compact sedan. Assessment of any advantages of dynamic K&C testing has been made through comparisons of the vehicle response to the various tests, along with the derived kinematics and compliances.

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Paper Number 4.3

Effect of Tire Stiffness on the Articulated Vehicles Understeer Gradient

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This paper introduces the Articulated Vehicles Understeer Gradient (AVUG) closed form algebraic formula and analyzes the effects of tractor and trailer tire stiffness on the stability of the system. The AVUG solution is the result of the articulated vehicle system's stability through the analysis of the characteristic equation. The new developed understeer gradient plays the same role as the understeer gradient used in the passenger vehicle system in terms of yaw directional stability. The articulated system within the linear range has an understeer gradient, critical speed and characteristic speed formulae analogous to passenger vehicle's solutions. It is understeer if AVUG is positive, neutral steer if AVUG is equal to zero, oversteer if AVUG is negative. It is not stable in the yaw plane if it is oversteer and driven above the critical speed. Using the AVUG, the articulated vehicles linear stability and steady state performances do not require numerical simulations; the problem is solved algebraically as it has been for passenger vehicles by using its understeer gradient. The AVUG is validated numerically using articulated vehicles with different axle configurations. This paper introduces the articulated system understeer impedance concept and the effect of lateral tire stiffness. The following concepts are introduced: Pin Static Margin (the distance between the tractor C.G. and pin position that makes the articulated vehicle neutral steer), the tractor impedance, the Trailer Understeer Load, and the Zero Impedance Pin Position (ZIPP), that is, the position of the pin where the trailer has no effect on the articulated vehicle understeer gradient. All these were derived algebraically and validated numerically.

Paper Number 5.1

Finite Element Modeling of Rolling Tire Dynamics for Noise Prediction

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Finite Element Methods are well established for the mechanical analysis of tires in industry. For stationary rolling contact analysis a relative kinematics description based on a mixed spatial-material description provides a suitable framework for efficient computations of quite detailed tire models. Despite these advantages, special effort is necessary for the reliable treatment of tractive rolling with friction or even when inelastic material properties have to be considered. An additional challenge is on the simulation of high frequency response, for example in comfort analysis.

The main focus of this contribution is on the latter aspect, namely the transient dynamics response with respect to rolling noise prediction. A careful modeling strategy will be presented, taking into account all essential physical effects like gyroscopic contributions, inflation and contact pressure. A staggered scheme is suggested for the transient dynamic response analysis. Starting with the solution of the nonlinear stationary rolling problem, a modal superposition approach is introduced. Special emphasis is paid to the physical interpretation of the vibration behavior of rolling bodies, while rather detailed finite element models enable identification and classification of tire modes in the frequency domain.

An outline on the model validation based on laboratory tests will be given. For the low- and mid-frequency response the computational results are compared with measured surface vibrations on non-rotating tires by optical techniques. For higher frequencies the sound radiation measured on laboratory drum test rig coated with different surface texture has been computed. From these investigations the constitutive description of rubber as well as the representation of the excitation by the road surface has been identified as most sensitive parameters. Nevertheless, the approach presented today already enables ranking of different tire constructions regarding their noise radiation.

The presented results are partial outcome of research project "Leiser Straßenverkehr" funded by the Federal Ministry of Economics and Technology (BMWi) and coordinated by the Federal Highway Research Institute (BAST) in close cooperation with Continental AG and Technical University of Hamburg-Harburg, Germany.

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Paper Number 5.2

Engineering Solution of Rolling Tire Vibration Model

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Vehicle noise, vibration and harshness (NVH) are important issues for vehicle manufacturers, tire manufacturers and consumers alike. To do computer simulation for vehicle NVH, a good tire model is needed. Since the working condition of the tire is under relatively high speed rolling, the tire model has to represent the influence of tire rolling. In this study, the theoretical differences between non-rolling tire vibration model and rolling tire vibration model are reviewed and analyzed. It is found that in addition to the obvious differences such as temperature effect on material properties, there are some fundamental differences between the non-rolling vibration model and the rolling one. Because of the differences, the traditional modal model used for a non-rolling tire cannot be used to represent a rolling tire. To solve the rolling tire model, an engineering approach is proposed that avoids solving the rolling tire model as a complex Eigenvalue problem. Special tests are designed to measure the tire spindle response under rolling and non-rolling cases. The simulation results are then compared with measurement results. Some interesting results are observed and discussed.

Paper Number 5.3

Validation of a Belt Model for Prediction of Hub Forces from a Rolling Tire

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An integrated model is under development to predict the interior noise due to the vibrations of a rolling tire that are structurally transmitted to the hub of a vehicle. Here, we briefly present and discuss the representation of the tire belt. This component will be linked to the tread blocks through normal and tangential forces, and to the sidewalls through impedance boundary conditions. The tire belt is modeled as an orthotropic cylindrical ring of negligible thickness. Curvature, rotational effects, internal pressure and pre-stresses are included. The associated equations of motion are derived by a variational approach.

The equations of motion are investigated for both unforced and forced motions. The model is found to support extensional and bending waves, which are believed to be the important features to correctly predict the hub forces in the mid-frequency (50-500Hz) range of interest. We compare the predicted waves both to the waves supported by an analytical three-dimensional model of an infinite isotropic cylindrical ring and to the waves supported by a one-dimensional (beam) model of a tire belt. We then discuss the effects of internal pressure, pre-stress, curvature, and angular velocity on free waves. The influence of the tire dimensions and the sidewall boundary conditions are also investigated.

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Paper Number 6.1

The Evaluation Method for One-sided Wear by Using Frictional Energy

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In this study, one-sided wear was evaluated by using frictional energy while tire was rolling. In the condition that one-sided wear is easily caused, a frictional energy difference occurs between outside and inside shoulder region. So we derived optimal wheel alignment line, advantaged in one-sided wear by using S.E.D. (Shoulder Frictional Energy Difference). We found wheel alignment range, resistant to one-sided wear throughout the review of optimal wheel alignment line and outdoor wear test result. These results are very useful for evaluation and prediction of one-sided wear under various wheel alignment conditions of vehicle.

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Paper Number 6.2

Experimental Validation of the Brush Tire Model

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This article presents an experimental validation of the physically-based brush-tire model towards the tire behavior in a number of different real conditions. Results are presented of measurements performed with summer, winter, and studded tires on different road foundations such as wet and dry asphalt, basalt, snow, and ice. The purpose behind the validation is to study the possibilities of using the brush model to estimate the friction coefficient from measurements or estimates of the longitudinal tire forces and tire slip. The article both validates the model agreement and investigates the sensitivity of the included parameters to various factors that may change during normal run of the vehicle. In the latter case further external experimental results also are regarded. The study has been performed within the Road Friction Estimation project that has been a part the IVSS-program financed by the Swedish government and a framework of automotive related companies. The measurements were conducted by VTI, the Swedish National Road and Transport Research Institute

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Paper Number 6.3

New Design Concept of Friction Rig; Fundamentals to Predict Tire Forces

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A new concept of rubber friction rig is introduced in this paper. Specifically the design contributes to the efficient evaluation technique of tread-road friction. Mainly three issues on the rig design were focused. The first of all is fixture positions of rubber strip and abrasive body. The second is on road surface representation applicable to tread-road friction test. The last is on temperature concern in the course of tread-road interaction.

The tyre-road interaction involves many parameters such as rubber properties, friction coefficients, temperature, and wear. Although rubber properties are well-studied in the previous publications, the study of friction in tread-road interaction is too complex to be comprehended. Even more, classical friction fixture has fundamental problems since pulling the rubber block by thin wire string on the abrasive surface. It may cause pitch, yaw, and undesirable deformations on corners or edges of rubber block. Therefore, the new design of friction rig was contemplated with regards to sliding stability and temperature effect.

Firstly, positions of rubber and abrasive body were thought out and were firmly fixed. It allows only abrasive body to slide on rubber sheet in sole axis without yawing and pitching. Secondly, road surface casts in resin to test friction generated by tread rubber and road asperities. Lastly, silicon rubber heater was installed amid of the rig to examine temperature effect on rubber friction.

The design was verified by finite element analysis and heat transfer analysis. Then, friction tests were carried out with road cast samples and various temperatures.

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Paper Number 6.4

A Study on the Frictional Energy of the Rubber Block According to the Effectiveness Factors

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The analysis of the frictional energy of the tread rubber block with contact to the surface is necessary to study the wear for rubber. It is important to define the relationship of the frictional energy and wear, as the most theory of the wear of tread block is based on the frictional energy of rubber block. To predict the life of a tire, the most of research has been focused on the use of the finite element analysis or the actual experiments which need the many time and expensive costs.

Therefore, this research is achieved the successful results of the analysis to the frictional energy by analytic method. From this research, with the factors affecting the wear, more precise analysis can be achieved.

Assume the displacement functions that express a transformation shape of the rubber block, the material properties of rubber as incompressibility for the analysis of frictional energy. The contact pressure, the tangential stresses, the slip length, the coefficient of friction and the frictional energy of the tread rubber block with contact to surface are calculated. Those values are function of the material properties, the shape of block, the vertical and horizontal load and the block moving speed.

These analytical results are compared with the test results of this paper which can be used for the analysis of the friction behavior for the wear estimation of the rubber products. These are good agreement between analytical results and experimental results.

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Paper Number 7.1

Novel Coupling Agents for silica-filled rubber with superior processing safety and improved hysteresis of the vulcanizates

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One challenge facing the Green Tire Technology is to achieve good silica hydrophobation / dispersion within the polymer matrix without a detrimental increase of the rubber compound's viscosity induced by premature unwanted coupling and / or crosslinking. State-of-the-art polysulfide silane TESPT and to a less extent TESPD need to be carefully incorporated, stepwise, with careful temperature control during the rubber compounding. This paper will present novel monofunctional silanes which are suited for preparing highly silica-loaded rubber compounds, under fewer mixing passes / reduced mixing times (faster throughput mixing → cost savings) and/or at higher temperature (more efficient ethanol removal → reduced VOC during the life cycle of the tire). The rubber compounds produced using these monofunctional silanes are characterized with lower Mooney viscosity and improved processability. Additional advantages are also seen in the end mechanical and dynamic vulcanizates' properties.

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Paper Number 7.2

Damping Characterization using Hysteresis on Static Non-rolling and Dynamic Rolling Behavior of Farm Tires

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This paper presents the empirical characterization of damping behavior as characterized by hysteresis for large farm equipment tires and time-domain numerical simulation of off-road tire rolling using ABAQUS finite element software. The hysteretic behavior is characterized by the load-displacement curves from static non-rolling vertical loading tests. Using a highly simplified finite element model based solely on tire catalog information and general constructional information, an ABAQUS hysteresis material model is used to simulate the hysteretic load-displacement behavior of large tires.

By choosing appropriate parameters for the hysteresis model, the static non-rolling finite element analyses results correlate very well to the experimental results. The fitted hysteresis material model is then used to simulate the dynamic rolling of a tire dropping off a curb. The bouncing vertical acceleration and bouncing height are of great interest to off-road tires.

First, implicit dynamics is used to simulate the rolling using the calibrated ABAQUS hysteresis model. Very good correlations between the simulation results and vehicle test results are obtained. For better off-road rolling performance, the hysteresis model is recalibrated to reduce the vertical acceleration of the tire after the first bounce following the drop-off.

A new ABAQUS/Explicit hysteresis model based on VUMAT user subroutine is employed to simulate the dynamic tire rolling using Explicit dynamics. The vertical acceleration is attenuated in excess of 50% after the first bounce following the drop off by introducing additional damping and creep dissipation. This hysteresis characterization has been shown to give good agreement with test data on non-rolling lateral and longitudinal stiffness tests. Simulations of transport of a tractor equipped with four tires over geometrical features such as ditches and obstacles in hard terrain have also given good agreement with test data.

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Paper Number 7.3

Non-Pneumatic Bicycle Tire: Design Concepts and Virtual Product Development

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A new class of non-pneumatic bicycle tire, which is under development, for mounting on a rim is proposed. The tire comprises outer and inner cylindrical coaxial members (hoops) and in the space between them circumferentially spaced omega-shaped webs made up of fiber-reinforced functionally gradient composite structure. The virtual development of this non-pneumatic tire technology using finite element (FE) analysis and concepts of functionally graded material (FGM) is presented in this paper. Transient rolling behavior of the proposed non-pneumatic tire is simulated using an explicit finite element code (ABAQUS/Explicit). Furthermore, a unique design concept of shock-absorbing tread structure for non-pneumatic tire is also proposed.

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Paper Number 7.4

Rubber Hyperelastic Behaviours Study with Application to TBR FEA

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The choice and accuracy of rubber constitutive laws is a key factor to tire Finite Element Analysis. This work presents an experimental rubber hyper-elastic laws study with application to FEA of truck radial tires. The operation loading of a truck radial tire is usually complex and variable, which leads to complicated stress and strain states in the tire materials. To meet the requirements of the tire FEA, rubber constitutive laws should be determined to consider their realistic strain states in the operating condition.

In addition to pure uniaxial tension tests, both bi-axial and planar tension experiment procedures are designed and performed for all the main rubber components used in a TBR tire. CCD and imagine analysis are used to obtain large deformation of rubber samples in bi-axial and planar tension experiment.

Rubber constitutive models are then investigated based on the test data. Several popular rubber hyperelastic models including Ogden, MR, and Boycle are compared with respect to accuracy, prediction capacity and time efficiency.

Then the rubber models are applied to a medium TBR tire FEA to compare the effects of different rubber hyper-elastic models on the total and local tire response. The tire simulation results will be compared with some available tire tests with respect to some key tire design parameters including load-defection curve, footprint stress and area etc.

Paper Number 8.1

Analytical Solution for the Stresses Arising in +/- Angle Ply Belts of Radial Tires

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Stresses arising in the belts of radial ply tires, particularly those at the belt edge, are known to be critical to tire durability. Belt edge stresses are commonly calculated using finite element (FE) methods that provide estimates of the levels, but do not necessarily give significant insight into the underlying mechanics. In contrast, analytical models can provide physical insight into the mechanisms affecting tire durability, but are currently incomplete due to the challenges faced in obtaining closed form mathematical solutions. Nevertheless, analytical solutions remain important to tire design and development because they expose the entire design space, show the mathematical relationships between the variables, and allow rapid parameter studies.

This work develops an analytical description of the belt deformations and stresses, particularly at the belt edge. The formulation captures all the first order mechanics pertinent to finite width, symmetric +/- angle belt packages present in radial tires. It incorporates interply shear stresses already recognized in the literature, and adds to that a new mechanism controlling the interaction of the plies via the Poisson effect. The analytical model is validated by comparison to FE simulations for a variety of loading conditions and is also contrasted with other analytical models in the literature. Finally, some of the more interesting parameter studies are presented, such as the effects of intraply and interply cable spacing on belt edge stresses and in-plane bending stiffness.

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Paper Number 8.2

Effect of Normal Pressure Distributions on the Analytical Solutions to Tire Forces

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The paper analyzes the effects of using different tire normal pressure models (uniform, elliptical and parabolic) on the analytical solutions of tire forces. The theoretical model, developed based on the physics of tire/surface contact, uses physical parameters like stiffnesses and friction properties. These are standard mechanical properties that characterize the force generating capacity of tires. The validation procedure compares the theoretical ground forces and moments with experimental data and shows the effect of pressure distribution on the accuracy of model predictions. The results show the extent of validity of linear tire models (widely used in vehicle dynamics and control), the extent of model accuracy using parabolic pressure distribution. A comparison to the elliptical pressure distribution method is provided. Five tire data, measured on a flat track tire testing machine, are used in the validation. It covers the full range of longitudinal, lateral, and combined slips at different loads.

Paper Number 8.3

Simulation and Measurement of Steel Cords Forces in a Typical Truck Radial Tire

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The steel cords in a truck tire play a primary role in carrying the applied loads, of which the construction and configuration in belts and carcass are key design parameters to obtain the optimum design of a tire.

This work presents a systematic research to understand the behaviors of steel tire cords in a typical radial truck tire. The FEA is used to obtain the cord force distributions under inflation and vertical loading cases. In the FE model, the rubber's hyperelastic constitutive laws are determined by uni-axial tension, bi-axial tension as well as planar tension tests, while the cord properties by just uni-axial tension tests.

Miniature force transducers specifically designed for the truck steel cords are used to measure the loads developed in the steel cord in belts, carcass as well chafer reinforcement ply.

Based on the comparison of numerical and experimental results, the FE model is updated to obtain the final benchmark model. Then parametric study is performed to obtain the design sensitivity of different tire and cord design variables including cord diameter, stiffness, belt and bead configuration etc.

It can be shown that the steel cords can be effectively designed to improve the truck tire behaviors in both inflation state as well as rolling and impact states.

Paper Number 8.4

A Case in Evaluating a Finite Element Tire Model: Measurements on Real Tire Configuration and Improved Computational Contact Pressure

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Based on a 185/60R14 radial tire, a refined nonlinear finite element model with complex tread patterns is constructed with ABAQUS software. When the reliability of the refined model is being evaluated, the numerical results of vertical displacement and vertical rigidity tally well with (are in good agreement with) the experimental ones, while those of the computational contact pressure differ from the experimental footprints a lot. In search of the reason, plenty of systematical measurements on configuration of real tires have been carried out. Measuring results as well as the comparison of designed configuration indicate that the inside profile of the tire cross-section and the distribution of belts angles in real tires are obviously different from the designed parameters, which may be the cause of the great difference in contact pressures. In further analysis in which the finite element model is corrected by modifying the tire shape and belts angles according to the data measured, the computational and the experimental results of the distribution of contact pressure show unanimous characteristics.

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