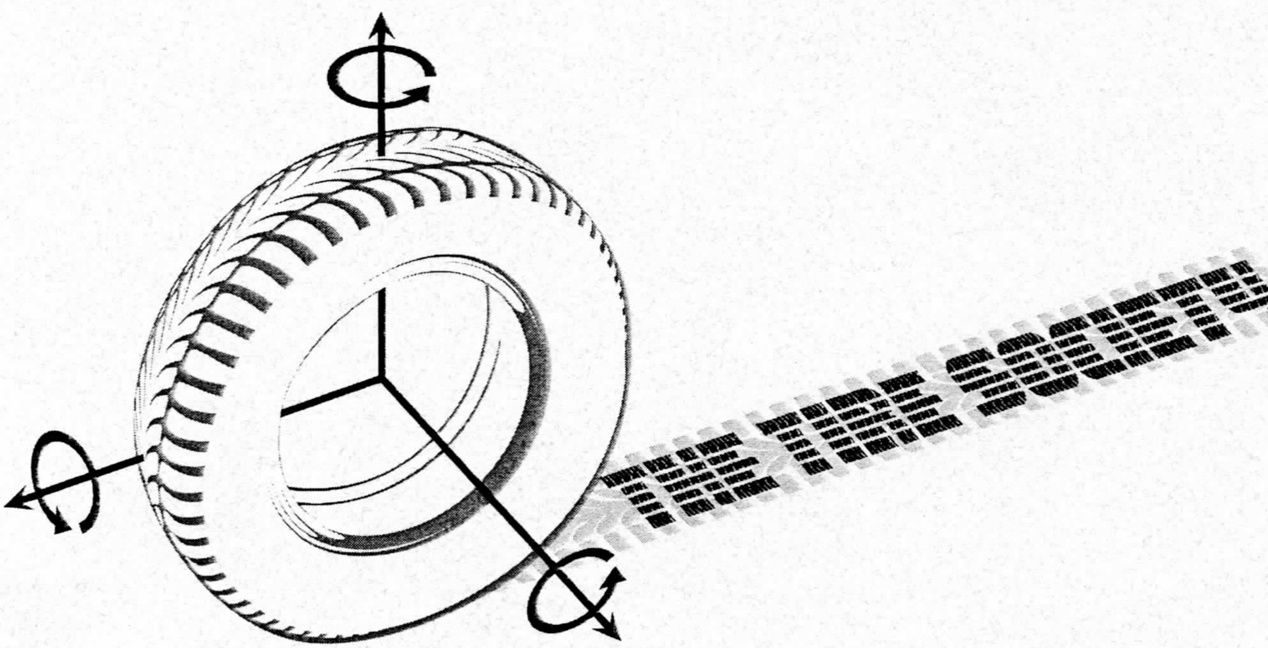
25th Annual Meeting and Conference on Tire Science and Technology

Program and Abstracts



September 11-12, 2006
Radisson Hotel, Akron City Centre
Akron, Ohio

www.tiresociety.org

The Tire Society thanks the following sponsors for their support:

ABAQUS, Inc.

MTS

Hankook Tire Co.

Goodyear Tire & Rubber Co.

The Tire Society, Inc.

25th Annual Meeting and Conference on Tire Science and Technology

September 11-12, 2006
Radisson Hotel, Akron City Centre, Akron, Ohio

Overview

Day 1 – Monday, September 11

7:15 Registration

8:15 Opening: *Hamid Aboutorabi*, President of The Tire Society

8:30 **Keynote Address**: *Dr. Francesco Gori*, Chairman and Managing Director Pirelli Tyre SpA

9:15 Program Opening: *Ron Kennedy*, 2006 Tire Society Program Chair

9:20 **Session 1**
Rolling Resistance
2 presentations

10:10 Break (20 minutes)

10:30 **Session 1 - continues**
Rolling Resistance
3 presentations

11:45 Lunch (1 hour, 45 minutes)

1:30 **Session 2**
Materials
4 presentations

3:10 Break (20 minutes)

3:30 **Session 3**
Student Papers
3 presentations

6:00 **Dinner**
Speaker: *Neal Lackritz*,
Team Leader for the Bose Suspension System

Day 2 – Tuesday, September 12

7:30 Registration

8:15 **Opening/Announcements**

8:20 **Session 4**
Tire F&M / Vehicle Dynamics
4 presentations

10:00 Break (20 minutes)

10:20 **Plenary Lecture**
Speaker: *Dr. Thomas Gillespie*,
Research Professor,
University of Michigan

11:10 **State of the Society**

11:30 Lunch (2 hours)

1:30 **Session 5**
Design for Tire Performance
3 presentations

2:45 Break (20 minutes)

3:05 **Session 6**
Tire / Road Interaction
3 presentations

4:20 End of Program

25th Annual Meeting and Conference on Tire Science and Technology

Day 1 – Monday, September 11

7:15 AM		**Registration**	
8:15 AM		**Conference Opening**	Hamid Aboutorabi President of The Tire Society
8:30 AM		**Keynote Address**	Dr. Francesco Gori Chairman and Managing Director Pirelli Tyre SpA
9:15 AM		**Technical Program Opening**	Ron Kennedy, Program Chair
9:20 AM		**Session 1: Rolling Resistance**	Jeff Schroeder, Session Chair
9:20 AM	1.1	A Commented Synopsis of the Report of the Committee for the National Tire Efficiency Study	M. G. Pottinger, J. D. Walter, J. D. Eagleburger
9:45 AM	1.2	Tire Energy Loss from Obstacle Impact	T. B. Rhyne, S. M. Cron
10:10 AM		**Break**	
10:30 AM	1.3	Accuracy, Sensitivity and Correlation of Coastdown Rolling Resistance Predictions by FEA	J. M. Terziyski, R. H. Kennedy
10:55 AM	1.4	The Fidelity of SAE J-1269 and SAE J-2452 Rolling Resistance Testing	J. A. Popio, J. R. Luchini
11:20 AM	1.5	Modeling Transient Rolling Resistance of Tires	J. R. Luchini, J. A. Popio
11:45 AM		**Lunch**	
1:30 PM		**Session 2: Materials**	Tom Fleischman, Session Chair
1:30 PM	2.1	Effect of Non-Standard Curing Conditions on Thermal Properties and Temperature Distribution of a Rolling Tire	H. B. Tabrizi, B. Afzali
1:55 PM	2.2	Effect of Coupling Agent on the Wear of Silica-filled Styrene-Butadiene Rubber - The Influence of Dump Temperature and Sulfur Rank	T. Iwai, K. Kato, Y. Uchiyama, J. Hayakawa
2:20 PM	2.3	Basic Study of Polyketone Fiber Tire Cord	M. Yamamoto, Y. Zuigyo
2:45 PM	2.4	Nitrogen Tire Inflation	K. R. J. Ellwood, J. M. Baldwin, D. R. Bauer
3:10 PM		**Break**	
3:30 PM		**Session 3: Student Papers**	Farhad Tabaddor, Session Chair
3:30 PM	3.1	Mechanistic Study of the Sulfide Layer at the Rubber-Tire Cord Interface	P. B. Harakuni, W. J. van Ooij
3:55 PM	3.2	Dynamic Fracture of Natural Rubber	A. A. Al-Quraishi, M. S. Hoo Fatt
4:20 PM	3.3	Evaluation of Steering Feel Using a Tire/Vehicle Simulation Model	M. U. Frank, H. R. Dorfi, R. L. Wollyung
4:45 PM		**End of Technical Session**	
6:00 PM		**Dinner** The Bose Suspension Project	Neal Lackritz

Day 2 – Tuesday, September 12

8:15 AM		**Opening/Announcements**	
8:20 AM		**Session 4: Tire F&M / Vehicle Dynamics**	Chris Wohlever, Session Chair
8:20 AM	4.1	Two Methods of On-road Tire Characterization: Direct Measurement and Using an Instrumented Vehicle	S. Jansen, R. Leenen, J. Zuurbier
8:45 AM	4.2	FTire Software: Advances in Modelization and Data Supply	M. Gipser
9:10 AM	4.3	Tire Forces and Moments Using an Analytical Model with Physical Parameters	M. K. Salaani
9:35 AM	4.4	An Analysis of the Influence of Tire Force and Moment Shape on Vehicle Handling Performance for Large Slip Angle Maneuvers	C. W. Mousseau, K. D. Norman
10:00 AM		**Break**	
10:20 AM		**Plenary Lecture:** A Brief History of Vehicle Dynamics: Why Tires Are So Important	Dr. Thomas D. Gillespie
11:10 AM		**State of the Society**	
11:30 AM		**Lunch**	
1:30 PM		**Session 5: Design for Tire Performance**	Ching-Chih Lee, Session Chair
1:30 PM	5.1	The Chemistry & Physics of a Natural Tread Separation	J. M. Baldwin, R. J. Pascarella, D. F. Tandy, Jr., K. T. Tandy, K. J. Granat, N. J. Durisek
1:55 PM	5.2	The Development of Integrated Optimum Contour Design System to Satisfy Multi Performances of the Tire	D. W. Lee, S. R. Kim, K. D. Sung, S. S. Cho, W. S. Joo, C. T. Cho
2:20 PM	5.3	High Speed Tire Analysis and Standing Waves Using a Mixed Lagrangian / Eulerian Method	C. Wohlever, M. Snyman
2:45 PM		**Break**	
3:05 PM		**Session 6: Tire / Road Interaction**	Reinhard Mundl, Session Chair
3:05 PM	6.1	Deformation Properties of Radial Tire in Contact with Road	K. Kabe, N. Miyashita, T. Akasaka
3:30 PM	6.2	Prediction of Tread Pattern Wear by Explicit FEM	J. C. Cho, B. C. Jung
3:55 PM	6.3	A 3D Tire/Road Interaction Simulation by a Developed Finite Element Model (ABAQUS Code)	M. Zamzamzadeh, F. Ariana, M. Negarestani
4:20 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.

2006 CONFERENCE COMMITTEE:

Program Chair	Ron Kennedy, Hankook Tire Co.
Assistant Chair	Mahmoud Assaad, Goodyear Tire & Rubber Co.
Local Arrangements	Mechelle Miller, Goodyear Tire & Rubber Co.

2005 AWARDS COMMITTEE:

Gary Tubb (Chairman), Goodyear Tire & Rubber Co.
Troy Hoagland, Cooper Tire & Rubber Co.
Uday Karmarkar, Akron Rubber Development Lab
Samuel Knisley, Hankook Tire Co.
Tom Niemoeller, Kumho America Tech Center
Brian Steenwyk, Bridgestone/Firestone, Inc.

2006 SESSION CHAIRMEN:

Tom Fleischman, Goodyear Tire & Rubber Co.
Ching-Chih Lee, Goodyear Tire & Rubber Co.
Reinhard Mundl, Continental AG
Jeff Schroeder, Cooper Tire & Rubber Co.
Farhad Tabaddor, Michelin Americas R&D Corp.
Chris Wohlever, ABAQUS, Inc.

2007 CONFERENCE COMMITTEE:

Program Chair	Mahmoud Assaad, Goodyear Tire & Rubber Co.
Assistant Chair	Jim McIntyre, Smithers Scientific Services
Local Arrangements	Mechelle Miller, Goodyear Tire & Rubber Co.

BUSINESS OFFICE:

Howard Snyder
The Tire Society
P.O. Box 1502
Akron, OH, USA 44309-1502

Voice: 330-929-5238
Fax: 330-929-3576

www.tiresociety.org

Paper Number 1.1

A Commented Synopsis of the Report of the Committee for the National Tire Efficiency Study

Marion G. Pottinger
M'gineering, LLC

Joseph D. Walter
The University of Akron

John D. Eagleburger
Goodyear Tire Company (Retired)

The Congress of the United States petitioned the Transportation Research Board of the National Academy of Sciences to study replacement passenger tire rolling resistance in 2005 with funding from the National Highway Traffic Safety Administration. The study was initiated to assess the potential for reduction in replacement tire rolling resistance to yield fuel savings. The time required to realize these savings is less than the time required for automotive and light truck fleet replacement.

Congress recognized that other factors besides fuel savings had to be considered if the committee's advice was to be a reasonable guide for public policy. Therefore, the study simultaneously considered the effect of potential rolling resistance reductions in replacement tires on fuel consumption, wear life, scrap tire generation, traffic safety, and consumer spending for tires and fuel. This paper summarizes the committee's report issued in 2006.

The authors, who were members of the multidisciplinary committee, also, provide comments regarding technical difficulties encountered in the committee's work and ideas for alleviating these difficulties in further studies of this kind. The authors' comments are clearly differentiated so that these comments will not be confused with findings, conclusions, and recommendations developed by the committee and contained in its final report.

Paper Number 1.2

Tire Energy Loss from Obstacle Impact

Timothy B. Rhyne, Steven M. Cron
Michelin Americas Research & Development Corporation

The paper "Development of a Non-Pneumatic Wheel", presented to this society in September, 2005, derived the energy loss of a rigid wheel due to rolling over an obstacle. A simulation of a pneumatic tire and a non-pneumatic tire were shown to have significantly less energy loss when rolling over the same obstacle. The mechanics of the differences were not explained.

This subject brings up the larger questions of what parameters and mechanisms control the coefficient of restitution of tires, how is energy dissipated from impact with an obstacle, and how does this relate to rolling resistance if at all.

It is found that tire energy loss due to obstacle impact is tied not only to the hysterysis of the tire materials but more importantly to the modal response of the tire structure. The first order parameters determining the energy loss due to obstacle impact are presented. The results are expected to have relevance to rough road rolling resistance, road hazard impacts, and rough road comfort among others.

Paper Number 1.3

Accuracy, Sensitivity and Correlation of Coastdown Rolling Resistance Predictions by FEA

Jan M. Terziyski, Ronald H. Kennedy
Hankook Tire Co., Ltd

This research deals with FEA predictions of coastdown rolling resistance as outlined by SAE J2452. The proposed procedure employs a physically-based formulation of hysteresis. Specifically designed test conditions determine material parameters which describe the hysteresis dependence on strain level, strain rate and temperature. Then, the octahedral shear strain and directional deformations at each finite element integration point are obtained from a quasi-static FEA of the loaded tire. In subsequent post-processing, the locations of hysteresis loops around the circumference are found, and rolling resistance solutions can be obtained for multiple speeds. A straightforward steady-state temperature solution can be obtained from the hysteretic loss results, and the component temperature effect on rolling resistance predictions is illustrated. The effects of modeling considerations on predicted rolling losses, including geometric accuracy, mesh resolution, and friction representation, are pointed out. The applicability of the current methodology to daily product engineering is discussed through benchmark studies of a variety of tires of different sizes, constructions, tread materials and test conditions. Correlation studies show that this is a robust and easily implemented technique for rolling resistance prediction.

Paper Number 1.4

The Fidelity of SAE J-1269 and SAE J-2452 Rolling Resistance Testing

James A. Popio
Smithers Scientific Services, Inc.

John R. Luchini
Cooper Tire & Rubber Company

This study compares data from the two SAE test methods for rolling resistance: J-2452 (Stepwise Coastdown) and J-1269 (Equilibrium) steady state. The ability of the two methods to evaluate tires is examined by review of data collected for 12 tires. The data are analyzed and the tires are ranked using each test method. Comparison of the results using each test shows similar results with either test. The ability of the two methods to evaluate tires is reviewed.

In addition, analysis of the two methods using this matched set of testing provides an opportunity to evaluate each of these test standards against each other. It is observed that each test has merits absent from the other. Based on this study, suggestions are offered for use of either test for certain situations. Some improvements in the selection of testing conditions and regression models are offered.

Paper Number 1.5

Modeling Transient Rolling Resistance of Tires

John R. Luchini
Cooper Tire & Rubber Company

James A. Popio
Smithers Scientific Services

This article shows that the transient rolling resistance of several tires can be predicted from knowledge of the behavior of each tire on an equilibrium test. The SAE has two recommended practices for tire rolling resistance: the J-1269 (equilibrium) test; and the J-2452 step-wise coast down (transient) test. The simulation model used for this study, to predict the results of J-2452 from J-1269 data, was presented in reference 1.

The study used data from one tire to establish values for a set of parameters of the simulation model. Then those parameters were used with tire and rolling resistance measurements from twelve (12) other tires of another size. These tires were from 4 samples of each of 3 different tire constructions (tread patterns) and manufacturer. The tire measurement and equilibrium rolling resistance data were provided "blind" to the simulation model. Each tire had been tested with SAE J-2452, so the simulation results could be compared to the test data.

The objective of the study was to determine if the theoretical model predictions would fall within the lab-to-lab experimental error described in the J-2452 test standard. The match between the model simulations and the experimental measurements was qualitatively good, and was sufficient to accept the assumptions of the theory. However, the hypothesis that the model would provide adequate predictions of transient results to substitute for J-2452 test data was not accepted.

The reasons for the differences between the predictions and the test result were investigated and two significant sources of error were identified. First, the simplistic assumption that one set of heat transfer parameters would apply to all tires was found to be inadequate. Second, the matrix of test conditions and regression model in J-1269, which must be used to extrapolate to the test conditions of J-2452, is inadequate.

In addition, the application of the precision and bias from J-2452 may have been overly severe. There is no published data associated with J-2452 indicating how the quoted values were obtained. In addition, the practice includes a statistical method for deleting "outliers" from the test data that may have artificially inflated the precision and bias statements associated with lab-to-lab variations. The statistical methods and criteria used in the analysis of the simulation results may not have been appropriate for comparison with J-2452 test data.

A fundamental value in using a computational model to determine transient tire rolling resistance from steady state test results is the ability to explain and predict complex interactions. The simulation model provided the ability to test ideas about testing protocols and tire behavior, without additional testing. The qualitative results from the simulation model were sufficient to identify small effects from test conditions, which can affect test variability. The modeling work in this article also found some of the details of the test protocols that may have significant effects on reported rolling resistance.

Key words: tire rolling resistance, tire rolling loss, transient coast down testing

Paper Number 2.1

Effect of Non-Standard Curing Conditions on Thermal Properties and Temperature Distribution of a Rolling Tire

Hassan Basirat Tabrizi, Babak Afzali
Mech. Eng. Dept., Amirkabir University of Technology

A finite element modeling of heat transfer and temperature distribution of a steady state rolling tire is investigated. The thermo-mechanical behavior of a tire in use is important in case of finding the critical points and maximum temperature to a rolling tire and it helps the designer to choose the best structure and materials. The study has been preformed on the effect of increase and decrease in cross link density of tire materials which could happen by non-standard conditions in production line.

Hence, the curing time has been considered as a factor to change cross link density. The changes in material properties such as heat conductivity coefficient and heat generation have been verified by experimental methods in range of working temperature of rolling tire. By imposing these information's to the model, the effect of increase and or decrease in polymeric of tire material links which could be caused by unpleasant factors in production process on the temperature distribution of a rolling tire is discussed.

Paper Number 2.2

Effect of Coupling Agent on the Wear of Silica-filled Styrene-Butadiene Rubber - The Influence of Dump Temperature and Sulfur Rank

Tomoaki Iwai, Kouichi Kato, Yoshitaka Uchiyama
Kanazawa University

Junpei Hayakawa
Yokohama National University

The effect of the dump temperature and sulfur rank of a silane coupling agent on the wear of silica-filled styrene-butadiene rubber (SBR) was studied. One of two coupling agents, bis(triethoxysilylpropyl)disulphide (TESPD) or bis(triethoxysilylpropyl)tetrasulphide (TESPT), was added to the compound; then, the influences of dump temperature and sulfur rank were investigated. SBR with TESPT showed better wear resistance than SBR with TESPD. The wear rate of SBR with TESPD increased as the dump temperature rose. On the other hand, the wear of SBR with TESPT was almost constant, despite the dump temperature.

The crosslink densities of the rubber specimens were investigated. It was found that the wear resistance of both SBR with TESPD and SBR with TESPT improved as the crosslink density increased within the range of this study.

Paper Number 2.3

Basic Study of Polyketone Fiber Tire Cord

Masahiko Yamamoto, Yugo Zuigyo
Bridgestone Corporation

Synthesis fibers such as PET, Nylon & Aramid have been used as tire reinforcements. For example PET & Nylon have been used as body ply or cap ply widely. But sometimes these general-purpose fibers can not satisfy enough performance required for High Performance Tires which have been developed in recent years. p-Aramid (PPTA etc.) fiber has high tenacity and high modulus but its application has been limited because of high price and less adhesion to rubber. The objective of this paper is to report investigation of physical properties of a new super fiber and its application as tire reinforcement. This new fiber showed very good adhesion to rubber and special heat characteristic. Furthermore this fiber has been applied as tire cord for practical development of high performance tires with unconventional values.

Paper Number 2.4

Nitrogen Tire Inflation

Kevin R.J. Ellwood, John M. Baldwin, David R. Bauer
Ford Motor Company

An FEA model for investigating the oxidative aging of tires (developed previously) has been used to investigate the effects of nitrogen fill gas on tire inflation pressure retention and rubber aging in the belt package. Oven aging experiments of a light truck tire filled with nitrogen have been used to validate the results of the FEA model. Two tire types and sizes were investigated; a P235/75R15 AT and an LT245/75R16 Load Range D.

Paper Number 3.1

MECHANISTIC STUDY OF THE SULFIDE LAYER AT THE RUBBER-TIRE CORD INTERFACE

Prasan B. Harakuni, William J. van Ooij
Dept. of Chemical and Materials Engineering, University of Cincinnati

Ever since their first use in tires, brass-coated steel tire cords have been extensively used in tires because of the increased ease in handling, ride comfort and better mechanical properties they can offer. The adhesion between these cords and the rubber and its mechanism has, however, been a mystery for many years and still remains partly unknown. In the present work we have analyzed this interface with emphasis on the crystallinity of the sulfide films as a function of compound formulation and aging conditions.

Five different compounds were cured to brass coupons and the cured rubber was then removed using o-dichlorobenzene. The adhesion/sulfide layer on the brass coupons was studied using Grazing Incidence Angle X-Ray Diffraction (GIXRD) at a synchrotron source (Brookhaven, NY), TOFSIMS and SEM/EDX. Tire cords from aged tires were also characterized using SIMS, SEM/EDX and DC polarization measurements. Results indicate the importance of the type of sulfide layer formed at the cord-rubber interface and provide a picture on how different aging conditions affect this layer.

Paper Number 3.2

Dynamic Fracture of Natural Rubber

Ali A. Al-Quraishi, Michelle S. Hoo Fatt
Department of Mechanical Engineering, The University of Akron

Natural Rubber (NR) is one of the most essential materials in the manufacture of tires because of its outstanding tensile strength and crack growth resistance, which are attributed to the material's ability to undergo strain-induced crystallization. This paper illustrates how the fracture toughness of unfilled and 25 phr carbon black-filled NR varies with strain rate over a range $10^{-2} - 10^{2}$ s^{-1}. Quasi-static and dynamic fracture tests were performed with an electro-mechanical Instron machine and Charpy tensile apparatus, respectively. A high-speed video camera operating at 50,000 frames per second was used to measure deformation and crack speed. In the Charpy tensile impact tests, the Charpy hammer was used to impart tensile forces on the ends of the rubber strip by hitting a slider bar, which was connected to two copper cables holding opposite ends of the specimen. Piezoelectric load cells in the grips recorded the dynamic tensile loads. All fracture tests were done at room temperature using a tensile strip specimen with an edge crack. Standard procedures for tear resistance of vulcanized rubber were used according to ASTM D624-54.

The change in fracture toughness of the unfilled and carbon black-filled NR specimens with strain rate was found to be markedly different. The fracture toughness of the unfilled NR increased steadily with increasing strain rates from about 9 KJ/m^2 at 0.01 s^{-1} to 18 KJ/m^2 at 130 s^{-1}. Throughout this range of strain rates the crack speed varied between 1.4 – 3.7 m/s. In contrast to this, the fracture toughness of the 25 phr carbon black-filled NR first decreased with increasing strain rate from about 25 KJ/m^2 at 0.01 s^{-1} to 9 KJ/m^2 at 32 s^{-1}. At strain rates above 32 s^{-1}, the fracture toughness of the filled NR increased with increasing strain rate. At about 160 s^{-1}, the fracture toughness of the 25 phr carbon black-filled NR was
28 KJ/m^2, which is comparable to its fracture toughness at quasi-static loading rates. The crack speed during quasi-static loading was 3.5 m/s and increased from 1.4 to 2.8 m/s between strain rates 32 – 160 s^{-1}. There was significant scatter in the data concerning crack speeds for both the unfilled NR and carbon black-filled NR because of crack meandering during growth. The data suggested that even though carbon black fillers are used to improve the fracture toughness of NR, they do not necessarily achieve this task for strain rates between 32 – 103 s^{-1}. Between this range of strain rates, the fracture toughness of 25 phr carbon black-filled NR was almost the same as the fracture toughness for the unfilled NR.

Paper Number 3.3

Evaluation of Steering Feel Using a Tire/Vehicle Simulation Model

Michael U. Frank
Mechanical Engineering Department , University of Akron

Hans R. Dorfi, Robert J. Wollyung
Bridgestone Firestone North American Tire, LLC

Steering feel is an important characteristic of a modern automobile. The prediction of steering feel and the contribution of the different sub-systems is therefore of great interest to OEM's and their suppliers. In this study different tire sets are evaluated through both objective and subjective testing for steering feel. The steering system and vehicle dynamics are also modeled in order to validate modeling techniques and simulations. An advanced steering model is developed to accurately predict steering feel. The objective testing is conducted using a sport-compact. Some of the measured data includes steering wheel angle, steering wheel torque, and vehicle speed. The hydraulic boost pressures from the steering system are also measured to validate and tune the steering model. Inputs of the steering model are steering wheel angle, vehicle speed, and kingpin moments. The outputs include handwheel torque and a modified steering wheel angle, which drives a commercial vehicle dynamics model. The vehicle dynamics model calculates the vehicle dynamics behavior and provides the feedback, i.e. kingpin moments, required for the steering model. Differences in steering characteristics due to tire sets are observed from both objective and simulated results and correlate to subjective ratings.

Paper Number 4.1

Two Methods of On-road Tire Characterization: Direct Measurement and Using an Instrumented Vehicle

Sven Jansen, Roel Leenen, Joost Zuurbier
TNO Science and Industry

Vehicle dynamics simulation is often based on tire test data from flat track or other testing machine; however an important aspect is that tire behavior is influenced by operation conditions. Therefore characterization of tires must be done under realistic conditions, so that surface, temperature and other influencing factors occurring during driving are well reproduced. TNO recently built a new Tire Test Trailer with State-of-the-art actuation and measuring equipment to accurately control the conditions during on-road tire testing. This is the first method to be discussed.

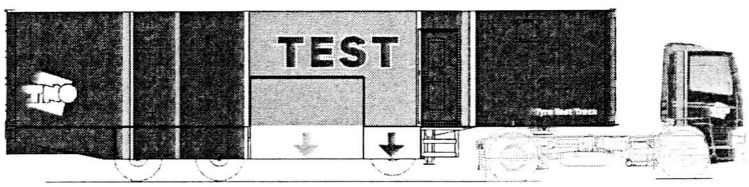


Figure 1: TNO Tire Test Truck 2006

Generally tire evaluation is done with driving tests to assess the vehicle handling performance subjectively. It is advantageous to combine subjective tire testing with objective tire characterization. The second method concerns a vehicle equipped with the TNO Tire Estimator. The system consists of a processing unit and it uses low cost sensors which may already be on the vehicle in the inertial package used for stability control. The system provides objective tire assessment which is sufficiently accurate for ranking tire performance.

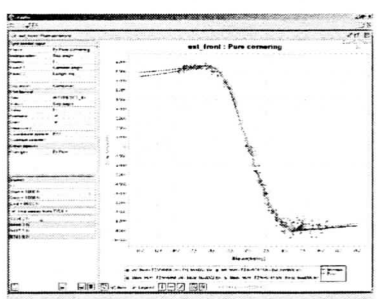


Figure 2: Comparison of Tire Estimator with wheel measurements

The TNO Tire Estimator uses a vehicle representation including a versatile non-linear tire model to cover also situations with large levels of slip. The algorithm calculates tire forces to the slip quantities derived from the vehicle motion signals, and thus a tire slip characteristic is estimated. This technology is integrated in a system that can be installed on any vehicle and a set of software tools run on a laptop for in-car evaluation. The presentation gives an overview of results achieved so far.

Paper Number 4.2

FTire Software: Advances in Modelization and Data Supply

Michael Gipser
Esslingen University of Applied Sciences

Being developed and continuously improved for more than 7 years now, the *FTire* simulation software has become one of the widely used and generally accepted tire models for ride comfort, handling, and road load prediction in durability applications. Strength of *FTire* is its strict physical background, taking into account most of the relevant sources and non-linear transfer mechanisms of excitations up to very high frequencies and short wavelengths. The model's level of detail is accompanied by a numerically robust and efficient solver, and by a very comfortable program interface. This allows to simulating even extreme maneuvers and situations with moderate computation time. *FTire* can be used together with most of the important MBS packages.

The contribution discusses recent advances in the *FTire* software. This discussion comprises enhancements in the model, like motorcycle tire simulation with very large camber angles, detailed lateral belt bending, distributed tire imperfections, tire temperature and wear, new efficient road models, as well as improved tools for parameterization and validation.

Paper Number 4.3

Tire Forces and Moments Using an Analytical Model with Physical Parameters

M. Kamel Salaani
Transportation Research Center, Inc.

The tire is a highly nonlinear system; its complexity has limited the development of a complete and reasonable theory governing tire mechanics. Tire modeling for vehicle dynamics simulation has been restricted to curve fitting of experimental tire data. This paper introduces the use of an analytical model with experimentally assessed physical parameters. The analytical part is based on an idealized contact with elliptical normal pressure distribution. The physics of the contact between the tire and the road surface is based on planar springs deforming independently of each other and obeying Hooke's stress-strain laws. This contact concept is augmented with formulations of physical parameters in terms of normal load variation. These physical parameters are universal to all tires and are what define the force generating capacity. They are cornering and longitudinal stiffness, aligning and overturning moment arms, lateral force dynamics delay, contact patch length and lateral and longitudinal frictional properties.

This idealized surface contact concept, augmented with formulations of physical properties, constitutes a practical tire model that can be applied to vehicle dynamics simulations up to extreme handling conditions. The model also has a validated normal load capacity, that is, it can span normal loads beyond the measured data envelope. It can also be used to assess the effects of the physical properties of an actual tire on vehicle dynamics performances. This Tire model is validated with numerous comprehensive data measured at a Flat-Track tire testing machine. The data spans different tire sizes and performance capacities.

Paper Number 4.4

An Analysis of the Influence of Tire Force and Moment Shape on Vehicle Handling Performance for Large Slip Angle Maneuvers

C.W. Mousseau, K.D. Norman
General Motors Proving Grounds

Vehicle handling performance depends largely on tire force and moment behavior, which in turn, depends on slip angle, camber angle, and vertical load. Each of these functional relationships have a distinct shape, but they all commonly rise to a peak value at a given slip angle value and then fall off with increasing slip angle. Most standard handling maneuvers (e.g., ramp steer, frequency response, and maximum lateral acceleration) occur at slip angles well below the peak. On the other hand, maneuvers that evaluate the handling performance of vehicle equipped with electronic stability control (ESC) systems can operate at, or above, the peak. This paper examines how changes in the shape of the lateral force, aligning moment, and overturning moment curves influence vehicle handling performance for the constantly increasing steer (i.e., ramp steer) and the proposed sine with dwell test maneuvers. Tire force and moment data is characterized in terms of parameters that define the shape of these data. The VehSim vehicle dynamics program is used to generate the time response data for each maneuver. The influence that each tire force and moment shape parameter has on key vehicle response metrics is examined. The effect that extrapolation of tire data has on vehicle response for these maneuvers is also addressed.

Paper Number 5.1

The Chemistry & Physics of a Natural Tread Separation

John M. Baldwin, Robert J. Pascarella
Ford Motor Company

Donald F. Tandy, Jr., Kenneth T. Tandy, Kevan J. Granat, Nicholas J. Durisek
Tandy Engineering & Associates, Inc.

To study vehicle response during a tire tread-belt detachment, The National Highway Traffic Safety Administration (NHTSA) and other researchers have employed a specially prepared 'cut' tire. These tires are cut along the shoulder on both inside and outside circumferences with an additional cut made diagonally across the tread. These cuts can initiate a tread-belt separation event after driving only a few miles at highway speeds. This method has been utilized by many to study tread-belt separations and its effects on vehicle performance, and has long been accepted by experts as surrogate data for duplicating naturally occurring tread-belt separation events experienced in the field. This study investigates the forces and moments imparted on a vehicle in a natural tread-belt detachment experiment.

A controlled experiment was performed to prepare a tire that would separate on a vehicle in a reasonable time, but not be cut as in previous studies. Separations needed to be induced into the belt edges of sufficient length, but without overheating or otherwise damaging the tire. The full vehicle experiment was conducted on a vehicle instrumented to record onboard accelerations and rotational velocities, the forces and moments that transfer through the road wheel at the right and left rear wheel locations using wheel force transducers, displacements between the rear axle and the frame, and accelerations on the rear axle.

In the experiment, the tread-belt detachment did not create forces that put the vehicle out of the driver's control, requiring only small steering corrections to maintain the travel lane. The results of the experiment also showed that a 'normal' tire (on the verge of a tread-belt separation) could be prepared in the laboratory. This paper will discuss how the 'normal' tire was prepared and provide the force and moment data that results from the full vehicle experiment.

Paper Number 5.2

The Development of Integrated Optimum Contour Design System to Satisfy Multi Performances of the Tire

Dong Woo Lee
Dong-A University

S. R. Kim, K. D. Sung
NEXEN Tire Company

S. S. Cho
Gangwon National University

W. S. Joo
Dong-A University

C. T. Cho
NEXEN Tire Company

Tire is an important part which has functions to support vehicle load and to turn or keep vehicle direction, and demands high performance along with increasing vehicle performance. Tire is a complicated structure which should satisfy durability, handling, wear, ride, etc. Various optimum contour design theories have been developed and applied to satisfy performances listed above.

Tire performance is affected by tire contour and there have been many researches related to contour design. But most of them could not be implemented into tire performance. In the present work, the optimum design of tire contour has been carried out by considering tread and sidewall shape at the same time in order to maximize tire performance. That is, this paper has constructed integrated optimum contour design system to satisfy multi performances of tire by regression analysis and genetic algorithm using DOE.

Paper Number 5.3

High Speed Tire Analysis and Standing Waves Using a Mixed Lagrangian/Eulerian Method

Chris Wohlever, Michael Snyman
ABAQUS, Inc.

The Steady State Transport (SST) capability in ABAQUS/Standard is commonly used to model the steady state rolling and sliding of pneumatic tires. A SST analysis uses a reference frame that is attached to the axle of the rotating tire. An observer in this frame sees the tire as points that are not moving, although the material of which the cylinder is made is moving through those points. This removes the explicit time dependence from the problem.

This description can be viewed as a mixed Lagrangian/Eulerian method, where rigid body rotation is described in a spatial or Eulerian manner, and deformation, which is now measured relative to the rotating rigid body, is described in a material or Lagrangian manner.

This paper describes recent efforts made to improve the convergence characteristics of the SST method in ABAQUS/Standard at high rolling speeds. It also discusses some observations made in the quest to predict the onset and evolution of standing waves in pneumatic tires.

Paper Number 6.1

Deformation Properties of Radial Tire in Contact with Road

Kazuyuki Kabe, Naoshi Miyashita
Yokohama Rubber Co., Ltd.

Takashi Akasaka
Professor Emeritus, Chuo University

The deformation with including the cord tension distribution of a radial tire in contact with the road are analyzed on membrane-shell model under the following assumptions; the cross section of the tire is approximated by an ellipse; the carcass layer and the belt layer are assumed to be an inextensible, cord-reinforced, membrane-shell and the belt layer to have stiffness; the initial membrane forces due to inflation pressure are assumed to be carried entirely by these carcass and belt layer cords; and the tread is considered as a spring-bedded, elastic ring with bending stiffness. The displacement components of the carcass layer and belt layer are approximated by Fourier series with finite numbers of terms which would in the end be determined numerically by mean of the principle of minimum potential energy. Numerical results for the deformation and the cord tension distribution agree well with the corresponding experimental results.

Paper Number 6.2

Prediction of Tread Pattern Wear by Explicit FEM

J. C. Cho, B. C. Jung
Hankook Tire Co., Ltd.

Tread pattern wear is predicted by using explicit FEM and compared with the indoor drum test results under a set of actual driving conditions. One pattern is used to determine the wear rate equation which is composed of slip velocity and tangential stress under a single driving condition. And two other patterns with the same size (225/45ZR17Y) and profile are used to be simulated and compared with the indoor wear test results under the actual driving conditions.

As a study on rubber wear rate equation, trial wear rates are assumed by using several trial constitutive equations and each trial wear rate is integrated along time to yield the total accumulated wear under a selected single cornering condition. The trial constitutive equations are defined by independently varying each exponent of slip velocity and tangential stress. The integrated results are compared with the indoor test results and the best matching constitutive equation for wear is selected for thereafter wear simulation of two other patterns under actual driving conditions.

Thousands of hundred driving conditions of a tire are categorized into small number of simplified conditions by a suggested simplification procedure which considers the driving condition frequency and weighting function. Both of these simplified conditions and the original actual conditions are tested on the indoor drum test machines. The results under the two conditions show almost the same results. Therefore the simplification procedure is justified.

By applying the selected wear constitutive equation and the simplified driving conditions to the explicit FEM simulation, the simulated wear results for the two patterns show good match with the actual indoor wear results.

Paper Number 6.3

A 3D Tire/Road Interaction Simulation by a Developed Finite Element Model (ABAQUS Code)

M.Zamzamzadeh
Kerman Tire & Rubber Company

F.Ariana
Mechanical Engineering Dept., Shahid Bahonar University

M.Negarestani
Chemical Engineering Dept., Sharif University of Technology

In the case of tire development, many types of FEM simulations have been performed to date. But, in most of them, tire models were either static or simplified models. This paper presents a 205/60R14 radial tire simulation under different loading conditions using the ABAQUS code. First, we modeled a 2D axisymmetric model, and then a full 2D model was created. Finally we developed a full 3D model whose components were included according to the real tire components. Our tire model comprised one body ply, two steel belts, and two cap plies. In the axisymmetric model two element groups (CGAX3H, CGAX4H) from ABAQUS were selected to represent our rubbery components. These elements have bilinear hybrid behaviour with twist to model incompressible rubber behaviour. Reinforcement materials in ply, belts, and cap plies were modeled with rebar in surface elements (SFMGAX1) embedded in continuum elements. It is a generalized two node element with twist that can be used in conjunction with other geometrical parameters to model rebar elements. Different hyperelastic models for rubbery components as Mooney Rivlin, Ogden, Arruda Boyce, were compared for this modeling. The 3D model was generated by revolving the 2D mesh developed from the tire cross section about the tire symmetry axis. One of the major applications of creating this model is to evaluate the behaviour of the tire when it has contact with a road during rolling. As we know it, is a very complicated problem to examine stress/strain status in real situations, so this model will help us a lot in this matter and we can predict footprint stress distribution and optimize tire construction to better performance. In the load steps, first we mounted the tire on a standard rim and then applied inflation pressure. We simulated steady state analysis at relatively high ground velocity and finally contacted it with a rigid surface as a road to evaluate different parameters as footprint, stress distribution, tire heat transfer, and camber angle effects on tire performance. The steady state analysis allows force for different slip angles. We claim that our results are very close to the experimental results.

Key Words: Tire, Finite Element Modeling, Footprint, Contact, Steady State, Rolling Tire