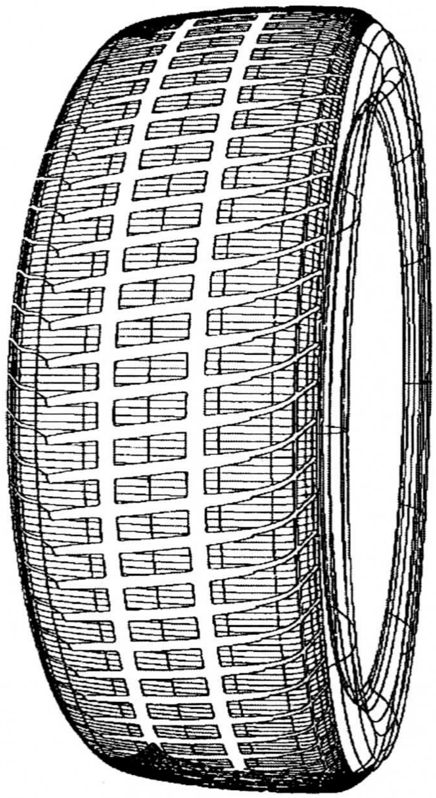
Jim McIntyre
Force Development

Tire Society 2003

22nd Annual Conference on

Tire Science and Technology



23-24 September 2003
Crowne Plaza Hotel at Quaker Square
Akron, Ohio
www.tiresociety.org

Program and Abstracts

The Tire Society thanks Smithers Scientific Services for sponsoring the printing of this booklet.

The Tire Society, Inc.

22nd Annual Meeting and Conference on
Tire Science and Technology
September 23-24, 2003
Crowne Plaza Quaker Square, Akron, Ohio

Overview

Day 1 – Tuesday, September 23

8:00 Registration

9:00 Opening: *Marion Pottinger*, Smithers Scientific Services

9:05 Welcome: *George Haritos*, Dean, College of Engineering, University of Akron

9:10 Keynote Address: *Manfred Wennemer*, Chair Executive Board, Continental AG

9:50 Break (10 minutes)

10:00 Program Opening: *Jon Gerhardt*, University of Akron

10:05 **Session I**

Design

5 presentations

12:15 Lunch

1:30 **Session II**

Material Models

4 presentations

3:15 Break (15 minutes)

3:30 **Session III**

Wear

5 presentations

6:15 Dinner

Speaker: *Professor Gary H. Koopmann*, Pennsylvania State University, "Acoustical Analysis of the Liberty Bell"

Day 2 – Wednesday, September 24

8:00 **Session IV**

Durability

5 presentations

10:10 Break (15 minutes)

2 presentations

11:15 Plenary Lecture

W.Riley Garrott,
Division Chief, Vehicle Stability and Control, Vehicle Research and Test Center, "Vehicle Dynamics – Tires & Safety"

12:00 Business Meeting (12:00 – 12:20)

12:30 Lunch

1:15 **Session V**

Noise

3 presentations

2:30 **Session VI**

Vehicle Dynamics

2 presentations

3:25 Break (15 minutes)

4 presentations

5:30 End of Program

Day 1 – Tuesday, September 23

8:00 **Registration**
9:00 **Opening:** Marion Pottinger, Smithers Scientific Services
9:05 **Welcome:** George Haritos, Dean College of Engineering, University of Akron
9:10 **Keynote Address:** Manfred Wennemer, Chair Executive Board, Continental AG

9:50 **Break** (10 minutes)

10:00 **Program Opening:** Jon Gerhardt, University of Akron
10:05 **Technical Session I: Design** (Chairman: M. Snyman)
10:10 **1.1.** "Customized Tire Design Solution Based on Knowledge Embedded Template Concept," *M. Stojkovic, M. Manic, M. Trajanovic, N. Korunovic*
10:35 **1.2** "On Development of the Safety Device of Commercial Vehicle Tires," *Y. Yamaguchi, T. Kamegawa, K. Kato*
11:00 **1.3** "A Preliminary Investigation of a Simple Apparatus For Measuring and a Simplified Model for Predicting Tire Load/Deflection Behavior at Various Pressures and Inflation Mechanisms," *W. Summers, C. Richards, N. Jarboe*
11:25 **1.4** "Improved Safety Tyre Construction for Mining Vehicles," *A. Smyrnov, V. Verbas, and A. Naumenko*
11:50 **1.5** "Pattern Recognition for Classification and Matching of Car Tires," *D. Colbry, D. Cherba, J. Luchini*

12:15 **Lunch**

1:30 **Technical Session II : Material Models** (Chairman: J. Popio)
1:35 **2.1** "Modeling the Thermomechanical Behaviour of Pneumatic Tires," *H. Yuksel, S. Karadeniz*
2:00 **2.2** "Modeling of The Dynamic Thermomechanical Response of Elastomers," *J. Bergstrom*
2:25 **2.3** "A Simple Method of Handling Thermomechanical Coupling for Temperature Computation in a Rolling Tire," *S. Futumura, A. Goldstein*
2:50 **2.4** "Evaluation of a Psuedo-Elastic Model for the Mullins Effect," *W. Mars*

3:15 **Break** (15 minutes)

3:30 **Technical Session III: Wear** (Chairman: J. Turner)
3:35 **3.1** "Effects of Shape of Tread Rubber Block on Dynamic Characteristics of Tire, Influence of Block Size on Frictional Force," *K. Araki, H. Ohnaka*
4:00 **3.2** "Effects of Shape of Tread Rubber Block on Dynamic Characteristics of Tire, Influence of Sliding Direction on Frictional Force," *C. Terao, K. Araki, H. Ohnaka*
4:25 **3.3** "Material Morphology Effects Underlying Tread Rubber Wear," *J. Padovan*
4:50 **3.4** "Numerical Prediction of Tyre Wear Phenomena and Comparison of the Obtained Results with Full-Scale Experimental Tests," *H. Lupker, F. Cheli, E. Gelosa, A. Keckman*
5:15 **3.5** "Measurement and comparing Simulation of the Movements of Tread Blocks in the Contact Patch," *S. Koehne, A. Rieger*

6:15 **Dinner**
Speaker: Professor Gary H. Koopmann, Penn State University. "Acoustical Analysis of the Liberty Bell"

Day 2 – Wednesday, September 24

8:00 **Technical Session IV: Durability** (Chairman: R. Kennedy)

8:05 **4.1** "Analysis of Tire Aging Protocols Proposed by NHTSA For Inclusion into FMVSS 139," *J. Baldwin*

8:30 **4.2** "Lifetime Prediction of Tires with Regard to Oxidative Aging," *L. Nasdala, Y. Wei, H. Rothert, M. Kaliske*

8:55 **4.3** "Force characteristics of Tire Tread Delamination," *J. Daws*

9:20 **4.4** "High Speed Testing of Tires And The Use of Constant Deflection," *J. Baldwin*

9:45 **4.5** "Fracture of Polyisoprene Vulcanizates," *G. Hamed*

10:10 **Break** (15 minutes)

10:25 **4.6** "The Evaluation of Fracture and Adhesion Properties Rubber-Steel Reinforcement Materials Composite for Tires," *P. Janypka*

10:50 **4.7** "Flat vs Curved Testing Surfaces; Effects on Tire Performance," *T. Ruip, J. Fenkanyn, M. Harvey, R. Hirschfelt, S. Rohweder, D. Swift*

11:15 **Plenary Lecture**
W. Riley Garrott, Division Chief, Vehicle Stability and Control, Vehicle Research and Test Center, "Vehicle Dynamics – Tires & Safety"

12:00 **Business Meeting** (12:00 – 12:20)

12:30 **Lunch**

1:15 **Technical Session V: Noise** (Chairman: T. Rhyne)

1:20 **5.1** "Acoustic Radiation from Tyres using Finite and Infinite Elements: Coupled and Uncoupled Approaches," *J. Migeot, J. Coyette, T. Leclercq, J. Thiébaut, L. Hazard, J. Lemberger*

1:45 **5.2** "Defining Sound Quality Characteristics of Tire Tread Pattern Pitch Sequences," *J. Stuckey*

2:05 **5.3** "Advances in Tire Road Noise Simulation," *J. Cipolla, M. Snyman*

2:30 **Technical Session VI: Vehicle Dynamics** (Chariman: R. Mousseau)

2:35 **6.1** "Simulations of Vehicle Dynamics with Tire/Rigid and Deformable Terrain Interface Using Simulink," *P. Saitana, C. Lin, T. Zhang, J. Lee, D. Goering*

3:00 **6.2** "A New Tire Model for Road Loads Simulation: Theory and Validation" *A. Dhir, M. Berzeri, R. Ranganathan, B. Balendran, P. Jayakumar, P. O'Heron*

3:25 **Break** (10 minutes)

3:50 **6.3** "A Study of the in-plane Force Transmission of Tires," *H. Dorfi*

4:15 **6.4** "Tyre "Out of plane" Parameter Identification from Experimental Tests on a Rolling Tyre," *G. Matrascia, D. Scaltritti, F. Cheli, G. Tomasini*

4:40 **6.5** "A Tire Force/Moment Formula using Meaningful Parameters," *T. Wielenga*

5:05 **6.6** "Analysis of Tire Rolling Contact Response by REF Model," *Y. Wei, L. Nasdala, H. Rothert*

5:30 End of Program

About The Tire Society…

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

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Assistant Chair	Will Mars, Cooper Tire & Rubber Co.
Local Arrangements	Mechelle Miller, Goodyear Tire & Rubber Co.

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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

Customized Tire Design Solution Based on Knowledge Embedded Template Concept

M. Stojkovic, M. Manic, M. Trajanovic, N. Korunovic
Faculty of Mechanical Engineering
University of Nis, Nis, Serbia and Montenegro

In modern environments of product development, a highly topical theme is the incorporation of knowledge and experiences specific to the given developmental environment into the process of development.

This paper presents a concept of inclusion of specific domain knowledge into computer aided tire design process which enables substantial increase of productivity and reducing costs in early phases of the tire development. The proposed solution is based on the Knowledge-Embedded Template concept as a new, but not an empty file of Computer Aided Product Development software. This kind of template has a set of user-defined knowledge, contents of highly specific–tire design domain knowledge, and experiences which are initially embodied in a new CAx file.

The customized solution of tire design process proposed in this paper was tested within passenger and truck tire design processes. Particular attention was paid to testing this knowledge based solution within tread design processes, and the corresponding manufacturing of tread rings and curing molds.

Paper Number 1.2

On Development of the Safety Device of Commercial Vehicle Tires

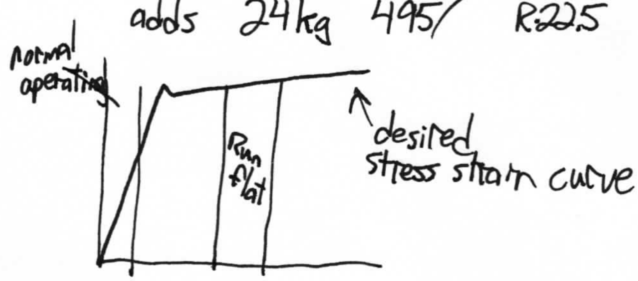
Y. Yamaguchi, T. Kamegawa, K. Kato
Bridgestone Corporation
Japan

The wide-base single tire, used on the truck and bus of modern configuration, enables significant environmental gains: less material used, improved fuel economy, high transportation efficiency with increased cargo/cabin space. However, the replacement of conventional dual tires with the single wide-base could raise the vehicle safety issue if the tire were to experience an accidental and instantaneous air leak due to road hazard. In the worst case, vehicle may suffer an instability behavior at the moment of the air leak, and an inability to move that follows.

In this paper, technical ingredients of the proposed safety device (AIRCEPT) are discussed. The core components of the technology are: the reinforced toroidal tube is installed between tire and wheel to maintain proper clearance when the tire is operated normally and to recover sudden drop of load carrying capacity when outer chamber is totally depressurized, non-woven fabric reinforcement with proper stress-strain relation is used for quick and uniform expansion of the supporting system in the event of a massive air leak, stiffness optimization is pursued to meet the requirements of various operating conditions. Aging and creep effect was also considered. As a consequence of vehicle tests under critical conditions, the proposed system showed outstanding performance.

How Does driver know deployed?
bladder puncture resistance
adds 24kg 495/ R22.5

wide base tires
lower RR
less wt
wider cabin space
problem is what happens if blown out
requirements for safety device
veh should be able to stop
RL change minimized
use std rim
Minimize effect on infl behavior



Alternatives
Self supporting) unusable
Support ring
Double bladder
fixed dell type
expanding type minimizes RL change
Reinforce using rubber coated non-woven fabric
insert must not creep to fill cavity

Paper Number 1.3

A simple model for predicting the Pneumatic stiffness of conventional and multi cell inflation systems

A Preliminary Investigation of a Simple Apparatus for Measuring and a Simplified Model for Predicting Tire Load/Deflection Behavior at Various Pressures and Inflation Mechanisms

Wade. Summers, N. Jarboe
TBDC, LLC

C. Richards
University of Louisville

A simplified two-dimensional model for predicting tire/load deflection behavior of both traditional and non-traditional tire inflation methods is described. The model predictions are compared to load deflection data generated on a simple apparatus made from an inexpensive hydraulic press.

The data presented are primarily for off-road motorcycle tires inflated by an inner tube and by multiple air cells (tire balls). However a brief comparison of load/deflection performance of current EMT automobile run-flat technology and motorcycle tire mousse (foam) inserts is included as well.

The traditional linear load/deflection performance of inner tube (or tube-less) inflation mechanisms is dramatically altered by non-traditional inflation mechanisms and tire construction.

The tunability provided by the novel tire ball inflation approach and its non-linear load/deflection response may allow vehicle designers to match vehicle suspension performance to the tire suspension characteristics and vice versa.

The simplified two-dimensional model provides quick and reasonably reliable results to allow a preliminary performance enhancement assessment for a variety of tire, wheel, and inflation methods.

pneumatic only, not carcass stiffness 10-18 psi
front motorcycle race tire
attempt to verify system for flat proof tire
balls, tire balls, descrete cells - instead of tube
traction a function of contact patch - more deflection increases traction
decreases suspension deflection safety
model assumption inextensible torus / contact patch an ellipse
want high initial deflection, but high stiffness thereafter to prevent pinch
lubricated to reduce heat, runs somewhat hotter - not good for sustained high speeds
50 balls in a motorcycle tire
use modified vicegrip to compress bead into well for mounting

Paper Number 1.4

Improved Safety Tyre Construction for Mining Vehicles

A.G. Smyrnov, V.V. Verbas, and A.P. Naumenko

Dneproshina Joint Stock Company,
City of Dnepropetrovsk, 49600, Ukraine.

In this paper, a special pneumatic tyre construction with increased resistance to mechanical damages is developed on the basis of analyses of tendencies to widening of mining vehicles service field. Regarding mining tyres of special construction, boundary conditions of layer-to-layer orientation of their rubber-cord elements are determined. These conditions are based on the results of original calculation model data processing and wide range of laboratory and bench tests. Scale modeling allowed for specific construction-technological methods of improved safety tyre manufacturing. Service tests of pilot lots of improved safety mining tyres, manufactured without depending on production conditions and road covering condition, confirm their improved safety.

Paper Number 1.5

Pattern Recognition for Classification and Matching of Car Tires

D. Colbry, D. Cherba
Michigan State University

J. Luchini
Cooper Tire & Rubber Co.

Commercial databases containing images of tire tread patterns are currently used by product designers, forensic specialists and product application personnel to identify whether a given tread pattern matches an existing tire. Currently, this pattern matching process is almost entirely manual, requiring visual searches of extensive libraries of tire tread patterns. Our work explores a first step toward automating this pattern matching process by building on feature analysis techniques from computer vision and image processing to develop a new method for extracting and classifying features from tire tread patterns and automatically locating candidate matches from a database of existing tread pattern images.

Our method begins with a selection of tire tread images obtained from multiple sources (including manufacturers' literature, website images, and Tire Guides, Inc.), which are preprocessed and normalized using Two Dimensional Fast Fourier Transforms (2D-FFT). The results of this preprocessing are feature-rich images that are further analyzed using feature extraction algorithms drawn from research in computer vision. A new, feature extraction, algorithm is developed based on the geometry of the 2D-FFT images of the tire.

The resulting FFT-based analysis allows independent classification of the tire images along two dimensions, specifically by separating "rib" and "lug" features of the tread pattern. Dimensionality of (0,0) indicates a smooth treaded tire with no pattern; dimensionality of (1,0) and (0,1) are purely rib and lug tires; and dimensionality of (1,1) is an all-season pattern. Using these initial classifications, the images are then further examined to define additional sub-classes such as "3-rib," "4-rib," or "5-rib" patterns. This analysis technique allows a candidate tire to be classified according to the features of its tread pattern, and other tires with similar features and tread pattern classifications can be automatically retrieved from the database.

pitch sequence
multiple shots per tire
worn tire changes
scale
perspective correction
resolution/pixellation
sizes of same tire

Paper Number 2.1

Modeling the Thermomechanical Behaviour of Pneumatic Tires

H. Tuncay Yuksel,
Standard Profil A.S., Duzce, Turkey

Sami Karadeniz
Karadeniz Technical University, Trabzon, Turkey

The durability of a pneumatic tire depends largely upon its operating temperature. The need for computational models for thermal analysis of tires has been realized some time ago. These have been found to be of great importance in the initial design stages of the screening analysis. Such models can also be used in the prediction of the thermomechanical behaviour of tires with the objective of forming a broad understanding of the interactions of the material and structural phenomena involved. Determination of the thermomechanical behaviour of a pneumatic tire is highly complex and involves formidable challenges due to complexities of the tire structure and the solution requirements of a dynamic non-linear coupled thermo-viscoelastic problem with heat sources resulting from internal dissipation and friction.

The first part of this paper summarizes the status and recent developments of computational models for the prediction of the thermomechanical behavior of the pneumatic tires. Survey covers different tire models including some novel approaches and the simplifying assumptions on geometry, material behavior, boundary conditions, loading, thermal effects, and other environmental effects.
In part two, a sequential computational model, based upon three analysis modules, is presented. The three modules are: deformation, dissipation and thermal. The major advantage of this approach is that it permits one to continually update and improve the model by substituting new modules or data bases without having to modify other parts of the model.

For the deformation module, a full-scale finite element model of a tire is established using rebar elements for the cord reinforced part and the Mooney-Rivlin material model for rubber. With the follower pressure force, firstly inflation (including centrifugal forces), and then contact analyses between tire and pavement were carried out. Using calculated stresses and strains from the deformation module as inputs, an analytic approach for the calculation of the heat source resulting from the internal dissipation in the rolling tire is established via viscoelastic theory. The steady state temperature distribution is obtained via the heat generation rate obtained from the dissipation module. Finally, in the deformation module thermal stresses are for given temperature distribution.
In part three, the solution is presented by implementing the outlined thermomechanical approach. In the analyses MSC MARC Finite Element Program is used. In the last section, the results are discussed and compared with existing data in literature.

Paper Number 2.2

Modeling of the Dynamic Thermomechanical Response of Elastomers

J. Bergstrom
Exponent Inc., 21 Strathmore Road, Natick MA 01760

This presentation outlines advanced technologies for modeling and predicting the dynamic behavior of elastomers. Elastomers have been used extensively in many commercial products, including tires, for many years. The mechanical behavior of elastomers is characterized by rate- and temperature-dependence, and the stress-strain response is known to be strongly non-linear. These experimental features are well-recognized and important, and have been extensively studied for more than 50 years. The understanding of the micro mechanisms controlling the macroscopic mechanical behavior is much more recent, and advanced modeling tools allowing for accurate predictions of arbitrary deformation histories have only started to become available during the last few years. This presentation outlines the current state of the art in finite element modeling of elastomer, and exemplifies the predictive capabilities of modern constitutive theories using the micro mechanism-inspired Bergstrom-Boyce model (*Mechanics of Materials*, Vol. 33, pp. 523–530, 2001) that has been shown to accurately predict the behavior of both filled and unfilled elastomers.

Paper Number 2.3

A Simple Method of Handling Thermomechanical Coupling for Temperature Computation in a Rolling Tire

S. Futamura and A. Goldstein
Goodyear Tire & Rubber Co., Akron, Ohio

The thermomechanical analysis of a pneumatic tire is a highly complex process due to the effects of temperature on both the mechanical state and the viscoelastic energy dissipation in the tire. This coupled thermomechanical behavior typically requires that rolling tire temperatures be determined iteratively. As a result, a steady-state analysis involves updating the temperature dependent elastic and viscoelastic properties as the solution proceeds. The process is further complicated in a transient analysis where material properties need to be updated at multiple intervals in time.

A simplified method is proposed. First, the sensitivity of the tire elastic response to changes in material stiffness is characterized using the "deformation index". Then, using a commercial finite element program and an appropriate user subroutine, heat generation is expressed as a function of the local temperature using a simple algebraic expression involving the temperature dependent material properties and the deformation indices. Temperatures are computed using the finite element program with the coupling information contained in the user subroutine. The result is a simplified method for a fully coupled thermomechanical analysis of a tire for steady-state and transient thermal analysis. The accuracy and the simplicity of the method are demonstrated using a small "tire-like" model. The simplified method is compared to the fully coupled iterative method for a steady-state thermal solution.

Paper Number 2.4

Evaluation of a Pseudo-Elastic Model for the Mullins Effect

W. V. Mars
Cooper Tire & Rubber Company
Findlay, Ohio 45840 USA

The stress-strain response in filled rubbers typically depends strongly on the maximum loading previously encountered. The phenomenon, known as the Mullins effect, can be idealized for many purposes as an instantaneous and irreversible softening of the stress-strain curve that occurs whenever the load increases beyond its prior all-time maximum value. At times when the load is less than a prior maximum, nonlinear elastic behavior prevails. Ogden and Roxburgh proposed an empirical model capable of describing this phenomenon, based on a pseudo-elastic concept. Their model, with minor adaptations, has recently been implemented in a commercial finite element program. This paper demonstrates the effectiveness of the implemented model for several benchmark cases including uniform hydrostatic loading, simple tension, pure shear, and equibiaxial tension. The paper also compares model predictions with experimental results for a series of experiments conducted with various combinations of axial tension/compression and torsion loading.

Paper Number 3.1

Effects of Shape of Tread Rubber Block on Dynamic Characteristics of Tire: Influence of Block Size on Frictional Force

Kazuo Araki and Hidefumi Ohnaka
Osaka Sangyo University, Daito, Osaka 574-8530, Japan

Various types of tread pattern are designed to get a friction characteristic on a tire, and recently the appearances have become important. In this way, various types of block pattern are engraved depending on the usage of tire. However, the relationship between the block shape and the friction/deformation characteristics has not been so cleared.

Therefore, in this study, various sizes of rubber block test pieces were slid in a certain direction, and the friction characteristic and deformation condition were examined by a difference of block size.

As a result, it is understood that there is a special relation between the magnitude of frictional force and the block size. Generally, when the contact pressure is the same, magnitude of a frictional force is in proportion to a contact area in a normal material body. However, the lateral force generates the deformation of rubber block.

On this account, if a block size becomes small, the deformation becomes larger, as a result, the contact pressure rises partially, and a frictional force falls down.

On the other hand, if the size becomes bigger, deformation becomes small, and a frictional force becomes bigger.

Therefore, as far as a dynamic standpoint is concerned, a large size of block is desirable.

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move speed 3mm/sec
200 kPa load
cut from tire
10x10x8
15x15x8
20x20x8
25x25x8
30x30x8 mm

load
slide 2directions
Triax loadcell

Paper Number 3.2

Effects of Shape of Tread Rubber Block on Dynamic Characteristics of Tire: Influence of Sliding Direction on Frictional Force

Chiharu Terao
Graduate student of *Osaka Sangyo University*, Daito, Osaka 574-8530, Japan.

Kazuo Araki and Hidefumi Ohnaka
Osaka Sangyo University, Daito, Osaka 574-8530, Japan.

Various types of tread pattern are designed depending on the usage of tire. However, the relationship between rubber block and friction/deformation characteristics has not been enough solved.

It is important to comprehend dynamic characteristics of tread rubber block to understand characteristics of whole tire. The authors paid attention to the rubber block and examined the relationship between sliding direction and frictional/deformation characteristics.

In this paper, we describe the details of the relationship between sliding direction and the direction of frictional force when the square rubber block is slid in various directions.

The frictional characteristics of a rubber block have certain specific tendencies. When the rubber block is completely sliding, the direction of frictional force corresponds to the sliding direction. In the adhesive region, the difference occurs in the direction of frictional force according to the sliding direction. This difference appears at the sliding direction except 0 degrees and 45 degrees, and the farther away from 0 degree or 45 degrees the sliding direction is, the larger the difference becomes.

Therefore, when the tread pattern is designed, it is one of the important factors to consider the arrangement of rubber blocks.

Paper Number 3.3

Material Morphology Effects Underlying Tread Rubber Wear

Joe Padovan
University of Akron, Akron, Ohio

Prototypically tire tread wear particles are predominately of the intrinsic type, i.e., with characteristic sizes ranging O(1-20um). The dimensional traits of such debris raises the basic question of what regulates their length scale. Recent comprehensive Continuum Mechanics-FEA models have worked out how asperity bumping induces particle pullout. While such models explore the formation process, as noted, the scale level and initiation mechanisms remain unidentified. Given that asperities themselves span a multitude of length scales above and below that of intrinsic particles, no answer appears to be available from this mode of investigation. In this context, the results of an extensive experimental – numerical simulation (FEA) study will be overviewed in the presentation. The main thrust will be to illustrate how processing induced local material morphology controls such problem features. Specifically it will be shown that processing induces a grainy like microstructure whose interfaces define intrinsic particle size. Since the interfaces have weaker strength characteristics than the grain interior, whenever they cross the surface, then natural cleavage zones are induced. As will be shown, these form the precursor cracks/flaws that act to initiate and control the crack growth process inherent to particle formation. This follows from the fact that the grain interiors are made up of highly entangled gelations whereas the interfaces are linked by diffusion processes generally of low molecular weight species. In addition to the formation characteristics, attention is also given to how various forms of processing and mixing - Banbury, mill- influence wear properties by adjusting micro-structural morphology.

Paper Number 3.4

Numerical Prediction of Tyre Wear Phenomena and Comparison of the Obtained Results with Full-Scale Experimental Tests

Franz Braghin
H. Lupker, *TNO Automotive*
F. Cheli, *Politecnico di Milano*
E. Gelosa, *Pirelli Tyres S.p.a.*
A. Keckman, *Nokian Tyres P.I.C.*

Both tyre wear and road polishing are complex phenomenon, which are obviously strongly related; the energy that polishes the road is the energy that wears the tyre. They both depend non-linearly on numerous parameters which include materials used, vehicle and road usage, environmental conditions (e.g., temperature), and many others. There is therefore much to gain from an integrated approach to studying the mechanisms behind both wears phenomena.

Due to their many economic and ecological implications, including those concerning the road users safety, the possibility to predict them is of major importance to tyre manufacturers, fleet owners, road authorities, and governments.

Based on these observations, in 2000 we started the three-year 5th framework EU project TROWS (Tyre and Road Wear and Slip assessment). The results include tools to analyze tyre wear and road polishing. These will be combined in a suitable wear prediction environment. This paper focuses on the followed methods and results of TROWS for tyre wear prediction.

One of the TROWS objectives is to provide a tool able to quantitatively predict tyre global wear as well as the wear distribution. The proposed methodology combines a mathematical model of the tyre with an experimentally determined local wear law: once the frictional power distribution inside the contact footprint is determined with the tyre model, the wear law is applied to convert this frictional power distribution into a tyre tread wear distribution. Thus, the tyre abrasion due to each single maneuver can be determined. Assuming that the wear process is linear (at least in a short time interval), it is possible to determine the wear distribution over the width of the tyre by summing the weighted (based on vehicle usage profiles), tread wear distributions obtained for the different single maneuvers.

Full-scale experimental tests were carried out with two cars (Peugeot 406) on a public road course in Italy. The wear profile of each of the tyres mounted on the test vehicle was determined. The tests were carried out twice using two different types of car tyres (Nokian Hakkapeliitta and Pirelli P6000 tyres). The collected data were used to validate the model. The methodology proved to give good tyre wear predictions, both qualitatively as well as quantitatively.

$m = k_1 w^{k_2}$

wear amount (mass) — wear energy

Paper Number 3.5

Measurement and Simulation of the Slip of Tread Blocks in the Contact Patch, Part I

S. Koehne, A. Rieger
Continental AG

For the tread pattern design irregular wear of a tire is an essential development criterion. From a physical point of view irregular wear results from frictional energy exerted onto the individual tread blocks. The local tangential stresses and movements are needed for the calculation of the local frictional energy.

The measurement of slip is carried out optically using a line scan camera. The line scan camera enables measurements at real speeds (40 kmph) due to their very high scan frequency. The picture acquirement is done through a glass window within a rotating drum of a test stand. With repeating roll over the complete tire can be measured.

The results of the new measurement method for the measurement of local slip at the tread block edges will be compared with FEM Simulation of the slip of single tread blocks passing through the contact patch.

To reduce computing effort a global-local approach is used. In a first step the pathway of the base of a single block is calculated using a full smooth tire model. This pathway is used in a second step to simulate local block behavior by prescribing the base movement as kinematic boundary conditions. Finally stresses and slip are combined to frictional energy to be visualized in colored distribution onto the block surface as indication for local wear behavior.

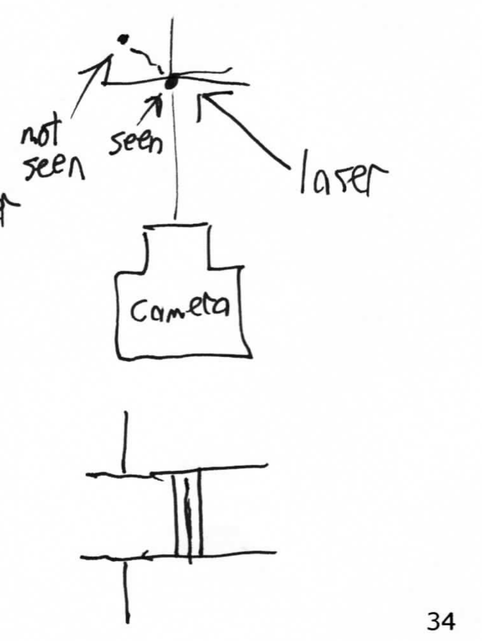
motion by line scan laser

Correlated to what

glass Friction Material ≙ 1.0

Measures edge movements only

calculated movement in center



Paper Number 4.1

Analysis of Tire Aging Protocols Proposed By NHTSA For Inclusion into FMVSS 139

J. M. Baldwin
Ford Motor Company
Dearborn, MI 48124 USA

The National Highway Traffic Safety Administration (NHTSA) has proposed three aging tests in the Notice for Proposed Rule Making (NPRM) for Federal Motor Vehicle Safety Standard (FMVSS) 139. The goal of NHTSA is to include one of the tests (or something similar) in new tire regulations. The purpose of this paper is to examine the effects of each aging protocol on the chemical and physical properties of the rubber surrounding the steel belt package. After running the aging tests on the selected tires, they were then dissected and analyzed for tensile and elongation properties of the rubber at the belt edges. Crosslink density measurements were made across the belt skim rubber, along with the peel adhesion force required to separate the two steel belts. Both passenger and light truck tires were used in the study.

Paper Number 4.2

Lifetime Prediction of Tires With Regard To Oxidative Aging

L. Nasdala, Y. Wei, H. Rothert
Institute for Structural Analysis,
University of Hannover, Germany

M. Kaliske
Institute for Structural Mechanics,
University of Leipzig, Germany

It is a challenging task in the design of automobile tires to predict lifetime and performance on the basis of numerical simulations. Several factors have to be taken into account to correctly estimate the aging behavior. Apart from mechanical and thermal aspects, in this paper, especially the influence of oxygen on tire durability is discussed.

Accelerated aging experiments are presented to demonstrate the change in mechanical properties (tensile and dynamic stiffness, elongation at break, damping behavior etc.) due to oxidation. Modulus profiling tests, or at least experiments with specimens of different thicknesses, have to be performed to be able to evaluate the so-called DLO-effect (diffusion limited oxidation). Then, the time-temperature-superposition-principle can be applied in order to determine oxygen diffusion and reaction parameters. Furthermore, homogenization techniques are needed to obtain effective material parameters (diffusivities and reaction constants) for cord-reinforced rubbers.

On the basis of nonlinear finite element analysis, criteria are developed to predict lifetime with respect to the tire design, which influences the temperature distribution and the oxygen penetration depth.

Paper Number 4.3

Force Characteristics of Tire Tread Delamination

J. W. Daws
Sr. Managing Engineer
Exponent Failure Analysis Associates

Belt-leaving-belt tread separations in radial tires have been pointed out as a cause of vehicle accidents. This paper presents the results of measurements on the level of forces generated during a tread delamination. This study showed that tires that had been cut to generate a belt-leaving-belt separation always generated a leading edge flap, and that the interaction of this flap with the vehicle body is responsible for the force generation. The research also showed that the total impulse generated by a belt-leaving-belt separation represents a small fraction of the total vehicle momentum at highway speed.

FT Flat or round
was test done at nonzero SA
No slip or camber

Paper Number 4.4

High Speed Testing Of Tires and the Use of Constant Deflection

J. M. Baldwin
Ford Motor Company
Dearborn, MI 48124 USA

The purpose of this research was to determine the appropriateness of relating tire performance using a high speed test run at different inflation pressures while adjusting the load at the initial test set-up so as to maintain a constant deflection. A load vs. deflection curve was obtained for five tires with identical DOT codes. The curves were measured from 0 to 907 kg (2000 lbs.) at tire inflation pressures of 96.5 to 234.4 kPa (14 to 34 psi). The slopes of the curves were then used to determine the correct load for each inflation pressure to obtain the desired deflection. The deflection chosen for this test was the result from having the tire loaded to 680 kg (1500 lbs.) at 179.2 kPa (26 psi). The Federal Motor Vehicle Safety Standard 109 high speed test protocol was used, except it was run to failure. The time-to-failure (TTF) and failure modes were analyzed vs. the test conditions.

Paper Number 4.5

Fracture of Polyisoprene Vulcanizates

G. R. Hamed
The University of Akron
Akron, OH 44325-3909

Over the past several years we have studied the fracture of polyisoprene vulcanizates (both synthetic and natural). The presentation will review some of the findings. Emphasis will be on the ways that cracks grow in these materials. Also, the applicability of simple fracture mechanics will be discussed.

Paper Number 4.6

The Evaluation of Fracture and Adhesion Properties Rubber-Steel Reinforcement Materials Composite for Tires

P. Janypka
Rubber Research Institute
Matador, a.s., Púchov
Slovak Republic

The paper is dealing with evaluation of composite rubber-steel reinforcement materials for tyres by ultrasonic stress and the others laboratory test methods. The main aim of work was determination of adhesion bond between steel cords of different constructions 2x0, 30, 2+2x0, 25, 3+9x0, 22+1x0, 15 bead wire with diameter 0, 89 mm and 1, 6 mm and three different rubberised compounds with variant reception, where were the materials cured. Compared were strength of adhesion bond tested by ultrasonic test method, Henley test, Wallace test, and test on the laboratory device in Technical University Poznan. Studied was also the influence of temperature and ultrasonic stress on the change of physical-mechanical properties of reinforcement materials and alone thermal ageing on the change of rubberised compound properties. At the conclusion of the work were also the characteristics of microstructure surface area reinforcement materials and compounds after ultrasonic stress, Henley test, and defect areas straight in tyres after tests on the dynamic test room.

Paper Number 4.7

Flat vs. Curved Testing Surfaces: Effects on Tire Performance

J. Fenkanyn, M. Harvey, R. Hirschfelt, S. Rohweder, T. Ruip, D. Swift,
The Goodyear Tire & Rubber Company

When developing laboratory tire tests to run on curved test surfaces and to replicate "real world" conditions/results, adjustments must be made to avoid unintended effects on the tire due to the curvature of the surface. If adjustments are not made, unrealistic conditions very often result in atypical, heat-induced failures rather than intended structural fatigue. Three test variables that can be adjusted are test speed, test load, and test inflation pressure.

This paper reviews the effects of simply transferring flat surface, real world test conditions directly to the curved-surface, laboratory environment. FEA analysis of increased strain energy absorption due to high test speeds on a curved surface are contrasted with energy absorption due to the same speeds on a flat surface. Adverse effects on footprint shape and footprint pressure distribution due to surface curvature are also examined via pressure sensing instrumentation. Finally, tire inflation effects on curved vs. flat surfaces are reviewed in light of tire deflections and operating temperatures they induce.

For larger diameter tires, test condition adjustment options become limited due to the inherent stiffness of the structure and the ratio of tire to test surface diameter. Some viable options are examined for these situations.

Paper Number 5.1

Acoustic Radiation from Tyres Using Finite And Infinite Elements: Coupled and Uncoupled Approaches

J. Migeot, J. Coyette, T. Leclercq, J. Thiébaut, L. Hazard, J. Lemberger
Free Field Technologies
16 place de l'Université, 1348 Louvain-la-Neuve, Belgium

Two methods for calculating the sound radiated by the vibrations of a tyre will be presented. In the first method the dynamic behavior of the tyre is calculated using an analytical model and then imposed as boundary condition on an acoustic model based on a combination of finite elements for the near field and conjugated infinite elements for the far field. In the second model, the complex, composite structure of the tyre is replaced by an equivalent shell structure and a fully coupled simulation of (1) the structural dynamics (2) the acoustic field inside the tyre cavity and (3) the radiated acoustic field is created. The first method is also adequate for evaluating purely acoustic effects like the well-known horn effect or the influence of the road surface impedance on the sound radiated by various sources.

Paper Number 5.2

Defining Sound Quality Characteristics of Tire Tread Pattern Pitch Sequences

Jon I. Stuckey
Bridgestone/Firestone North American Tire, LLC

Applying a sequence of varying design cycle lengths about the circumference of the tire has been a staple of the tire design community to optimize the acoustic performance of the tire tread pattern. Many patented technologies currently exist to define the distribution of the design cycles, the lengths of the cycles, or the order of the cycles in an effort to minimize and/or reduce the sound pressure level.

In this paper, the aspects of the acoustic sound quality associated with the tire tread pattern design cycle or pitch sequence will be discussed. Inherently, every tire tread pitch sequence produces a repeating signal as the tire rotates against a surface. Fourier transform techniques are generally utilized to define the sound pressure level characteristics. These techniques lack the adequate ability to define the sound quality characteristics. A new technique will be discussed in this paper to define the sound quality metric of modulation in the context of tire tread pitch sequence design.

Paper Number 5.3

Advances in Tire Road Noise Simulation

J. Cipolla, M. Snyman
ABAQUS, Inc.

This article describes types of tire acoustic analyses that can be undertaken with the existing, commercially available finite element technology in ABAQUS. Recent advances significantly improve the physical resolution and engineering relevance of the acoustic analysis of tire systems. In particular, current software enables analysis of nonlinear static preloading, internal air cavity effects, modal analyses, time-harmonic analyses, and advanced substructure generation. In this paper we will discuss acoustic analyses as linear perturbations about a state of finite deformation; that is, the acoustic analyses of tires are performed on the loaded, deformed state of the tire-air-wheel system.

Paper Number 6.1

Simulations of Vehicle Dynamics with Tire/Rigid and Deformable Terrain Interface Using Simulink

P. Saitana, C. Lin, T. Zhang, J. Lee, D. Goering
University of Alaska Fairbanks

This paper discusses the potential of vehicle dynamics integrated with tire/terrain simulation. A Simulink vehicle model with independent sub modules is under development. Individual sub-system of the vehicle comprises of body with pitch, bounce and longitudinal motion as outputs, secondly a tire with jounce, rotational motion and forward motion. The dynamic effect of the vehicle is considered on the tire along with the static weight. The parameters like slip, traction are updated from time to time. The inputs of the terrain profile of the rigid ground to the simulations are of step and sine wave. Parameters involved in vehicle and wheel dynamic models include dynamic properties of the vehicle body, suspensions, wheels, driving torque and dynamic responses of the whole system.

The tire/terrain interface model comprises two interrelated force components: one is the traction/slip component and the other is the lateral force/slip angle component. The simulations of traction/slip are presented for both rigid and deformable terrains. The existing equations are refined by curve fitting equations using validated FEM simulation results. Parameters involved in traction/slip on rigid ground include tire load, longitudinal slip, variable friction coefficient and boundary conditions. For deformable surfaces, the system becomes more complicated. Presently the simulations for deformable terrain, the key parameters involved are cohesion, internal friction angle, normal and shear stress beneath the wheel, normal load due to suspension and slip. Results obtained from the developed tire/terrain formulae are reasonably close to the results obtained from FEM simulations for both rigid terrain and deformable terrain. Numerical examples are used, in this study, to investigate the vehicle dynamics responses and transient values of slip, sinkage and traction forces of tires to a give set of inputs, such as wheel torque, terrain profiles and terrain properties.

Paper Number 6.2

A New Tire Model for Road Loads Simulation: Part 1: Theory and Validation

A. Dhir, M. Berzeri, R. Ranganathan, B. Balendran, P. Jayakumar
Ford Motor Co.

P. J. O'Heron
MSC Software Corporation

Road loads tire models are used in the automotive industry in full vehicle simulations to compute the loading from the road into the chassis encountered in proving ground durability events. Such events typically include Belgian Block events; bump events, potholes and others. Correctly capturing tire enveloping forces in such events has historically been challenging – several different approaches exist, each with its own limitations. In this paper a model is presented which captures the first order tire dynamics and associated enveloping loading without the need of an equivalent road profile. The theory behind this tire model is presented, the tire tests required as inputs for the tire model are summarized, and suggested applications are given. Importantly, a comprehensive study of the validation of the tire model is given which shows correlation for static tire tests, dynamic cleat tests and also full vehicle dynamic proving ground events.

A Virtual Tire Lab (VTL) pre-processing tool is also presented which is used to compute tire model input parameters from a validated non-linear FEA tire model. This VTL eliminates the need for design-intent tire hardware for testing, and hence considerably reduces time and costs in testing tires. VTL makes available the road-loads tire model parameters early in the vehicle development process, enabling early prediction of road loads.

Paper Number 6.3

A Study of the In-Plane Force Transmission of Tires

H. R. Dorfi
Hankook Tire
Akron Technical Center

A better understanding of the tire force transmission mechanisms from footprint to spindle due to cleat impact and other road disturbances is important to improve the ride performance of the tire/vehicle system.

In this study the in-plane force transmission of tires rolling over cleats is studied using various approaches: analytical, numerical and experimental. The tire force response at the spindle is compared and several important observations are made. Results reported in the literature are critically reviewed as well.

Paper Number 6.4

Tyre "Out-of-Plane" Parameter Identification from Experimental Tests on a Rolling Tyre

G. Matrascia, D. Scaltritti
Pirelli Tyres S.p.a.

F. Cheli, G. Tomasini
Politecnico di Milano

It is well known that, for a given tyre, its behaviour depends on the inflation pressure, the vertical load, and the rolling speed. In the present work, an experimental set-up and a numerical identification procedure have been developed to determine the out-of-plane parameter values up to a frequency of ca. 100Hz (rigid modes of the tyre belts). This frequency range is more than enough to describe the tyre handling and lateral comfort behaviour both in steady-state and in transient manoeuvres.

The tyre testing procedure for "out-of-plane" parameter identification is based on cleat tests with a specially designed oblique obstacle. The proposed tyre testing procedure is easy and fast to carry out and requires just a dynamometric hub and a drum on which the oblique obstacle has to be mounted. The identification of the rolling tyre vibration modes is done at different inflation pressures, vertical loads and rolling speeds in the time domain using three different methods (Prony's method, Ibrahim's method and Ibrahim's modified method). The confidence as well as the dispersion of the results obtained with the three identification methods has been analysed.

Once the model parameters of the tyre have been identified, they can be used to identify the parameters of any tyre model. They will also be able to describe the tyre behaviour at changing inflation pressure, normal load and rolling speed.

Paper Number 6.5

A Tire Force/Moment Formula using Meaningful Parameters

T. J. Wielenga
Engineering Insight, LLC

wheel'-an-ga

Representation of tire force and moment properties currently relies on such representations as splines or the "Magic Formula." A new formula is proposed that represents tire forces and moments accurately with a minimum of parameters. However, in this formulation the parameters are meaningful and can be easily identified from inspection of tire test data.

The formulas' parameters include those used in the analysis of vehicle handling and dynamics. For example, the lateral force character of the tire is represented in terms of five parameters: 1) cornering coefficient, 2) peak slip angle, 3) peak slip coefficient, 4) sliding coefficient, and 5) sliding inflection angle. These parameters are easily identified from inspection of the lateral tire force data curve. They consist of 1) the slope at zero slip angle, 2) the peak of the curve, 3) the slip angle at the peak, 4) the final value of the curve, and 5) the angle at which the curve has an inflection in it.

The formula works equally well for moment data. The major advantage to the formula is that the most important properties of the tire are included in the parameters and the character of the curve can be immediately visualized.

has new model for single Fy/SA curve

pacjeka parameters are functions of these

α γ ↗L p

Paper Number 6.6

Analysis of Tire Rolling Contact Response by REF Model

Y.T. Wei, L. Nasdala, H. Rothert
University of Hannover
Appelstr. 9A, 30167 Hannover, Germany

Analysis for tire dynamic response rolling over an obstacle is important to study automobile NVH properties, determine vehicle fatigue load, investigate combined longitudinal and sideslip properties, develop ABS system on uneven roads. Based on the model of Ring on the Elastic and Viscoelastic Foundation (REF) and its analytical solution previously developed by the first author, the rolling contact problem between tire/flat and tire/cleat are dealt with in this paper. The static contact problem is treated as the first step to show the effectiveness and accuracy of the model. Then the time domain simulation of tire rolling contact on uneven roads is conducted. Meirovitch modal analysis method and first-order matrix perturbation theory are applied to obtain the general forced response of damping REF vibration. An effective numerical quadrature method is developed to obtain the time-varying modal coordinates of the system under various loading conditions. Numerical examples of a tire rolling over a cleat are given to verify the developed method. It is found that both damping and velocity have strong effects on tire response over a cleat and the frequency of dynamic load is mainly controlled by the first tire mode.