28th Annual Meeting and Conference on Tire Science and Technology

Program and Abstracts

September 15-16, 2009
Akron City Centre Hotel
Akron, Ohio

www.tiresociety.org

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28th Annual Meeting and Conference on Tire Science and Technology

Day 1 – Tuesday, September 15

7:30 AM		**Registration**	
8:15 AM		**Conference Opening**	Ed Terrill, Conference Chair
8:20 AM		**Welcome**	Bob Wheeler, President
8:30 AM		**Keynote Address**	Robert Keegan, CEO Goodyear Tire & Rubber
9:00 AM		**Break**	
9:15 AM		**Session 1: Wear / Friction / Rolling Resistance**	John Luchini, Session Chair
9:20 AM	1.1	Fracture Mechanisms Underlying Road Wear	Joe Padovan
9:45 AM	1.2	Validation of Steady State Laboratory Lateral Force Slip Characteristics of Small Tires	Rene van der Steen
10:10 AM		**Session 2: Vehicle Dynamics**	Russ Moser, Session Chair
10:15 AM	2.1	A Modified Dugoff Tire Model for Combined-Slip Forces	Nenggen Ding
10:40 AM	2.2	A Study on the Influence of Tire Properties on SUV Rollover Using the Dynamic Simulation of Fish-Hook Maneuvers	Taeyun Koo
11:05 AM		**Break**	
11:15 AM		**State of the Society**	Robert Wheeler, President
11:35 PM		**Luncheon –** 19th floor **Tire Society Distinguished Achievement Award Presentation**	Ric Mousseau, Selection Committee Chair
1:30 PM		**Session 3a: New Light on Tire Technology (Student Papers)**	Marion Pottinger, Session Chair
1:35 PM	3.1	Design, Construction, and Testing of a Portable Tire Test Rig	Brad Hopkins
2:00 PM	3.2	Characterization of Tire Behavior by a Finite Element Method	Vijaykumar Krithivasan
2:25 PM	3.3	An Alternative Technique to Evaluate Crack Propagation Path in Hyperelastic Materials	Renan Ozelo
2:50 PM	3.4	Evaluation of the Contact Pressure Distribution of a Rear Combine Tyre on a Hard Surface	Paula Misiewicz
3:15 AM		**Break**	
3:30 PM		**Session 3b: New Light on Tire Technology (Student Papers)**	Marion Pottinger, Session Chair
3:35 PM	3.5	Use of Orthogonal Arrays for Efficient Evaluation of Geometric Designs for Reducing Vibration of a Non-Pneumatic Wheel During High-Speed Rolling	William Rutherford
4:00 PM	3.6	Parameter Estimation and Evaluation of LuGre Tire Friction Model Using Data Collected at Multiple Pavement Surfaces	Madhura Rajapakshe
4:25 PM	3.7	GIXRD and SIMS Analysis of the Rubber-Steel Tire Cord Interface	Prasan Harakuni
4:50 PM	3.8	Effect of Aging on the Morphology of the Rubber-Brass Interfacial Layer	Ahshay Ashirgade
5:15 PM		**End of Tuesday's Technical Sessions**	
5:15 PM		**Reception** – 19th floor	(Cash Bar / Hor d'oeuvres)
6:00 PM		**Dinner Banquet:**	
7:00 PM		Presentation of 2008 Superior Paper Awards and 2009 Student Paper Award	Gary Tubb, Award Chair
7:20 PM		**Dinner Speaker:** The GM Chevy Volt: Extended-Range Electric Vehicle	Dr. Terry Woychowski, Vice-President GM Global Vehicle Program Management
8:00 PM		**Adjourn**	

28th Annual Meeting and Conference on Tire Science and Technology

Day 2 – Wednesday, September 16

8:00 AM		**Opening/Announcements**	Ed Terrill, Conference Chair
8:05 AM		**Session 4: Noise, Vibration and Harshness**	Jan Terziyski, Session Chair
8:10 AM	4.1	Calculation of Dynamic Tire Forces from Aircraft Instrumentation Data	Gary McKay
8:35 AM	4.2	Uniformity: A Crucial Attribute of Tire/Wheel Assemblies	Marion Pottinger
9:00 AM		**Break**	
9:15 AM		**Session 5: Modeling**	Osama Hamzeh, Session Chair
9:20 AM	5.1	Optimization of Reinforcement Turn-up Effect on Tire Durability and Performance for Racing Tire Design Finite Element Analysis	Oluremi Olatunbosum (presented in absentia by Hamid Aboutorabi)
9:45 AM	5.2	Prediction of Cord-Rubber Composite and Tire Response Using Nonlinear Continuum Damage Mechanics Approach	Mahmoud Assaad
10:10 AM	5.3	Carbon Fiber-Polyurethane Self-Supporting Airless Tire	Abraham Pannikottu
10:35 AM	5.4	Modeling Material Storage Modulus for Tire Natural Frequency Prediction	Bob Wheeler
11:00 AM		**Break**	
11:10 AM		**Plenary Lecture – Advances and Changes in Tire Science and Technology**	Marvin Janssen, Retired Tire Engineer
11:50 PM		**Lunch – On your own**	
1:05 PM		**Session 6: Structural Performance**	Saied Taheri, Session Chair
1:10 PM	6.1	Inflation Pressures at Less Than Maximum Tire Loads	John Daws
1:35 PM	6.2	Mathematical Model of the Effective Properties of a Fiber Reinforced Composite with a Linearly Graded Transition Zone	Carey Childers
2:00 PM		**Session 7: Durability/Tire Testing/Tire Building**	Rusty Adams, Session Chair
2:05 PM	7.1	ASTM Committee F09.30 Task Group Update on Commercial Truck/Bus Tire Test Practice Development	Jim Popio
2:30 PM	7.2	Erroneous or Arrhenius - Potential Impact of Oven Temperature Variations on Laboratory Aging of Tires	Greg Altman
2:55 PM	7.3	Correlated Dual Sheet-of-Light Measurement of Preparation Material	Oliver Scholz
3:20 PM		**Break**	
3:35 PM		**Session 8: Materials/Materials Development**	John Harris, Session Chair
3:40 PM	8.1	Investigation of the Microscopic Viscoelastic Property for Crosslinked Polymer Network by Molecular Dynamics Simulation	Yuuki Masumoto
4:05 PM	8.2	Network Evolution During Intensive Service in Large OTR Tire Compounds – Evidence for “Double Network” Formation.	Fred Ignatz-Hoover
4:30 PM	8.3	UTQG Tire Traction Rating Comparisons with 0°C Tan Delta and Coefficient of Friction Compound Measurements	Ed Terrill
4:45 PM		**Closing remarks**	
5:05 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 Society is a not-for-profit Ohio corporation managed by a duly elected Executive Board of tire industry professionals who serve on a volunteer basis.

In addition to the Executive Board, many members volunteered their time to put together the 2009 conference, including:

CONFERENCE COMMITTEE:

Program Chair:	Ed Terrill	*Akron Rubber Development Lab, Inc.*
Assistant Chair:	Barry Yavari	*The Goodyear Tire & Rubber Co.*

AWARDS COMMITTEE:

Gary Tubb (Chair)	*The Goodyear Tire & Rubber Co. (Retired)*		
Gene Chen	*Bridgestone Firestone NA Tire*	Steve Cron	*Michelin Americas R&D Corp.*
Josh Herron	*Hankook Tire Company*	Vladimir Kerchman	*Kumho America Technical Center*

SESSION CHAIRS:

John Luchini	*Cooper Tire and Rubber Company*	Russ Moser	*Bridgestone Firestone NA Tire*
Marion Pottinger	*M'gineering, LLC*	Jan Terziyski	*Hankook Tire Company*
Osama Hamzeh	*The Goodyear Tire & Rubber Co.*	Saied Taheri	*Virginia Polytechnic Institute and State University*
Rusty Adams	*The Goodyear Tire & Rubber Co.*	John Harris	*Transportation Research Center, Inc.*

TECHNICAL ASSISTANCE:

Jim McIntyre	*Smithers Scientific Services, Inc.*

The 2010 conference committee would appreciate your assistance and suggestions:

2010 CONFERENCE COMMITTEE:

Program Chair:	Barry Yavari	*The Goodyear Tire & Rubber Co.*
Assistant Chair:	Saied Taheri	*Virginia Polytechnic Institute and State University*

In addition to the Journal Editor, the associate editors volunteer time to contribute to the peer review process associated with publishing manuscripts in the Tire Science & Technology Journal:

The Tire Society Executive Board is also supported by an Advisory Board:

Other administrative activities are handled by:

BUSINESS OFFICE:

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

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

Local Arrangements: Beth Berkheimer, ACS Rubber Division

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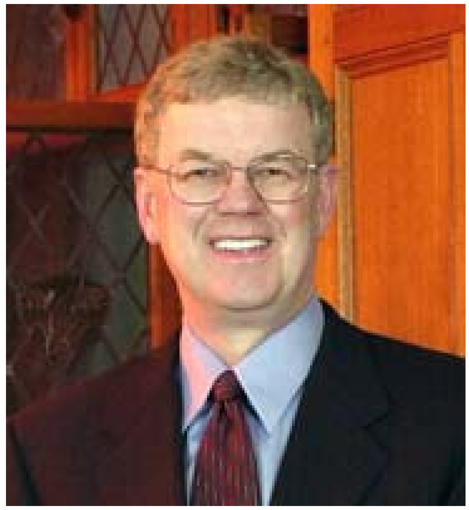
Keynote Address

Tuesday, September 15, 2009, 8:30 - 9:00 am

"Innovate and Prosper"



Robert J. Keegan is Chairman of the Board, Chief Executive Officer and President of The Goodyear Tire & Rubber Company. He was elected chairman effective July 1, 2003, and chief executive officer January 1, 2003.

Prior to joining Goodyear, Mr. Keegan was president of the Consumer Imaging business and an executive vice president of Eastman Kodak Company in Rochester, N.Y.

Mr. Keegan began his Kodak career in 1972 with distribution and marketing staff assignments in Rochester. He held a series of positions in finance and marketing in the United States and Europe before being named general manager of Kodak New Zealand in 1986. Returning to Rochester in 1987, he was named director of finance for the Photographic Products Group. In 1990, he was named general manager of Kodak Spain. In 1991, he was named general manager of Consumer Imaging for Kodak's European, Middle Eastern and African Region. In November 1993, he was elected a corporate vice president.

In 1995, Mr. Keegan left Kodak to join Avery Dennison Corporation, in Pasadena, Calif., as executive vice president and global strategy officer.

In July 1997, he returned to Kodak as president of Kodak Professional and was elected a corporate vice president. In October 1997, Mr. Keegan was appointed president of Consumer Imaging and elected a senior vice president. He became an executive vice president of Kodak in January 2000.

Mr. Keegan received a Bachelor of Science degree in mathematics from LeMoyne College in Syracuse, N.Y., and a master of business administration degree in finance from the University of Rochester.

Mr. Keegan and his wife Lynn have two children.

Luncheon

Tuesday, September 15, 2009, 11:35 am - 1:15 pm

Tire Society Distinguished Achievement Award Presentation

Dr. Samuel Clark (1924-2006) is the inaugural recipient of the Tire Society Distinguished Achievement Award. This bi-annual award recognizes outstanding contributors to tire science and technology. A presentation will be given in his honor.

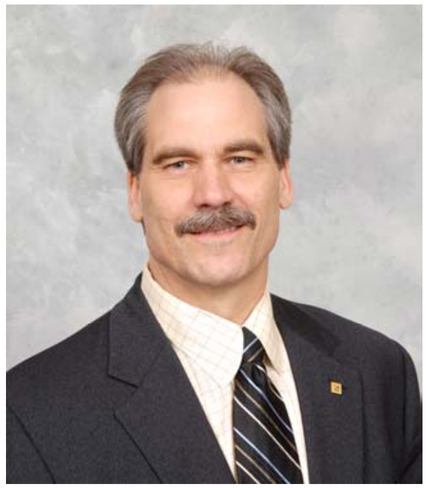
The life-time achievement and record of contributions by Dr. Clark, (1924-2006), to tire science and technology and his mentorship and support of technical organizations make him an exemplary recipient for this reward.

Dr. Clark made seminal contributions in research related to aircraft and automotive tires. His work was sponsored by major rubber, automobile, and aircraft companies as well as by the U.S. Air Force, NASA, NSF, and the Department of Transportation and he authored over 100 journal articles and research reports. Dr. Clark was asked to write a book on tire mechanics, and in 1971, the U.S. Bureau of Standards published his first edition of "Mechanics of Pneumatic Tires." Since then, tire engineers have relied on "The Clark book" for detailed information about the principles of tire design and use. In 1981, a substantially revised second edition was published. Dr. Clark also served as chair of an Editorial Board composed of leading executives of the tire industry, which provided guidance during the monograph's third revision.

Dr. Clark was a founding member of The Tire Society, and presented the plenary lecture, by invitation, at the first meeting of The Tire Society in 1982. He was an Associate Editor of The Journal of Tire Science and Technology until his death. He was also a member of the American Society of Mechanical Engineers, The Society for Experimental Stress Analysis, the National Materials Advisory Board Committee on Surface Effect Vehicles, and The Society of Automotive Engineers. In honor of his many achievements, he was named a fellow of the Society of Automotive Engineers in 1985. Dr. Clark was a professor of mechanical engineering at the University of Michigan for over 50 years, where he taught and mentored hundreds of students, many of whom continue to contribute to tire research.

Awards Banquet Dinner Speaker:
Tuesday, September 15, 2009, 7:20 - 8:00 pm

"The GM Chevy Volt: Extended-Range Electric Vehicle"



Dr. Terry J. Woychowski is the vice-president of General Motors Global Vehicle Program Management. He is responsible for the program management and execution of all General Motors' car and truck platforms globally.

Dr. Woychowski is General Motors' key executive liaison with Michigan Technological University in Houghton, MI, in addition to being a member of the M.T.U. Industrial Advisory Board.

In 2008, Dr. Woychowski was named to the Board of Directors for the Engineering Society of Detroit. He was recently voted President Elect to the Board, and is chairman for the Young Engineers Committee.

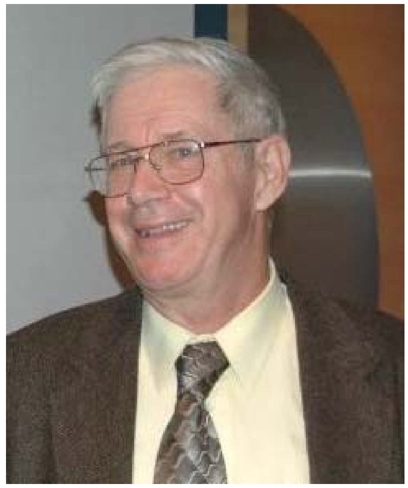
Dr. Woychowski was raised in Bad Axe, MI. He received a Bachelor of Science degree in Mechanical Engineering from Michigan Technological University in 1978. He took post-graduate studies in the pre-medical program at Wayne State University in Detroit from 1980-1981, and attended the Global Executive Development Program at the Duke University School of Business in 1998. He was awarded his Doctorate in Business Management, honoris causa, from Indiana Wesleyan University in December 2003.

In 2007, Dr. Woychowski was inducted into the Michigan Technological University Academy of Mechanical Engineering and Engineering Mechanics.

Dr. Woychowski resides in Commerce Township, MI, with his wife, Rochelle. Together they have three children, Justin, Jamie and Jenna.

Plenary Lecture
Wednesday, September 16, 2009, 11:10 -11:50 am

"Advancements and Challenges in Tire Science and Technology"



Dr. Marvin Janssen received his PhD in Theoretical and Applied Mechanics from the University of Illinois in 1970. Upon graduation he joined Firestone Tire and Rubber Company as a Research Scientist. During his 25 year career he was group leader of Engineering Mechanics, group leader of the Dynamics Research laboratory and manager of the Advanced Tire Engineering Department. In these positions he was involved in tire mechanics research and the development of Computer Aided Engineering Technology for Tires. He retired from Firestone in 1995 and joined Hankook Tire Company as Manager of Tire Engineering Technology where he continued work in tire mechanics and tire technology until his retirement from Hankook in 2007.

Abstract
Changes and progress in the tire industry from the early 1970's to the present day will be reviewed. The formulation and development of the fundamental tire mechanics principles and computational techniques that provide the basis for today's computer aided engineering tools for tire development will be presented. Key challenges for successful implementation of CAE technology into the tire design and development process will be discussed.

Paper Number 1.1

Fracture Mechanisms Underlying Road Wear

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The main focus of the presentation will be to outline how factory induced material morphology, and compounded dynamic mechanical and fracture properties control the wear of elastomers. FEA modeling will be employed to demonstrate how such properties combine to effect wear particle evolution during successive road surface asperity passing events. Specific attention will be given to determine how these factors combine to control debris formation. This will be established in a multi step process which:

1) Sorts out scale, and specifics of morphological and associated interfacial topologies including stochastic characteristics;

2) Establishes agglomerated and constituent material dynamic properties at appropriate geometric scale level;

3) Sets up FEA model including specifics of material morphology and dynamic properties as well as randomness of road surface asperity geometry;

4) Simulates debris evolution.

Attention will also be given to establish how compounding and factory processing specifics control wear performance.

Paper Number 1.2

Validation of Steady State Laboratory Lateral Force Slip Characteristics of Small Tires

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It is advantageous to use small scale testing in the design phase of tires due to the costs and uncontrollable environmental conditions of outdoor testing. Therefore a laboratory abrasion and skid tester is used to obtain more insight in the contact of a tread compound with the road for dry conditions.

In the experimental setup a small solid tire, with adjustable slip angle, is pressed on an abrasive corundum disk. The present friction between the abrasive disk and solid tire drives the tire and the resulting forces are measured with a triaxial force sensor. Several experiments under different normal loads, slip angles, and velocities of the disk are conducted.

To explain observed phenomena of lateral force measurements for a free rolling tire under a number of slip angles a FE model is used. The relevant parts of the setup are modeled in Abaqus and the steady state performance of the small tire under different slip angles is evaluated. It is shown that the present turnslip, which has great impact on the slip velocity field at the trailing edge of the contact area, is captured well with the model. Furthermore the calculated cornering stiffnesses are in good agreement with the experiments.

[1] Presenting author

Paper Number 2.1

A Modified Dugoff Tire Model for Combined-Slip Forces

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Easy-to-use tire models for vehicle dynamics have been persistently studied for such applications as control design and model-based on-line estimation. This article proposes a combined-slip tire model based on Dugoff-tire. The proposed model takes emphasis on less time consumption for calculation and uses a minimum set of parameters to express tire forces. Revision for Dugoff-tire model is made on two aspects: one is taking different tire/road friction coefficients for different magnitudes of slip and the other is employing the concept of friction ellipse. The proposed model is evaluated by comparison with the LuGre tire model. Although there are some discrepancies between the two models, the proposed combined-slip model is generally acceptable due to its simplicity and easiness to use.

[1] Presenting author

Paper Number 2.2

A Study on the Influence of Tire Properties on SUV Rollover Using the Dynamic Simulation of Fish-Hook Maneuvers

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The accidents of Sports Utility Vehicles (SUV) sometimes lead to vehicle rollover which is defined as a vehicle rotation of 90 degree or more around its longitudinal axis. Rollover crashes are significantly more fatal than that in other types of crashes. In order to help consumers understand, National Highway Traffic Safety Administration (NHTSA) proposed a rollover resistance rating program which uses the Static Stability Factor (SSF) to determine the rating. SSF is a vehicle design factor determined by the ratio of one half the track width to the C.G. height. However there may be some other influences on the rollover propensity such as tire and suspension characteristic properties. Thus, in 2002, NHTSA published another notice to present a dynamic rollover test procedure through the Fish-Hook maneuvers.

The aim of this study is to analyze the influence of tire characteristic properties on the rollover stability using a vehicle dynamic simulation technique. In order to investigate the rollover propensity, the multi-body vehicle dynamic model has been developed. The vehicle dynamic model consisted of body, suspension, steering, power-train, brake, tire, road, and driver subsystems. The whole vehicle parameters, each vehicle's part parameter, part connecting elements such as spring, damper and bush, and tire characteristic factors were measured by an experiment to accomplish accurate rollover analysis. With the developed vehicle dynamic model, a rollover analysis due to tire characteristic factors, such as cornering stiffness and cornering force peak has been carried out in accordance with the Fish-Hook test.

[1] Presenting author

Paper Number 3.1

Design, Construction, and Testing of a Portable Tire Test Rig

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Tire force and moment testing is a valuable way of quantifying the performance of various tires. The data is also used by many researchers for vehicle dynamic simulation studies as well as chassis control system development. Although various studies have claimed correlation between data from rolling-road type machines and road-testing trailers, the claim only extends for on-road conditions. Many military vehicles as well as agricultural vehicles operate in an environment which requires new levels of tire test data. This paper will discuss the design and testing of a portable trailer tire test rig. This rig was conceived and constructed for use on- and off-road and is also fitted for wet-road testing. The rig will be used to collect tire data on various tire sizes both on and off-road at various road surfaces (grass, asphalt, concrete, and gravel) speeds, pressures, loads, and slip angles. The data will be used to develop a modified Pacejka Magic Formula Tire Model that can be used for conducting simulation in both on and off-road conditions.

[1] Presenting author

Paper Number 3.2

Characterization of Tire Behavior by a Finite Element Method

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This paper investigates the effective use of finite element methods to characterize the behavior of an automobile tire. A 3D finite element model of standard size automotive tire is developed to better understand the tire deformation under loading conditions. A parametric study of inflation pressure, normal loading, camber angle and slip angle was carried out to capture the influence of these parameters. A parametric study of the combined case scenario of the effects of the previously mentioned parameters is also performed. Using these results, an empirical model will be developed that will demonstrate how the hoop strains measured on the inner surface of the tire could be used to quantify desired parameters such as camber, slip, and normal load. This model will comprise equations relating strains to the contact area, slip, camber, and normal load.

[1] Presenting author

Paper Number 3.3

An Alternative Technique to Evaluate Crack Propagation Path in Hyperelastic Materials

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The analysis of cracks in tires aims to provide safety and reliable life prediction. Tires' materials are usually nonlinear and present a hyperelastic behavior, therefore, the use of nonlinear fracture mechanics theory and a material constitutive model based on energy are necessary. The material constitutive model used in this work is the Mooney-Rivlin.

There are many techniques available to evaluate the crack propagation path in linear elastic materials and estimate the growth direction. However, most of these techniques are not applicable to hyperelastic materials. This paper presents an alternative technique for modeling crack propagation in hyperelastic materials, based in the *J-Integral*, to evaluate the crack path. The *J-Integral* is an energy-based parameter and is applicable to nonlinear materials. The technique was applied using ABAQUS software and validated with experimental tests.

[1] Presenting author

Paper Number 3.4

Evaluation of the Contact Pressure Distribution of a Rear Combine Tyre on a Hard Surface

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Only a vehicle's tyres have contact with the ground on which they roll, therefore, the tyre contact patch transmits all the forces from the vehicle to the ground. Furthermore, the size of tyre contact patch and contact pressure distribution affect the forces acting on the wheel which are traction force, rolling resistance and braking force. It determines the vehicle's grip, wear on the rubber and fuel consumption.

The aim of this paper is to report on the findings of the research which involved the development of a method to estimate tyre contact pressure and its distribution. The results of an investigation into the contact pressures obtained when a smooth rear combine tyre was loaded on a hard surface are presented. The tests employed a piezo-electric pressure mapping system. The experiments involved placing the pressure sensors on an un-deformable surface and loading them with a rear combine tyre at a range of inflation pressures and loads. This method allowed an accurate measurement of the mean and maximum contact pressure, and pressure distribution across the contact area.

The results obtained indicate non-uniform pressure distribution across the contact patch. The findings gave an understanding of the influence of tyre inflation pressure and load on the resulting contact pressure which contributed to a better understanding of tyre behaviour.

[1] Presenting author

Paper Number 3.5

Use of Orthogonal Arrays for Efficient Evaluation of Geometric Designs for Reducing Vibration of a Non-Pneumatic Wheel during High-Speed Rolling

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Timothy B. Rhyne
Steven M. Cron
Michelin Americas Research Company
Greenville, SC

During high speed rolling of a non-pneumatic wheel, vibration may be produced by the interaction of collapsible spokes with a shear deformable ring as they enter the contact region, buckle and then snap back into a state of tension. In the present work, a systematic study of the effects of six key geometric design parameters is presented using Orthogonal Arrays. Orthogonal Arrays are part of a design process method developed by Taguchi which provides an efficient way to determine optimal combinations of design variables. In the present work, a 2D planar finite element model with geometric nonlinearity and explicit time-stepping is used to simulate rolling of the non-pneumatic wheel. Vibration characteristics are measured from the FFT frequency spectrum of the time-signals of perpendicular distance of marker nodes from the virtual plane of the spoke, thickness change in the ring between spokes, and ground reaction forces. Both maximum peak amplitudes and RMS measures are considered. Two complementary Orthogonal Arrays are evaluated. The first is the L_8 orthogonal array which considers the six geometric design variables evaluated at lower and higher limiting values for a total of eight experiments defined by statistically efficient variable combinations. Based on the results from the L_8 orthogonal array, a second L_9 orthogonal array experiment evaluates the nonlinear effects in the four parameters of greatest interest, (a) spoke length, (b) spoke curvature, (c) spoke thickness, and (d) shear beam thickness. The L_9 array consists of nine experiments with efficient combinations of low, intermediate, and high value levels. Results from use of the Orthogonal Array experiments were used to find combinations of parameters that significantly reduce peak and RMS amplitudes, and suggest that spoke length has the greatest effect on vibration amplitudes.

[1] Presenting author

Paper Number 3.6

Parameter Estimation and Evaluation of LuGre Tire Friction Model Using Data Collected at Multiple Pavement Surfaces

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Accurate analytical modeling of tire/pavement friction phenomena is of utmost importance in many applications, such as vehicle braking control and frictional evaluation of pavements. LuGre model is such an analytical model which can be used after estimating its parameters using measured data. In this investigation, LuGre model parameters were estimated using field data collected by a standard pavement friction measuring device (Locked Wheel Skid Trailer- ASTM E 274) at a group of pavements having different surface friction properties. Adequacy of the model to predict measured friction data from the device was statistically evaluated and the accuracy of estimated model parameters was determined. The results show the potential of this model to facilitate tire/pavement friction evaluation using dynamic friction measuring equipment.

[1] Presenting author

Paper Number 3.7

GIXRD and SIMS Analysis of the Rubber-Steel Tire Cord Interface

Prasan Harakuni[1]
Akshay Ashirgade
William Vanooij
Department of Chemical and Materials Engineering
University of Cincinnati
Cincinnati, OH 45221-0012

Adhesion of steel tire cords to rubber plays an important role in the overall performance of tires. Brass-coated steel wires are extensively used in the belts of radial tires because this not only leads to better handling but also improves the mechanical properties of the tire. Past research done on the tire cord-rubber interface has shown the adhesion is a result of the formation of a CuxS layer at the interface which leads to chemical bonding and mechanical interlocking. Grazing incidence angle Xray diffraction (GIXRD) analyses of flat-rolled brass-coated steel wires containing two different Cu loadings were conducted in order to study the effects of different brass loadings on the adhesion interface. The GIXRD data shows that a change in the copper loadings does affect the crystallization behavior of the sulfide, these differences are, however, fairly subtle and based on just these one would not really expect the Cu loadings in brass to have an impact on the rubber-tire cord adhesion. Time-Of-Flight Secondary Ion Mass Spectroscopy (ToF-SIMS) analyses however show that the change in copper loading leads to significant differences in the thickness and chemical make-up the interfacial sulfide layer. ToF-SIMS analyses of samples aged in different conditions including steam, heat and humidity once also showed that the different conditions affect the adhesion layer differently. While steam aging leads to an almost complete destruction of the interface, heat and humidity aging lead to extensive growth of the sulfide layer.

[1] Presenting author

Paper Number 3.8

Effect of Aging on the Morphology of the Rubber-Brass Interfacial Layer

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Adhesion between rubber compound and brass-plated steel tire cord is a crucial in governing the overall performance of tires. The rubber-brass interfacial adhesion is influenced by the chemical composition and thickness of the interfacial layer, which in turn are influenced by the rubber formulation. Previously, various adhesion promoters such as organic cobalt salts and resins have been used to impede degradation of the rubber-brass bonding layer during aging. It has been shown that the interfacial layer consists mainly of sulfides and oxides of copper and zinc. A strong correlation exists between the nature of the interfacial layer and the rubber-brass adhesion. This paper discusses the effect of changes in the chemical composition and the structure of the interfacial layers due to addition of adhesion promoter resins. Grazing incidence X-Ray Diffraction (GIXRD) experiments were run on sulfidized polished brass coupons previously bonded to six experimental rubber compounds. It was confirmed that heat and humidity conditions lead to physical and chemical changes of the rubber-steel tire cord interfacial layer, closely related to the degree of rubber-brass adhesion. The adhesion promoter resins inhibit the unfavorable morphological changes in the interfacial layer thus stabilizing it during aging and prolonging failure. Tire cord adhesion tests illustrated that the one-component resins improved adhesion after aging using a rubber compound with lower cobalt loading. Based on the acquired diffraction profiles, these resins were also found to impede crystallization of the sulfide layer after aging leading to improved adhesion. Secondary Ion Mass Spectrometry (SIMS) depth profiles and SEM micrographs strongly corroborated the findings from GIXRD. This interfacial analysis adds valuable information to our understanding of the complex nature of the rubber-brass bonding mechanism.

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Paper Number 4.1

Calculation of Dynamic Tire Forces From Aircraft Instrumentation Data

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When evaluating aircraft brake control system performance, it is difficult to overstate the importance of understanding dynamic tire forces – especially those related to tire friction behavior. As important as they are, however, these dynamic tire forces cannot be easily or reliably measured. To fill this need, an analytical approach has been developed to determine instantaneous tire forces during aircraft landing, braking and taxi operations.

The approach involves using aircraft instrumentation data to determine forces (other than tire forces), moments, and accelerations acting on the aircraft. Inserting these values into the aircraft's six degree-of-freedom equations-of-motion allows solution for the tire forces.

While there are significant challenges associated with this approach, results to date have exceeded expectations in terms of fidelity, consistency, and data scatter. The results show excellent correlation to tests conducted in a tire test laboratory. And, while the results generally follow accepted tire friction theories, there are noteworthy differences.

Paper Number 4.2

UNIFORMITY: A Crucial Attribute Of Tire / Wheel Assemblies

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Good ride, acceptable comfort for passengers, is a required attribute for all road vehicles particularly automobiles and light trucks. The tire / wheel assembly is a critical component in providing good ride. Indeed, obtaining good ride was the crucial factor that drove the invention of and rapid popularization of the pneumatic tire. Today, the ride effect of tires is often thought of in two ways. The first is in terms of the transmission of vibration produced by the interaction of the tire with road surface irregularities, harshness. The second is in terms of tire structural irregularity generated energy transmitted during operation on a smooth road, uniformity. Both types of energy share the dynamic properties of the tire structure though they differ in source. This paper concentrates primarily on uniformity induced vibration particularly at the frequency of tire rotation, but does touch on harshness to a small degree, when the sharing of structural dynamics makes it appropriate. This review of the subject of force uniformity includes the effect of wheels, as wheels contribute to the vibration that reaches the vehicle spindle. Balance is touched on only as it affects force uniformity in well-balanced assemblies. This is not a treatise on balancing. A suggestion is made, which should, if practical, improve the installed uniformity of tire/wheel assemblies.

Paper Number 5.1

Optimization of Reinforcement Turn-up Effect on Tire Durability and Performance for Racing Tire Design using Finite Element Analysis

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The damage occurring in the bead region has been pointed out as one of the causes of critical failure during tire service. This study investigates the influence of the body ply turn-up and bead reinforcement turn-up around the bead region on tire durability and performance using finite element analysis (FEA). A slick motorsport tire with two body plies is modeled in ABAQUS based on the material properties obtained from tests and the profile provided by the tire manufacturer. Various reinforcement turn-up factors including the height of turn-up, the material property, the cross-section area, the spacing and angles of the reinforcement cords are characterized by numerical experiments using design of experiment method. The effects of these parameters identified by mean response of strain energy density of element in the critical region, carcass stress, lateral stiffness and cornering stiffness are determined from the FEA model. The optimized reinforcement turn-up heights are used to validate the tire design. Furthermore, the overdesign in the tire bead region is observed from the prediction of FEA model. Meanwhile, in order to satisfy the requirement of lower tire spring rate for Formula Student racing, an improved tire based on the original design but with single body ply is presented. In tests by the tire manufacturer and a FS racing team the new tire has been shown to have improved performance as predicted by FE analysis carried out on it. It is concluded that the prediction technology using FEA can be utilized to optimize the tire reinforcement turn-up effect in future tire design.

[1] Presenting author

Paper Number 5.2

Prediction of Cord-Rubber Composite and Tire Response Using Nonlinear Continuum Damage Mechanics Approach

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The phenomenon of damage observed in cord-rubber composite regions of the tire is the result of deformation, heat, chemical degradation and fracture. Initial microcracks and voids grow through the mechanism of coalescence and generate permanent macroscopic cracks.

A damage approach is proposed to describe the cumulative effects and damage evolution under cyclic loading, thermal and chemical impact. The approach parallels the Continuum Damage Mechanics (CDM) approach advocated by Kachanov and Rabotnov. It is a phenomenological model which depends on laboratory testing to describe the evolution of the damage indicator and contains one scalar damage parameter to describe the collective effect of material degradation.

The following analysis is based on the premise that the cyclic interlaminar shear strain coupled with the running temperature at the free edge are the primary cause of damage. The model constants were derived from an S-N curve at room temperature. The temperature effect on the material degradation was accounted for by an Arrhenius shift function of the S-N curve. Numerical simulations of a composite laminate and several tire models were conducted using the user subroutine UMAT in ABAQUS. The results derived from the proposed methodology to predict the location of the ensuing damage and the path of the damage propagation are only valid under well-controlled laboratory conditions.

[1] Presenting author

Paper Number 5.3

Carbon Fiber - Polyurethane Self-Supporting Airless Tire

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Military tire-wheel (MTW) assembly for future tactical and combat vehicles is placing emphasis on handling, traction, and cornering tire performance for the light trucks. In order to meet these high performance standards, solid tires with an aspect ratio lower than 0.35 have been developed by American Engineering Group (AEG), Akron, Ohio

- Tire Size: LT225/35R19
- Rim Width: 7.0 inches
- Tread Width: 7.6inches
- Overall Diameter: 25.0 inches
- Speed rating:40mph

AEG aims to eliminate tire blowouts with its remarkable integrated Carbon Fiber Ring-Wheel "MTW" assembly, a solid one-piece wheel-and-tread system that could soon enter manufacturing. The MTW's rim is bonded to soft polyurethane foam that provides the shock-absorbing property of a traditional pneumatic tire. The circumference of the soft polyurethane foam layer is bonded to a Carbon Fiber ring along with tire tread. By varying the thickness and geometry of the polyurethane soft layer, this unique tire-wheel assembly can generate a wide array of ride and handling performance.

The MTW's vertical stiffness (ride comfort performance) and lateral stiffness (handling and cornering performance) can both be optimized, pushing the performance envelope in various military applications. The purpose of this paper is to illustrate the effectiveness of integrated footprint analysis using FEA in the designs of "pneumatic tires", "high aspect ratio airless tires", and "solid foam tires". This research work is development of a military airless tire using carbon fiber and Polyurethane. This paper provides an integral step by step approach to model the footprint analysis using ABAQUS standard software. The computer simulation developed in this paper is divided into three tire designs according to the type of tire applications.

[1] Presenting author

Paper Number 5.4

Modeling Material Storage Modulus for Tire Natural Frequency Prediction

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This research deals with the material storage modulus aspects of tire natural frequency predictions in the low to mid frequency range (0 to ~200 Hz) using finite element analysis (FEA). Obtaining accurate predictions is important for ride, handling, durability, and NVH design. FEA models are often used either directly or indirectly to generate associated specialized models for simulations of events within each of the aforementioned areas of performance. Known nonlinearities of the storage modulus associated with strain state make it difficult to obtain accurate representations of the tire stiffness for both steady state loading and natural frequency predictions. The proposed method introduces separate linear elastic representations of the storage modulus in implicit solutions to account for these nonlinearities. The method is shown to be sufficient for accurate prediction of natural frequencies for static and steady state rolling loading events. It provides the benefit of reduced testing associated with material characterization and reduced simulation times making it a valuable design tool. Material characterization tests are performed at appropriate strain states for non-rolling, steady state rolling, vibratory, and combined rolling and vibratory conditions (bi-modal). The predicted natural frequencies are validated with measurements using modal tests. Non-rolling tire modal tests are performed using SAE J2710 recommended procedure in which the tire is attached to a fixed spindle. Rolling tire modal tests are performed using a pseudo free-spindle boundary condition.

[1] Presenting author

Paper Number 6.1

Inflation Pressures at Less-Than-Maximum Tire Loads

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One of the most important parameters to be established for tire operation, whether on a new vehicle being designed by a vehicle manufacturer or on a plus-size fitment, is the recommended cold inflation pressure for the tire. The tire carries a maximum inflation pressure label, but operation at lower loads and pressures is generally beneficial for overall vehicle performance. Recommended inflation pressures have historically been provided by tire standards organizations in the form of tables of load versus pressure or in the form of simple mathematical models. This paper reviews these models, and develops a new formulation based on a tire stiffness model. It is shown that the stiffness model predicts higher inflation pressure requirements at lower-than-maximum loading conditions than some of the models in use in the industry.

Paper Number 6.2

Mathematical Model of the Effective Properties of a Fiber Reinforced Composite with a Linearly Graded Transition Zone

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Tires are fabricated using single ply fiber reinforced composite materials, which consist of a set of aligned stiff fibers of steel material embedded in a softer matrix of rubber material. The main goal is to develop a mathematical model to determine the local stress and strain fields for this transversely isotropic fiber and matrix separated by a thin linearly graded transition zone. This model will then yield expressions for the internal stress and strain fields surrounding a single fiber. The fields will be obtained when radial, axial and shear loads are applied. The composite is then homogenized to determine its effective mechanical properties – elastic moduli, Poisson ratios and shear moduli. The model allows for analysis of how composites interact in order to design composites which gain full advantage of their properties.

Paper Number 7.1

ASTM Committee F09.30 Task Group Update on Commercial Truck/Bus Tire Test Practice Development

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ASTM Truck/Bus Tire Test Development Task Group of ASTM Committee F09 on tires has investigated and completed the following:

1) An algorithm to determine "highway equivalency" for laboratory roadwheel testing to replicate road operating temperatures,

2) A standardized laboratory endurance test method, and

3) A standardized laboratory high speed test method.

These developed practices are based upon fourteen representative tires from long-haul, bus, mixed service, regional, and urban commercial truck applications.

The results of the laboratory and field experiments allowed for adequate understanding of the severity that tires are subject to on a 1.7m roadwheel in the laboratory, where on average center rib temperatures were 44% higher than on the road. These experimental observations resulted in mathematical algorithms that allowed the creation of test conditions that can be used to evaluate tire performance on a roadwheel that minimize atypical test removal conditions.

[1] ASTM F09.30 task group member assigned to present results to The Tire Society

Paper Number 7.2

Erroneous or Arrhenius - Potential Impact of Oven Temperature Variations on Laboratory Aging of Tires

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During the ASTM F09.30 Tire Aging Task Group's development of a test standard for the accelerated oven aging of tires, seemingly erroneous results were obtained from a single test method being conducted by multiple facilities. Ultimately these differences were associated with variations in oven temperature among the sites involved. The Arrhenius Law provides a means of understanding the potential impact of oven temperature variation on thermal oxidative aging of tires and is used to draw inferences with respect to both laboratory oven aging and in-service tire use. Limitations of applying the Arrhenius equation, possible actions to compensate for oven-to-oven and within-an-oven temperature variation, and suggestions for potential validating experiments are also discussed.

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Paper Number 7.3

Correlated Dual Sheet-of-Light Measurement of Preparation Material

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In tire production preparation materials of various widths are required. These materials are produced at the manufacturer's plant from a drum of material with a standard width by cutting sheets of the required width, and splicing them together after rotating the sheets by 90 degrees. The resulting material is an endless drum of preparation material with the proper width required for a specific tire type.

The properties of this splice are critical for the subsequent tire production process. Automatic measurement and evaluation of the splice across the entire material width is desirable along with automatic detection of a variety of standard defects, like e.g. dog ears. This information can be used to ensure consistent quality of the preparation material while at the same time lowering production cost, partly because operator intervention is only required for critical faults.

In this paper an approach is described consisting of a dual correlated sheet-of-light measurement setup, using a standard PC for automatic evaluation. Two calibrated sheet-of-light cameras are used to measure the material simultaneously from the top and bottom on the machine producing the spliced material before the material is wound on a drum. The result of the image processing operations is a continuous surface data stream of top and bottom surfaces, allowing the measurement of the material thickness as well as precise measurement of the splice. The data is also suitable for detection of other material flaws not related to the splice.

We will also present information about the use of this setup at a major tire manufacturer's plant over an extended period of time, including measurement data, accuracies and experiences with this new approach to measurement of preparation materials for tire production.

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Paper Number 8.1

Investigation of the Microscopic Viscoelastic Property for Cross-linked Polymer Network by Molecular Dynamics Simulation

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The purpose of this work is to develop a new analytical method for simulating the microscopic mechanical property of the cross-linked polymer system using the coarse-grained molecular dynamics simulation. This new analytical method will be utilized for the molecular designing of the tire rubber compound to improve the tire performances such as rolling resistance (RR) and wet traction.

For the first, we evaluate the microscopic dynamic viscoelastic properties of the cross-linked polymer using coarse-grained molecular dynamics simulation. This simulation has been conducted by the COGNAC simulator in the OCTA (http://octa.jp/). To simplify the problem, we employ the bead-spring model, in which a sequence of beads connected by springs denotes a polymer chain. The linear polymer chains that are cross-linked by the cross-linking agents express the three-dimensional cross-linked polymer network. In order to obtain the microscopic dynamic viscoelastic properties, oscillatory deformation is applied to the simulation cell. By applying the time-temperature reduction law to this simulation result, we can evaluate the dynamic viscoelastic properties in the wide deformational frequency range including the rubbery state.

Then, the stress is separated into the nonbonding stress and the bonding stress, we confirm the contribution of the nonbonding stress is larger at lower temperature. On the other hand, the contribution of the bonding stress is larger at higher temperature.

Finally, analyzing a change of microscopic structure in dynamic oscillatory deformation, we find out that the temperature/frequency dependence of bond stress response to a dynamic oscillatory deformation depends on the temperature dependence of the average bond length in the equilibrium structure and the temperature/frequency dependence of a bond orientation. We show our simulation is a useful tool for studying the microscopic properties of a cross-linked polymer.

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Paper Number 8.2

Network Evolution During Intensive Service in Large OTR Tire Compounds – Evidence for "Double Network" Formation.

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Large off-the-road tires (OTR) experience reversion both during cure and during service. Intensive service exacerbates heat build up, creep and set characteristics, especially in sulfur networks rich in polysulfidic crosslinks. Recent experiments demonstrate network evolution during intensive service. The networks subjected to intensive service show analogous behavior analogous to the "Double network". This suggests that as some bonds break due to thermal-mechanical forces, new bonds form when the rubber is in a strained state during the intensive service.

Antireversion agents (ARA's) work by either slowing the rate of reversion or a mechanism of "crosslink compensation". The slower rate of reversion and compensation for broken crosslinks provide for significantly improved networks. During thermomechanically induced reversion, newly formed bonds generated during intensive or severe service reduces heat build-up, creep and permanent set characteristics. This work explores compounding variations and the study of network evolution especially with ARA's, which provides improved performance in large tires under severe applications. Tires compound as such, have lower running temperatures, less heat build-up, less, creep and less permanent set providing better durability under severe conditions.

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Paper Number 8.3

UTQG TIRE TRACTION RATING COMPARISONS WITH 0°C TAN DELTA AND COEFFICIENT OF FRICTION COMPOUND MEASUREMENTS

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UTQG traction ratings result from instrumented trailer braking tests conducted at 85% rated load and 40 MPH on wet concrete and asphalt surfaces. Tan Delta at 0°C is one predictor used to rank candidate tread compounds. These two tests take a narrow look at either whole tire or individual compound performance. Can traction performance predictions be improved by coefficient of friction measurements over a wider range of surface pressures? To answer that question, seven candidate tires were selected and sampled for Tan Delta and coefficient of friction test specimens. The UTQG ratings for each tire are compared with rankings derived by 0°C Tan Delta measurements in tension and shear as well as coefficient of friction measurements. The peak coefficient of friction is measured at 100, 200, 300, 400, 500, 600, 700 and 800 psi on two dry sandpaper surfaces at 0.11 MPH (2 in/sec). This research shows the coefficient of friction correlates fairly well with 0°C Tan Delta ranking and traction rating. However, the whole tire UTQG traction test includes more design variables than testing the tread compound alone. Additionally, tires for different vehicles have wide variations in design requirements making tire to tire comparisons impractical. By analyzing the coefficient of friction over a range of surface pressures, the compound can be ranked for load conditions and surface textures other than those tested by UTQG or Tan Delta.

[1] Presenting author

Notes Page

Notes Page

The Tire Society, Inc.

28th Annual Meeting and Conference on Tire Science and Technology

September 15-16, 2009
Akron City Centre Hotel
Akron, Ohio

Overview (detailed schedule inside)

Day 1 – Tuesday, September 15

7:30 Registration

8:15 Opening Remarks: *Ed Terrill*, 2009 Tire Society Program Chair

8:20 Welcome: *Robert Wheeler*, President of The Tire Society

8:30 **Keynote Address**
Speaker: *Robert Keegan*
CEO Goodyear Tire & Rubber

9:15 **Session 1**
Wear / Friction / Rolling Resistance - 2 presentations

10:10 **Session 2**
Vehicle Dynamics
2 presentations

11:05 Break (10 minutes)

11:15 **State of the Society**
Robert Wheeler
Tire Society President

11:35 **Luncheon – Tire Society Distinguished Achievement Award Presentation**

1:30 **Session 3a**
Student Papers - 4 presentations

3:15 Break (15 minutes)

3:30 **Session 3b**
Student Papers - 4 presentations

5:15 End of Technical Sessions

5:15 **Reception**
Akron City Centre Hotel

6:00 **Dinner / Awards / Speaker**
Speaker: *Dr. Terry Woychowski,*
Vice-President GM Global Vehicle Program Management

8:00 Adjourn

Day 2 – Wednesday, September 16

7:30 Registration

8:00 Opening/Announcements

8:05 **Session 4**
Vibration and Harshness -
2 presentations

9:00 Break (15 minutes)

9:15 **Session 5**
Modeling - 4 presentations

11:00 Break (10 minutes)

11:10 **Plenary Lecture**
Speaker: *Marvin Janssen*
Retired Tire Engineer

11:50 **Lunch – on your own** (1 hour 15 minutes)

1:05 **Session 6**
Structural Performance
2 presentations

2:00 **Session 7**
Durability / Tire Testing / Tire Building
3 presentations

3:20 Break (15 minutes)

3:35 **Session 8**
Materials / Materials Development
3 presentations

4:45 Closing Remarks

5:05 **End of Conference**