An NSF Industry/University Cooperative Research Program

TRTC Project Summaries

October 2010

Tire Research and Test center

Virginia Tech
Mechanical Engineering Department
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Danville, VA 24540
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AND

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Dispersion and Exfoliating of Nano-Particles into Polymer Matrices

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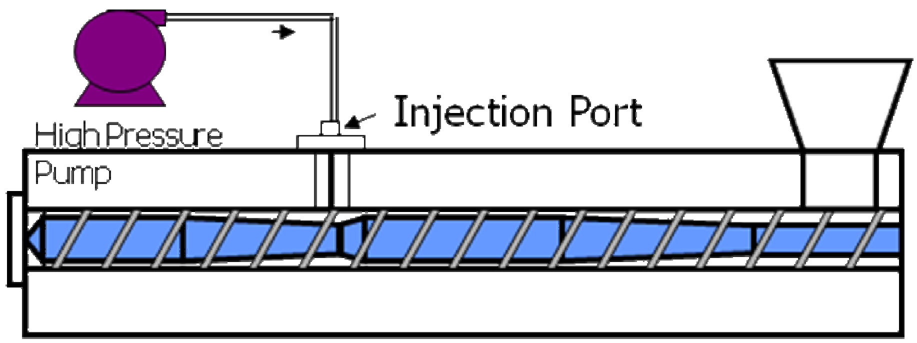
Project Description:

- Development of an environmentally benign process, which uses supercritical carbon dioxide (sc-CO2) as a processing aid to exfoliate and disperse nano-clays and tubes into polymer and rubber matrices
- Use CO_2 exfoliation process to produce debundled /exfoliated carbon nano-tubes in polymer and rubber matrices.
- Determine mechanical properties as a function of nano-particle concentration



Two-Stage Single-
Screw Extruder

Tire/Vehicle Impact:

- Improved tire performance in terms of reduced energy usage and wear…
- Reduced use of the amount of rubber and tire weight…

Schedule/Milestones:

- By 12/31/10 show that the level of particle loading can be varied from 4 wt% to 10wt% while exfoliation is maintained
- 6/30/11 establish the level of increase in strength and stiffness
- By 12/31/11 show that strength can be increased by a factor of 100% while stiffness can be controlled as desired
- By 6/30/12 show that particle orientation can be controlled as necessary for optimum tire design

Budget: $53,000 per year (graduate student support, supplies, travel, salary)

Slip and Contact Patch Analysis on Deformable Soil

Principal Investigator: Corina Sandu, Associate Professor, Director AVDL, Virginia Tech

Problem Statement

In this project we propose to investigate the behavior of the pneumatic tire in off-road conditions, specifically on deformable soil, with a focus on the slip development and contact patch variation.

Overall Goals

This study will focus on the estimation of the effective tire rolling radius, tire slip, and variation of the contact patch, with the final goal of providing more accurate estimations of mobility and performance of off-road vehicles on deformable soil.

Benefit to the industry

- The slip at the tire-running surface contact is critical in the tractive and braking performance of a tire.
- Whereas adhesion and lateral stability are a concern in on-road tire modeling, compaction resistance and tripping arising from bulldozing are additional concerns for tires in off-road conditions.
- In off-road conditions, the combined effect of tire deformation, sinkage, soil compaction, tire slip, and obstacle crossing make the analysis of traction and handling extremely challenging.

Objectives and Proposed tasks

<u>Year 1:</u>

- Establish a proper design of experiment based on the key elements to be investigated
- Perform the experimental testing using the Terramechanics Rig at AVDL, seen in Figure 1, and collect data for the tractive performance of pneumatic tires of interest on deformable soil (soil type to be determined based on input from industry) at different slip ratios
- Quantify and analyze the data collected

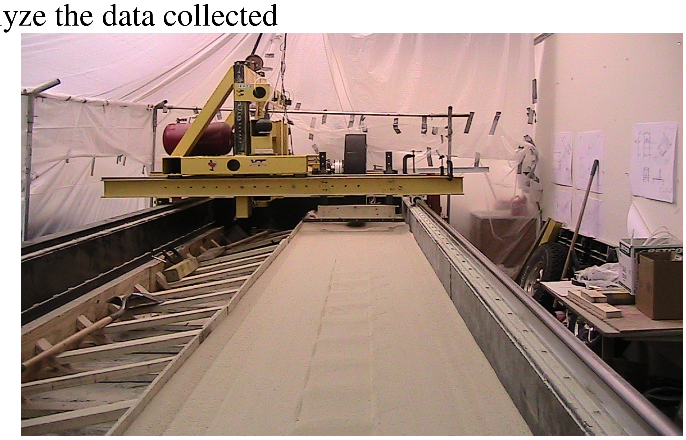


Figure 1. Terramechanics Rig at AVDL

Notes: a) If lateral dynamics is also of interest to the industrial partners, a range of toe angles can be imposed on the tire, and the lateral force in the contact patch can be recorded. This will simulate the lateral forces developed during steering. The addition of this task may require an extension of the experimental work with 6 months, and the budget will change accordingly

b) The tire diameters that the rig can accommodate are between 22 in and 32 in; thus, LT and ATV tires would be good candidates for testing. If more than one tire is to be tested, the experimental work will increase with about 4 months per tire, and the budget will change accordingly.

c) If mud is desired (or other soil type), instead of sand, the PI will work with the industrial partners to bring such material in the laboratory. Additional funding may be needed.

<u>Year 2:</u>

- Develop enhanced off-road pneumatic tire models that account for the influence of the slip, sinkage, and changes in the contact patch.
- Use test data to validate the newly developed tire-soil contact models

Deliverables

<u>Year 1:</u>

- Database of tractive properties of specific pneumatic tires on a specific soft soil at a range of slip ratios.

<u>Year 2:</u>

- Improved and validated steady-state tire model for traction on soft soil.

Overall Project Outcomes

- Enhanced understanding of the pneumatic tire behavior on deformable soil
- Improved tire-soil contact models
- Advanced off-road tire models based on the knowledge acquired during the study
- Experimental data base for a variety of tires on one (or more) soil and/or sand types to be used for future studies
- In the end, the study will lead to improved tire designs for off-road conditions, improved mobility and handling, increased safety, and overall better vehicle performance

Budget

<u>Year 1:</u> $75,000.

This budget includes the following:

- Stipend, tuition, and fringes for one and a half graduate research assistants
- 33% of summer salary for the principal investigator, plus fringes
- Travel money for meetings and conferences
- Materials money for the experimental work
- 10% indirect cost at Virginia Tech

<u>Year 2:</u> $52,000

This budget includes the following:

- Stipend, tuition, and fringes for one graduate research assistant
- 33% of summer salary for the principal investigator, plus fringes
- Travel money for meetings and conferences
- 10% indirect cost at Virginia Tech

Pneumatic Tire Performance on Ice

Principal Investigator: Corina Sandu, Associate Professor, Director AVDL, Virginia Tech

Problem Statement

The frictional mechanisms at the tire-ice interface are very complex. At relatively high temperatures and high velocities frictional heating produces a thin water layer, which leads to small values of the friction coefficient. At low temperatures and low velocities the dry friction coefficient becomes very large. Other factors (e.g., ice structure, hardness, thickness, rubber compound, loose material on ice) contribute to the friction properties of the ice surface. In this project we propose to conduct a study that will help assess and improve the performance of pneumatic tires in winter conditions, such as on icy roads.

Overall Goal and Benefit to the Industry

This study will enhance the understanding of tire-ice contact which can lead to improved vehicle safety in icy road conditions.

Objectives and Proposed tasks

Year 1:

- Establish a proper design of experiment based on the key elements to be investigated
- Perform the experimental testing using the Terramechanics Rig at AVDL, seen in Figure 1, and collect data for the tractive performance of pneumatic tires of interest on ice at different slip ratios
- Quantify and analyze the data collected

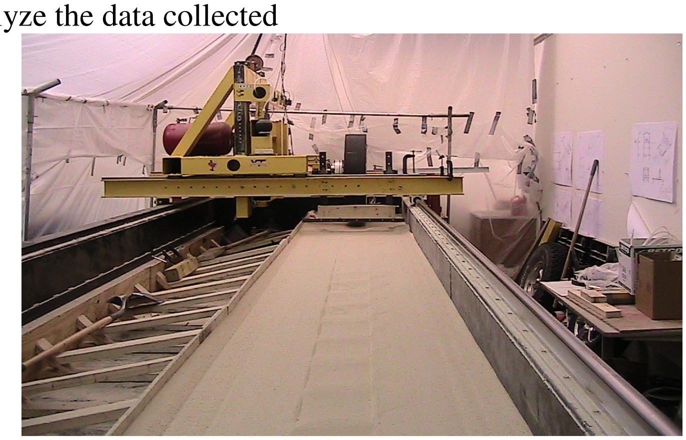


Figure 1. Terramechanics Rig at AVDL

Notes: a) If lateral dynamics is also of interest to the industrial partners, a range of toe angles can be imposed on the tire, and the lateral force in the contact patch can be recorded. This will simulate the lateral forces developed during steering. The addition of this task may require an extension of the experimental work with 6 months, and the budget will change accordingly

b) The tire diameters that the rig can accommodate are between 22 in and 32 in; thus, LT and ATV tires would be good candidates for testing. If more than one tire is to be tested, the experimental work will increase with about 4 months per tire, and the budget will change accordingly.

Year 2:
- Develop pneumatic tire-ice contact models.
- Use test data to validate the newly developed tire-ice contact models

Deliverables
Year 1:
- Database of tractive properties of specific pneumatic tires on ice at a range of slip ratios.

Year 2:
- Validated steady-state tire model for traction on ice.

Overall Project Outcomes
- Enhanced understanding of the pneumatic tire behavior on ice
- Improved tire-ice contact models
- Experimental data base for a variety of tires on ice to be used for future studies
- In the end, the study will lead to improved tire designs for better traction in winter conditions, increased safety, and overall better vehicle performance

Budget
Year 1: $75,000.

This budget includes the following:
- Stipend, tuition, and fringes for one and a half graduate research assistants
- 33% of summer salary for the principal investigator, plus fringes
- Travel money for meetings and conferences
- Materials money for the experimental work
- 10% indirect cost at Virginia Tech

Year 2: $52,000

This budget includes the following:
- Stipend, tuition, and fringes for one graduate research assistant
- 33% of summer salary for the principal investigator, plus fringes
- Travel money for meetings and conferences
- 10% indirect cost at Virginia Tech

Analysis of tire wear and age effects on tire performance and fuel efficiency

Principal Investigator: Corina Sandu, Associate Professor, Director AVDL, Virginia Tech

Problem Statement

Tires are manufactured with tread patterns that are permanently improved by the designers, based on specific applications. For example, a specific class of tires is represented by the winter tires that are designed for improved traction on snow. It is very important, though, to thoroughly understand how the process of wear affects the normal tire performance (i.e., the performance of a new tire). The tire wear could have very serious consequences, from lost fuel efficiency to endangering the life of the occupants in extreme cases. Thus, it is very important to investigate the effects of tire wear in a structured and systematic manner. Moreover, studying the impact of the tire age on tire performance is also significant, as changes in the materials used in tire manufacturing may degrade over time, even if the tire has not been used. One such situation will be the spare tire, while tires sitting in the stores represent another example.

Overall Goal and Benefit to the Industry

The primary objective of this study is to investigate how various degrees of tire wear affect the tire performance. A secondary objective is to investigate how tire age affects the tire performance.

Objectives and Proposed tasks

<u>Year 1:</u>

The following tasks are needed to accomplish the research objective proposed in this project:

1. Select a number of tire models of interest. For each tire model obtain a new tire and also tires at different levels of wear.
2. Perform experimental studies on the Terramechanics Rig illustrated in Figure 1, and collect data (such as the drawbar pull) under different conditions.
3. Study the performance of a re-treaded tire of the same model compared to a new one.
4. Study the performance of an unused, but aged tire of the same model, compared to a new one.
5. Investigate the effect of tire wear and/or age on fuel efficiency, by using the experimental data collected as input data in tire models developed in-house.

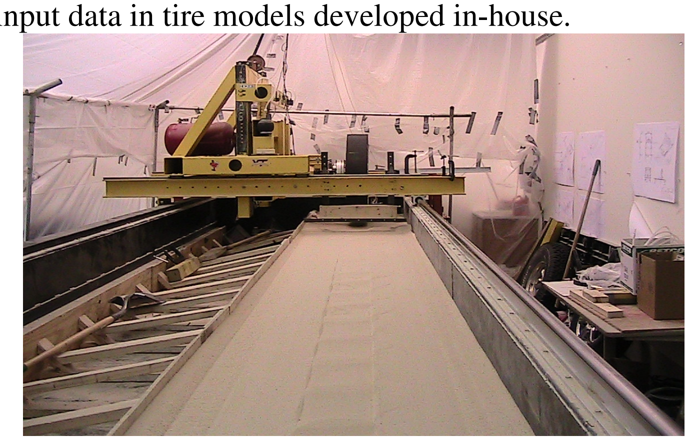


Figure 1. Terramechanics Rig at AVDL

Deliverables

Year 1:

Comparative analysis and evaluation report discussing the differences observed in the tractive performance of the tires studied due to tire wear, age, and re-treading. Improved tire models that will account for such effects.

Overall Project Outcomes

- Enhanced understanding of the effect of the tire wear, age, and re-treading.
- In the end, the study will lead to improved vehicle performance, increased safety, and reduced fuel consumption.

Budget

Year 1: $75,000.

This budget includes the following:

- Stipend, tuition, and fringes for one and a half graduate research assistants
- 33% of summer salary for the principal investigator, plus fringes
- Travel money for meetings and conferences
- Materials money for the experimental work
- 10% indirect cost at Virginia Tech

FULL-FIELD STRAIN MONITORING FOR TIRE TESTING AND TIRE CONSTITUTIVE MODELING

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Problem Statement

Recent years have seen the growing use of full-field strain monitoring methods in the tire manufacturing and performance test phases. While most dominant, constitutive modeling using test coupons cannot accurately capture complex directional behavior of tire's anisotropic properties. Simulation, as a result, often fails in predicting the actual behavior and capabilities of tires although it also has its value in being able to monitor internal states such as strains, stresses and energies, which have not been measurable by the traditional testing setup. The full-field strain monitoring, allowing the visualization of the actual strains and subsequent quantities such as stresses and energies, can provide the accurate information of the internal states, which none of the simulation and the traditional testing setup could achieve, and better predict the actual behavior and capabilities of tires based on the accurate information. Moreover, the full-field strain monitoring can contribute to simulation significantly by developing a constitutive model that can capture the complex directional behavior by feeding the actual full-field strain information. Nevertheless, currently available commercial full-field strain monitoring systems generally (1) are very expensive, (2) do not have comprehensive capabilities and functions for tire testing, and (3) require skills and efforts for settings.

Objectives

The objectives of this project are to develop

- A real-time three-dimensional full-field strain monitoring method,
- A method that creates a constitutive model automatically from full-field strain measurements, and
- Performance metrics for constitutive modeling

The methods will be used for various specimens including two-dimensional test coupons and actual three-dimensional tires.

Benefits to Industry

- The methods will be made available with open source programs,
- Constitutive models with standardized performance metrics will evaluate the reliability of tire simulation, and
- Predict performance and life of tires using actual full-field strain measurements.
- Significant reduction of tests is expected.
- Companies that do not have a test rig will have access to it.

Approach

Figure 1 shows the schematic diagram of the proposed approach. The development of full-field strain measurement, constitutive modeling and quantification methods is the core of the project. They are to be performed iteratively and in real time so that the test can be terminated when desired metrics are achieved.

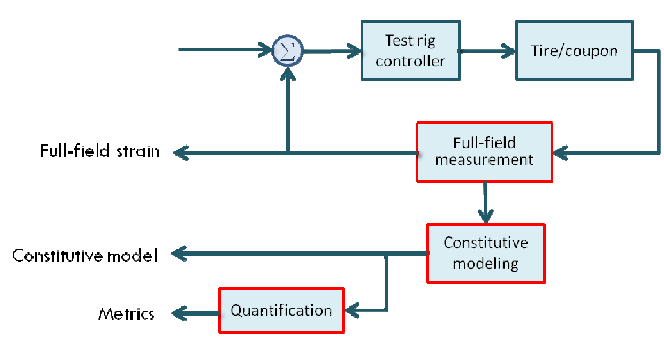

Figure 1: Schematic diagram of proposed approach

Deliverables

- Open source programs for full-field strain measurement;
- Open source programs for constitutive modeling and its quantification;
- One degree-of-freedom test rig and its control system (basic system to be shared by companies that do not have their own testing facilities).

Timeline and Budget

- **Phase 1-One year**: $70k (Full-field strain measurement)

  Graduate student assistantship: $45k (overhead + benefits included)

  Other assistantships: $20k (overhead + benefits included)

  Cameras: $3k

  Travel: $2k

- **Phase 2–Six months**: $60k (Test rig development and full-field monitoring)

  Test rig: $40k

  Part-time assistantship: $10k

  Tests and associated costs: $10k

- **Phase 3-One year**: $70k (Constitutive modeling)

  Graduate student assistantship: $45k (overhead + benefits included)

  Other assistantships: $20k (overhead + benefits included)

  Travel and communication with industry: $3k

  Miscellaneous: $2k

Project Title: Human-In-the-Loop Virtual Tire Prototyping Platform

Principal Investigator:

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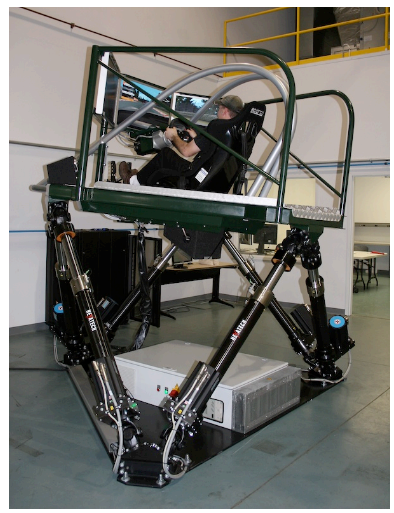
Goal:

The primary goal of this project is to establish a standardized platform for human-in-the-loop (HIL) real-time virtual prototyping with a range of simulated tires on customer-supplied vehicle models. Virtual prototyping is a proven approach for reducing the expense and cycle time associated with physical prototyping. This project will enable significant additional reductions by streamlining and standardizing the process of vehicle and tire integration into the driving simulator platform so that test time can be focused on the actual HIL evaluation. Another critical goal is to insure the security of proprietary data and models.

Objectives:

Leveraging the existing 6-DOF full-motion HIL driving simulators located at VIPER Service, the project goal will be achieved through completion of the following objectives:

- Using sponsor input, analyze tire and vehicle models to determine an efficient standardization strategy
- Develop a means for integrating externally supplied tire data or models into the HIL simulation platform
- Develop a means for integrating externally supplied vehicle models into the HIL simulation platform
- Conduct a HIL evaluation study to validate the simulation platform fidelity



Deliverables:

The objectives of this project will be carried out in close collaboration with sponsor representatives. The deliverables will include:

1. Periodic project reviews to share the results and findings of the project
2. A HIL demonstration incorporating the integration tools developed for the project
3. Final report documenting the project tasks and results

Budget:

The budget for this one-year project is listed in the table below.

Budget Item	Cost
Personnel (Graduate Student Assistantship)	$40,000
Driving Simulator Rental	$16,000
Indirect (@10%)	$4,000
TOTAL	**$60,000**

Identifying Pavement Surface Characteristics

Submitted by

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EXECUTIVE SUMMARY

Problem Statement

Many of the issue faced by the tire designer concern the ability to predict the effectiveness of the tire as it interacts with the vehicle and the pavement. Specifically, the ability to predict the pavement surface characteristics (e.g., grade, banking, rolling resistance, fuel efficiency, tire wear, traction, and friction) as they relate to the tire-interaction in terms of the pavement surface features (e.g., texture, roughness, banking, elevation change). Presently, multi-scale pavement measurement devices are being developed allowing accurate measurement of the pavement surface features. The critical link that is missing is the relationship between these features and the pavement surface characteristics that can be used by tire designers to improve their designs.

Overall Goals / Benefit to the Industry

The goal of this proposal is to identify the pavement surface features that affect the interaction between the tire and the pavement. Consider a simple representation of the pavement surface as a set of equally-spaced points describing the height of the pavement along a line running longitudinally along the pavement in the wheel path. The pavement can be categorized by the amplitude and wavelength of features in that profile. Preliminary investigations into the classification of pavement features are summarized in Table 1. Specifically, the features are classified as: Global Features, Surface Roughness, Megatexture, Macrotexture, and Microtexture.

Table 1: Pavement Features Classification

Feature Classification	Application	Feature Wavelength Range
Microtexture	Friction, Tire Wear	0.001 mm - 0.1 mm
Macrotexture	Noise, Splash and Spray	0.1 mm - 10 mm
Megatexture	Tire Damage	10 mm - 100 mm
Roughness	Rolling Resistance, Chassis Excitation	100 mm - 30 m
Global	Grades, Banking, Vehicle Dynamic Responses	Greater than 10 m

Objectives

Year 1

Through literature reviews, a set of required pavement surface characteristics will be established. A comprehensive review of the current modeling techniques to predict these characteristic will be completed. In-field testing will measure these characteristics (such as grade, banking, rolling resistance, fuel efficiency, tire wear, traction, and friction) either directly, or methods to infer pavement characteristics from auxiliary instrumentation will be developed. A set of pavement surfaces also will be measured at multiple scales to include roughness and irregularities on the scale of 100mm to 100m, and texture at scales of sub-millimeter to 100mm.

Year 2

In the second year, models will be developed to predict the pavement characteristics from the pavement surface features. The measured data acquired in the first year (both the characteristics and the features of the pavement) will be used to parameterize these models, analyze each model for accuracy, and judge the quality of the model in predicting each of the characteristics from the features.

Deliverables

Year 1

Specific Deliverables include:

1. Specification for required pavement surface characteristics and features
2. Review of current modeling techniques
3. Measurement of pavement surface characteristics (e.g., friction)
4. Measurement of pavement surface features (e.g., macro-texture)

Year 2

Specific outcomes include:

1. Development of models to estimate pavement surface characteristics from pavement surface features
2. Parameterization and statistical analysis of models.

Budget

Year 1: $50k

- 50% of a GRA for 12 months
- 10% Summer salary for faculty
- Travel expenses for data acquisition

Year 2: $50k

- 50% of a GRA for 12 months
- 10% Summer salary for faculty
- Expenses for follow-up data acquisition and modeling software

Effective Parametric Finite Element Tire Models for Simplified Transient Response

Presented to the
Tire Research and Test Center
An NSF I/UCRC

Two-Year Project Brief

Performance Period
January 2011 – December 2012

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Submitted October 11, 2010

1 Executive Summary

This summary provides a brief outline of a two-year program to develop effective parametric finite element tire models to predict simplified transient response. A parametric finite element template will be developed for a single demonstration tire, including geometry and meshing parameters. Executable scripts will be developed to modify tire model template parameters and extract desired results. Scripting tools must include modules for post-processing tire experimental and simulation response. The tire model will have two primary uses; (1) calibration/exploration of tire/wheel performance models, (2) elastodynamic tire-vehicle simulations. The scope of the two-year project is restricted to developing and reconciling steady-state rolling tire models with experimental data. The deliverable from the project is a set of reusable scripts that develop a parametric finite element model and associated post-processing functions.

1.1 Problem Statement

Multibody dynamics and elastodynamic vehicle simulations used by tire makers, suppliers and vehicle manufacturers require scalable, higher fidelity, nonlinear tire models to support design/analysis/testing. While there are several common elements in a tire model that can be scripted, tire models should be tailored for specific types of analysis and evaluated against independent data to establish the model's range of applicability. Today's tire model must be able to utilize material data and post-process model response consistent with experimental data for purposes of correlation and parameter estimation. While transient dynamic vehicle simulations are becoming more tractable, they are still expensive. A hierarchical approach to tire modeling at multiple scales is needed for faster simulation times at an application appropriate resolution. Additional post-processing tools must be developed to evaluate the "model order" of the hierarchical tire model relative to the noise floor of the experimental data used for input to or validation of the model. Lastly, engineering expertise/time is very expensive, the use of modifiable tire finite element model templates and scripts by engineering staff for trade-off studies involving tire-modeling tasks are very attractive. Today, the finite element tire model is often a component in a larger simulation requiring effective and efficient tire models, especially in applications involving vehicle dynamics and resolving load transfer into vehicle systems.

The following specific needs are the basis for the work proposed in this project:

1. Utilize material/experimental data for tire material model development as well as model validation/verification,
2. Accommodate multiple modeling scales for effective/efficient run-time finite element models,
3. Develop hierarchical reusable, parametric, tire models for a given class of tire model to enable tailored FE models with variable "model order',
4. Develop reusable model result extraction and post-processing modules that support "model order" studies for model performance/model effort analysis.

Considerable effort and investment has been made in tire finite element model development over the last thirty years, most of the tire models/data and support processes are proprietary. The development time and expertise required to build a finite element tire model that rivals the tire models found in a multibody dynamics simulation is a large undertaking. Investment in time and resources in finite element tire models also requires calibration of the tire model for a specific tire application, another significant barrier since data in a standard test sequence is often not available for the tire or the operating conditions.

1.2 Overall Goals/Benefit to Industry

The overall goal for this research is to develop effective and efficient reusable parametric tire models that can utilize independent experimental tire data for model development and evaluation. The goal of this study is to demonstrate the concept and implementation on a specific tire and show that it can be extended to a family of tires of the same construction. The development of a coordinated and quantitative evaluation of the finite element tire model performance against experimental data is also a goal for this work.

The "Benefit to Industry" from this research effort is the realization of a reusable hierarchical modeling framework for finite element tire models that can be modified by an engineering group and tailored for their applications. Specifically the following points are:

1. Industry Modifiable FE Tire Templates/Scripts
   - Reusable parametric template for FE-based modeling in vehicle design/analysis
   - Support scripting for pre- and post-processing of FE model inputs/results
   - Opportunity to compare elastodynamics approaches to multibody systems
2. Industry Validation of the Tire Model at Successive Stages (Analysis Steps)
   - Exploit 3-D full-field strain development and evaluation of tire model and BC's
3. Use of Non-Dimensional/Normalized Master Surfaces
   - Non-dimensionalized or normalized response surface from tire data/models
   - Process for utilizing tire test data to develop a tire material model
4. Exploration/Refinement of Tire FE Models
   - Identify the parsimonious FE tire model based on the dominant mechanics,
   - Reduced run times => toward practical elastodynamic vehicle design simulations
5. Graduate/Undergraduate Students Involved
   - Tire Modeling/Vehicle Systems: testing, computational modeling, simulation.

1.3 Objectives

The objectives in this project are primarily associated with the development of the reusable tire finite element model and the correlation of the model with tire data. The run-time execution of the model is another large component of the program; sensitivity analysis will be used to make run-time trade-offs compared against model fidelity. The program objective is to develop finite element tire models with the most appropriate fidelity per run-time resources. The specific objectives of the study are as follows:

1. Updated Literature Search
   - Update/Share Literature on the public-domain state of the art
2. Establish Baseline Tire and In-Service Load Conditions for Study
   - Utilize tire/experimental data:
   - Material data – type of data and format to be specified in spreadsheet format,
   - Performance Data – response type, wheel spindle or vehicle based.
3. Development of Reusable Parametric Tire Templates: The development of parametric tire models is developed around customizable templates for geometry, FE modeling and scripting,
   - Tire model templates include geometry, meshing schemes, materials, load, boundary and initial conditions, assembly constraints, contact mechanics, data extraction,
   - Pre-processing and Execution Scripts,
   - Result Extraction and Post-Processing Scripts,
4. Develop Non-Dimensional/Normalized Tire Mechanics Representation
   - Establish the non-dimensional or normalized independent and dependent response variables,
   - Develop the response surface for the FE tire model,
   - Quantify the performance of the tire model relative to experimental data,
5. Exploration and Refinement of Tire Models
   - Tailor the performance of the tire model from the response surface => model effectiveness,
   - Explore model run-time performance from response surface => model efficiency.
6. Educate Graduate and Undergraduate Students in Tire Modeling

The majority of the new work will be developed in objectives (3), the development of the templates and scripting, (4), the development of the non-dimensional mechanics and response surface, and (5), exploration and refinement of the tire models. The project expects to acquire data for the materials through quasi-static multiaxial and rheological testing using Design of Experiments and load-frame and rheometer facilities already in place. Tire performance data may also be acquired by working through the Tire Consortium, which Virginia Tech is a member.

1.4 Deliverables and Reports (Task 6)

The duration of the project is for two-years projected to start in January 2011 and go through December 2012. The deliverables of the project include intermediate deliverables through the end of the first year. Specifically, the deliverables for the project are as follows:

1. Updated Literature Search
   - Review and classification of approaches on the State of the Art on Tire Modeling, (6-9 months, Jan-Sep, 2011),
2. Actual Vehicle and Tire Platform for the Study
   - Working baseline vehicle and tire, loading, BC's and in-service loads for the study, (3-6 months, Jan-Jun 2011),
   - Criteria to evaluate the model performance, (6-12 months, Apr 2011-Mar 2012),
3. Develop Parametric Tire Subassembly FE Models; Tire Template
   - Parametric Finite Element model templates, (3-18 months, Jan 2011–Jun 2012),
   - Executable scripts: model building, execution, result extraction and post-processing, (3-21 months, Feb 2011-Oct 2012),
4. Develop Non-Dimensional Mechanics Representation
   - Non-dimensionalized response surface from tire forces/moments, (6-18 months, Mar 2011-Sep-2012),
   - Process for utilizing tire test data to develop and evaluate a tire material model, (6-24 months, Jun 2011-Dec 2012),
5. Exploration/Refinement of Tire FE Models
   - Parsimonious FE tire model based on the dominant mechanics, (12 months, Jan 2012-Dec 2012),
   - Reduced run times => more practical elastodynamic vehicle simulations (9 months, Mar 2012-Dec 2010),
6. Graduate/Undergraduate Students in Tire Modeling and Vehicle Systems

<u>Two-Year Project Duration Major Milestones</u>

Year 1 Major Milestones:

- Development of FE Templates/Scripts, Quasi-Static-Steady-State Models

Year 2 Major Milestones:

- Refinement of Templates/Scripts/Response Surface, Model/Exp correlation of simplified transient dynamics tire models, Reduced Run-Times

Reporting is proposed on a quarterly basis with dates of April 30, July 31, Oct 31 and Jan 31. The final report will be comprehensive including literature summary, model formulation, trade-off studies, data for development and validation of the models. Installation of scripts and model templates will also be included.

1.5 Budget

An updated budget estimate is outlined below based on a two-year project for a reusable simplified transient dynamic response tire models.

Two-Year Budget Estimate: $145K, Year 1: $75K, Year 2: $70K

- Faculty Partial Summer: 2 years,
- Graduate Student: 2 years,
- Undergraduate Students: 1 per year,
- Instrumentation/Sensors: $5-10K,
- Engineering Workstation: $8K,
- Additional Abaqus license tokens support: $2K,

Executive Summary: The Application of Smart Materials for Improving Tire Performance and Processing

Problem Statement

Users of all variety of tires stand to greatly benefit from the continued improvement of tire performance, whether it is for on or off-road tires. Potential performance gains of greatest interest to all tire users include the areas of tire life, wet and dry traction, handling performance, puncture resistance, and fuel efficiency. Improving these characteristics over the wide temperature and operating conditions that tires often operate in will be a major benefit for tire companies, their suppliers, and their customers.

Overall Goals and Benefits to the Industry

To enable the tire to adapt to its operating condition, reducing rolling resistance, improving braking characteristics, improving low-μ traction, and increasing tire strength, the goals of this research consist of the following:

- Explore the integration of Shape Memory Alloys (SMA) into tire belts for changing the mechanical and dynamic characteristics
- Establish the improvements that can be achieved through using SMA in the tire belts
- Research thermo-mechanical properties of suitable SMAs for such tasks as compressing rubber and reducing tread depth
- Investigate mechanical properties of selected SMAs for increasing cross tire lateral stiffness of tread elements

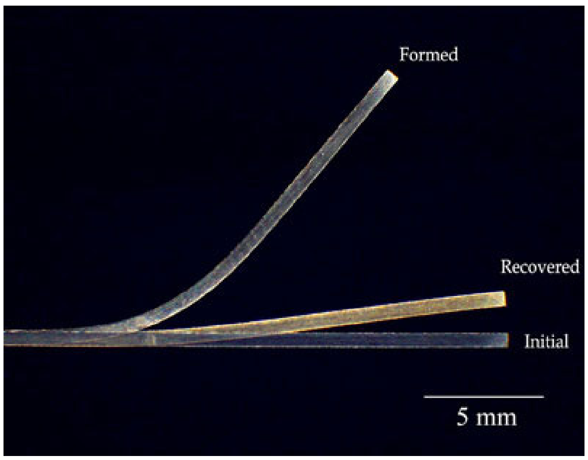

Figure 1: Common SMA behavior (courtesy of NASA.gov)

Objectives

To achieve the research goals, the following tasks will be performed over the course of the research:

- **Year 1: SMA Selection**

  A comprehensive scanning of smart material technologies will identify SMAs that can be used for tire applications. A particular emphasis will be placed on how SMAs can be properly integrated in the tire and processed such that they survive the demanding tire manufacturing process

- **Year 2: Study the Effect of Integrating SMAs in Tire**
  Establishing and documenting the mechanical and thermal properties of the SMAs that are identified throughout the study. Integrate the thermo-mechanical properties of SMAs into tire models that will allow us to evaluate the extent by which various tire properties can be changed by the SMAs
- **Year 3: Establish Improvements due to SMAs**
  Establish the improvements that can be gained as a result of the integration of SMAs in tires. Research and report on some of the processing issues that need to be considered for successfully integrating SMAs in tires, in collaboration for our project partner(s)

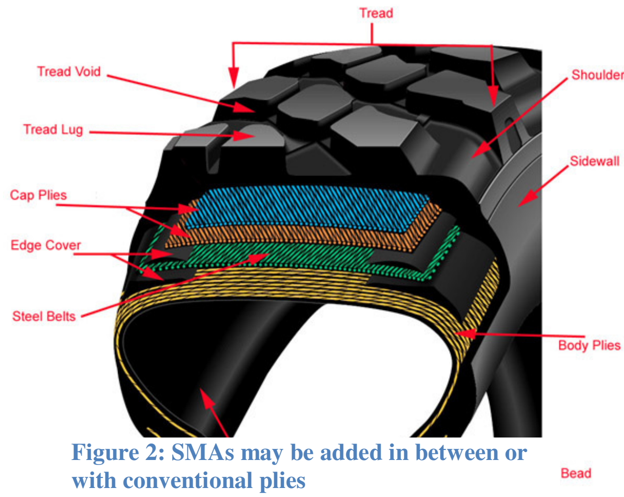

Figure 2: SMAs may be added in between or with conventional plies

Deliverables

The deliverables from each year's research consist is listed below:

- **Year 1: SMA Selection**
  - Monthly videoconference meetings with industrial sponsors
  - Travel to industry locations for students to gain firsthand experience of tire manufacturing techniques and areas of possible SMA integration
  - Quarterly reports of technology scanning progress
  - A comprehensive report covering the scanning of smart material technologies for use in tire applications.
- **Year 2: Study the Effect of Integrating SMAs in Tire**
  - Monthly videoconference meetings with industrial sponsors
  - Work with industry to find develop SMA integration techniques during the tire development process
  - Develop computer models and simulations of tires to quantify possible performance benefits of SMA integration into tires
  - Quarterly reports of SMA integration progress
  - A comprehensive report documenting the mechanical and thermal properties of the SMAs and SMA integration techniques
- **Year 3: Establish Improvements due to SMAs**
  - Monthly videoconference meetings with industrial sponsors
  - Work with industry to use SMA integration techniques in the construction of prototype tires or carcasses
  - Test prototype tires or carcasses and compare performance to standard tires to quantify possible performance benefits of SMA integration into tires
  - Quarterly reports of SMA integration progress
  - A comprehensive report documenting the mechanical and thermal properties of the studied SMAs, SMA integration techniques, numerical models, and any other applicable technology transfer to our industrial partners

Budget

The total budget for this effort will be $360,000, for the total duration of the project (3 years). This amount will be used primarily for supporting 2 graduate students ($240,000), supporting one post-doc or research faculty ($60,000), supporting the Principal Investigator, Dr. Mehdi Ahmadian ($39,000), and travel and materials and supplies ($21,000). A detailed budget will be submitted pending proposal approval.

- **Year 1: SMA Selection: $123,000**
  - Graduate students (2 at 100%): $80,000
  - Research Faculty (25%): $20,000
  - Principle Investigator (10%): $13,000
  - Travel: $3000
  - Materials and Supplies: $7,000
- **Year 2: Study the Effect of Integrating SMAs in Tire: $119,000**
  - Graduate students (2 at 100%): $80,000
  - Research Faculty (25%): $20,000
  - Principle Investigator (10%): $13,000
  - Travel: $3000
  - Materials and Supplies: $3,000
- **Year 3: Establish Improvements due to SMAs: $118,000**
  - Graduate students (2 at 100%): $80,000
  - Research Faculty (25%): $20,000
  - Principle Investigator (10%): $13,000
  - Travel: $3000
  - Materials and Supplies: $2,000

Empirical Modeling of Tire-Road Contact Mechanics

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Problem Statement

Although a vast amount of literature exists on tire-road contact mechanics, most models are based on theories that make use of various assumptions and fundamental equations of elasticity and plasticity. Contact mechanics in other fields and applications has suffered from the same shortcomings with the advantage of having better understanding of the physical phenomenon.

The problem with understanding the tire-road contact comes from the fact that such contact is not visible and if seen through the glass plate, it does not include the actual road surface which mainly contributes to traction and wear of the tires.

In this project, a new methodology is presented which makes use of testing equipment already available to derive empirical models of tire-road contact mechanics. The tire test trailer will be used to test tires on glass plates with various size and length protrusions (each section will only have one type protrusion with the last section having the completed road profile)). These protrusions will mimic what is seen on the road (the road profile will be measured and used to extract data needed for the protrusions). Using cameras, the state of tire stress and strain will be captured both at the contact patch and sidewall/crown as the tire rotates at different speeds. A fitting routine will be developed which will place the protrusion results in random orders (as is with the road) and will develop an empirical model. This model will then be validated using FE based modeling and test data.

Objectives

The objectives of this project are as follows:

- To develop a testing procedure for understanding tire-road contact mechanics

- To develop semi-empirical and empirical models that can be used in FE based models and design processes

Timeline & Deliverables

Year 1: Design the testing equipment and procedure required to understand contact mechanics
Year 2: Develop and validate the models.

Budget

The total two-year budget for this project is estimated at $86,500, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $50,500

- Glass plates, $14,500
- Graduate student, $36,000

Year 2; Cost= $36,000

- Graduate student, $36,000

Large Tire Force and Moment Trailer

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Problem Statement

In order to understand the force and moment properties of large on-road and off-road tires, a test trailer capable of accommodating these tires with the capability to input slip angle, camber angle, tractive force, and braking force is needed. Since this trailer must be capable of collecting data in harsh and rugged environments, it must have a very unique design. This project is aimed at the design and development of such trailer. The PI has extensive experience in this area and has designed and built a tire test trailer for passenger tires and will use that experience to design and develop the new trailer.

Although this will provide more benefit to the non-tire companies, nevertheless it will provide a single framework for collecting and reporting tire test data on various road surfaces which could be used by all member companies to develop/enhance their products.

The majority of funding for this project will be solicited from NSF Equipment Grant Program and NIST.

Objectives

The objectives of this project are as follows:

- To develop a one-of-a-kind tire testing equipment capable of measuring forces and moments and equipped with terrain profiling equipment as well as high speed cameras for full field stress/strain measurements (years 1 and 2)
- To develop the post processing software for processing the data and providing the information (year 3)

Timeline & Deliverables

Year 1: Design the equipment, complete the fabrication and order parts.
Year 2: Build and validate the equipment.
Year 3: Develop the post processing software to provide Pacejka coefficients in relevant cases, force and moment properties, full field stress/strain results, and terrain profile.

Budget

The total three-year budget for this project is estimated at $616,500, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $501,000

- Kistler P5HT Hub and electronics, $225K
- Road profiler, INS, GPS, supporting hardware and software, $186,000
- High speed cameras, fixtures, controls, daq boards, etc, $37,000
- Air bag system (for load application), steer and camber actuators, power source, a generator, etc, $17,000
- Graduate student, $36,000

Year 2; Cost= $78,500

- Metals, wheels, axles, electronics, etc, $42,500
- Graduate student, $36,000

Year 3; Cost= $36,000

- Graduate student, $36,000

Traction Optimization Based on Inverse Modeling of an Anti-Lock Braking System (ABS)

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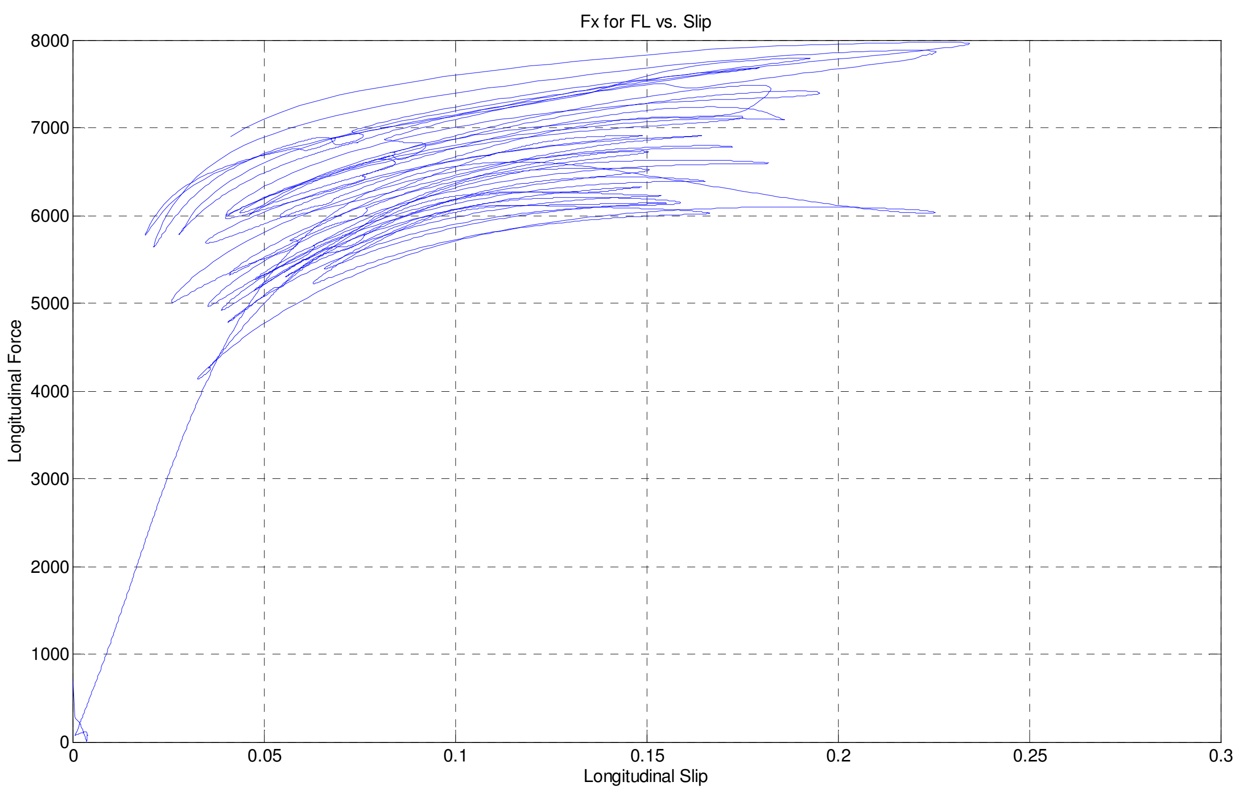
Problem Statement

It is well known that the function of an ABS is to optimize the braking event by providing the maximum available braking force between the tire and the road. The same is true for traction control systems. The control algorithms used in these systems are independent of the tire properties which require each system to be tuned for the specific tire/vehicle application. It is possible to derive control algorithms that include various tire traction properties. Assuming the control algorithm will provide optimum braking/traction, it will be possible to find the inverse r maximum braking/traction.



This project is aimed at developing an optimization process for tire traction properties.

Objectives

The objectives of this project are as follows:

- To develop an optimization routine capable of optimizing tire traction/braking properties (years)

- To validate the model based on test data collected (year 2)

Timeline & Deliverables

Year 1: Develop the new tire-based control algorithm and solve the inverse problem.
Year 2: Develop a simulation model and validate the process.

Budget

The total three-year budget for this project is estimated at $72,000, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $36,000
- Graduate student, $36,000

Year 2; Cost= $36,000
- Graduate student, $36,000

Simulator-Based FEM-Based Tire Design Process

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Problem Statement

The use of motion base simulators has traditionally been limited to ergonomics and safety related studies (intoxicated drivers, obstacle avoidance, etc). However, they can be adopted for tire design studies if the right models are implemented and used. Since the vehicle model that can be implemented on the system has no limitations in complexity (as long as it runs real-time), a high fidelity tire and vehicle model can be implemented which can provide the correct amount of feedback to the driver (one advantage of these systems is the ease of becoming familiar with driving them). Therefore, an FE tire model can be used which generates the force and moment results that can then be into the tire model used on the simulator. This will provide the driver with new forces and moments which he/she can then assess as he/she drives the vehicle on the simulator. Variety of design changes can be made to the FE model and the same process can continue. Since the original FE results can be considered to be the "control" tire, the driver can then evaluate all other cases against the "control" providing valuable feedback to optimize a design for handling performance. In a day's time, several tire designs can be evaluated by a professional test driver who has been trained on the simulator.
A simulator of this capacity exists which is part of the laboratories affiliated with the Center (if established). This simulator can be used to implement such technology. If the technology proves to be of value, the tire industry can transfer the technology to their site by purchasing a new simulator.

Objective

The objective of this project is as follows:

- To develop a one-of-a-kind tire design and evaluation technology

Timeline & Deliverables

Year 1: Develop the turn-key technology.

Budget

The total budget for this project is estimated at $56,500, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $56,500

- Simulator usage, $20,500

- Graduate student, $36,000

Energy Harvesting for Tire Applications

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Problem Statement

One of the major issues in using battery powered wireless sensor nodes inside a tire based application like the TPM system arises when the battery is extinguished of all its power. In such a scenario, the sensor has to be retrieved and the battery replaced. Due to the remote placement of these devices within the tire carcass, battery replacement can become a very expensive task or even impossible. So even though a battery has the advantage of a fixed, stable voltage supply, its disadvantages are its limited total energy availability, its temperature dependency and it`s relatively short life span. To tackle this problem, over the past few years a number of novel energy harvesting systems have been proposed which have the capability to capture energy which otherwise would be lost. The energy captured could then be used to prolong the life of the power supply or in the ideal case provide endless energy for the electronic devices lifespan. In the case of tires, harvesting a small amount of the wheel's vibration energy, to power the sensing and wireless communication devices is an attractive proposition. This explains the increasing popularity of this concept in the tire fraternity, with the main focus being on developing a tire specific harvester unit to power wireless sensor nodes for a low duty cycle tire based application such as the tire pressure, temperature, and/or material strain monitoring system, that require sensors to be installed for long durations (up to 10yrs) or embedded in structures where battery replacement is impractical.

Objectives

The objectives of this project are as follows:

- The project is aimed at developing a broad band harvester unit, which would be adapted to the tire vibration spectra using certain novel power processing techniques, so as to meet the overall power demand requirements for a tire application.

- The tire harvester would be capable of generating power levels that would be sufficient for a multitude of wireless platforms such as ZigBee and Wi-Fi protocols which are expected to find their way in the next generation intelligent tires also.

- These harvesters designed for the harsh tire environments would provide a distinct advantage in cost and flexibility of installation while extending the lifetime of the power supply for sensor data acquisition and communication.

Timeline & Deliverables

Year 1:

- Instrument a tire with accelerometers to analyze the tire vibration spectra.
- Carry out extensive outdoor testing of the instrumented tire using the portable in-house tire test rig.
- Select an optimal operating frequency range for the harvester by analyzing the tire vibration spectra under a range of different dynamic test conditions.
- Based on the harvester design constraints identified from the above analysis, select an optimal harvester configuration selected for our analysis.
- Using the concept of modal analysis, develop a coupled electromechanical mathematical model of the harvester unit and using the vibration spectra of the tire, optimize the harvester design. Predict the electrical output for prescribed base excitation conditions.
- Validate the above results experimentally by testing the harvester using shaker experiments.

Key deliverable: Experimental test results of the selected harvester configuration.

Year 2:

- Fabricate the harvester prototype.
- Develop suitable interfacing power processing circuitry to enable broad band operation of the harvester.
- Validate the performance of the broad band harvester on a shaker.

Key deliverable: Experimental test results of the harvester interfaced with external power processing circuitry.

Year 3:

- Implement the power processing circuitry on a microchip. Mount the complete harvester assembly inside a tire.
- Analyze the performance of the harvester inside the tire environment by carrying out outdoor testing.
- Validate the ability of the harvester to cater to the power supply needs of a low duty cycle application e.g. TPMS, tire strain monitoring system.

Key deliverable: Final Product

Budget

The total three-year budget for this project is estimated at $115000, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $36,000

- Graduate student, $36,000

Year 2; Cost= $43,000

- Material and supplies, $7,000
- Graduate student, $36,000

Year 3; Cost= $36000

- Graduate student, $36,000

Off-Road Tire Model Based on Pacejka Magic Formula Model

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Problem Statement

Currently, much literature can be found for on-road tire testing, which is typically performed on a rolling road or a flat track. Off-road tire testing can be difficult and expensive, but is necessary for vehicles that are commonly driven on off-road terrain. This project proposes a method for extending an on-road tire model developed from rolling road testing to off-road driving surfaces.

During the course of previous research by the PI, an extension of Pacejka model for off-road studies was developed. Although this model works for lateral force and aligning moment on dirt and gravel roads, it lacks the fundamental characteristics of traction/braking and adjustments for penetration of tire into the soft surface. This project is aimed at developing such model that will use the test data generated on an off-road condition (soil, etc) and will provide the coefficients for the new model.

Objectives

The objectives of this project are as follows:

- To develop a new tire model capable of generating forces and moments for lateral, longitudinal forces and aligning moment (year 1)
- To validate the model using test data (year 2)

Timeline & Deliverables

Year 1: Develop the model.
Year 2: Collect data and validate the model.

Budget

The total three-year budget for this project is estimated at $72,000, excluding the university overhead (10% in this case). A breakdown of costs per year is as follows:

Year 1: Costs = $36,000

- Graduate student, $36,000

Year 2; Cost= $36,000

- Graduate student, $36,000

Continuous ultrasonic in-situ copolymerization of rubber blends suitable in tire applications

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Background

Rubber blending is a useful approach for the preparation of new rubbers with specially tailored or improved properties that are often absent in the single component polymers. Enhanced properties of polymeric materials are achieved by developing multi-component systems in the form of rubber blends composed of two or more homopolymers [1-4]. However, many rubber pairs are incompatible or immiscible with each other and exhibit very low or no interfacial adhesion and phase separate on blending. In most cases, melt mixing of two dissimilar rubbers results in blends that are weak and brittle. Some rubber pairs are almost impossible to mix with or disperse into one another. The mechanical properties of rubber blends are strongly influenced by the strength of the interfaces between the different phases, as well as the dispersion and interaction or adhesion between them.

Compatibilization of polymer blend has been studied for decades [1-4]. It is commonly known that compatibilization is achieved by addition of a third component, typically a block copolymer, to the system, or by inducing chemical reaction using chemicals, leading to modification of the polymer interfaces in two-phase blends, and thereby to tailoring of the phase structure, and hence properties. The addition of pre-made block copolymers can lead to a reduction of interfacial tension [5-8]. Block copolymers contain blocks chemically identical to the blend component polymers assuring miscibility between the copolymer segments and the corresponding blend component. However, these methods are likely to be restricted to the use of available polymers and the synthesis of block copolymers is not available for most polymer pairs of interest. Reactive blending relies on the *in-situ* formation of interacting polymers using specifically selected or tailored chemicals [3, 9]. The blend components themselves are chosen so that reaction at the interface occurs during melt blending leading to a reduction in particle size of the dispersed phase [10]. Although some polymers naturally contain functional groups at chain end, most must be functionalized prior to reactive compatibilization and the reaction rates are very slow thus, this method is impractical for use. Also, existing technologies for making plastic/rubber blends use mixing of components with aid of chemicals or dynamic vulcanization of rubber phase with aid of curatives [11]. Notably, the ability to make polymer blends at low cost from practically any pairs of existing polymers is very desirable.

It is known that by high intensity ultrasonic waves, long-chain polymer molecules can be ruptured during extrusion [12, 13]. The particular interest of ultrasonic degradation is the fact that, contrary to all chemical or thermal decomposition reactions, ultrasonic depolymerization carried out in solutions is a nonrandom process that produces fragments of definite molecular size [14-16]. The mechanical rupture of polymer chains leads to the formation of macro-radicals [17, 18]. The breakage of the C-C bond by the action of ultrasound usually leads to the formation of long-chain radicals [14]. Obviously, in the absence of scavengers the macro-radicals are free to combine. In polymer blends, both polymers can be ruptured by the high intensity ultrasonic waves. Moreover, the recombination of the macro-radicals, of the two polymers may occur with the formation of block copolymers [19]. It will obviously be more important when the chains of the polymers do not have vulnerable sites easily accessible to the free macro-radicals.

In recent years, plastic/rubber and rubber/rubber blends were prepared by ultrasonic treatment during continuous extrusion in order to investigate the *in-situ* compatibilization of the blends without any chemicals [20-. After ultrasonic treatment, the viscosity of the blends was decreased due to the breakup of main chains. However, tensile strength, elongation at break, Young's modulus and toughness and impact properties of plastic/rubber blends were significantly improved by ultrasonic treatment as compared to the untreated blends. After annealing, the domain size in the morphology of ultrasonically treated blend is much smaller than that of untreated blends. After ultrasonic treatment, the weight and z-average molecular weight of the blend was increased and the molecular weight distribution was broadened. The increase in the molecular weights was a clear indication of the creation of copolymer during ultrasonic treatment of blends. Similar to plastic/rubber blends, the tensile strength and elongation at break of ultrasonically treated rubber/rubber blend were significantly improved. It is believed that ultrasonic treatment of the blends enhances intermolecular interaction, improves adhesion and possibly makes chemical bonds between immiscible polymers without use of any chemicals. Also, the results of extraction experiments supported the belief that copolymers are created during ultrasonic treatment of the blends. The developed process can be applied for preparing plastic/rubber blends to make thermoplastic elastomers or plastic/plastic and rubber/rubber blends, and for making novel copolymers from practically any pairs of existing polymers to achieve desirable chemical and physical properties.

Proposal

The present proposal outlines the research for future manufacturing of novel rubber blends by in-situ ultrasonic compatibilization through making copolymers at the interface in nanolayers between components and its vicinity by means of ultrasonic treatment. Unexpectedly, the ultrasonic treatment of rubber blends during or after mixing is found to greatly improve their mechanical properties. An ultrasonic extrusion process developed in our laboratory for carrying out in-situ compatibilization without adding chemicals will be used. It utilizes high power ultrasonic treatment of the blends during extrusion to enhance intermolecular interaction to make chemical bonds between dissimilar rubbers creating copolymer without use of any chemicals. Carbon black and silica will be used as fillers in blends. This technology can be applied for preparing novel rubber/rubber blends and will provide technology to make novel copolymers with desirable chemical and physical properties useful in tire applications.

In-situ copolymerization experiments will be carried out using a coaxial ultrasonic extruder at a frequency of 20 kHz and various ultrasonic amplitudes. Blends of butadiene/natural rubbers, butadiene/SBR rubbers and SBR/natural rubbers will be studied. Carbon black and silica will be used as fillers. In particular, blends of butadiene/SBR rubbers and butadiene/natural rubbers are presently used in passenger tires. It is expected that in-situ compatibilization of these blends will lead to new rubbers that would enhanced tire performance.

Experimental studies on blends will include an extensive investigation of the effect of varying barrel temperature, flow rate and ultrasonic parameters on rheology, molecular structure, morphology and its stability upon heating and vulcanization characteristics and performance properties. Pressure at the entry to the ultrasonic treatment zone, output and the power on the screw extruder and the power on the ultrasonic generators will be measured. Based on these measurements the energy balance will be made to find the efficiency of the process concerning the total and specific energy consumption.

The die characteristics and their dependence on processing parameters will be established. In addition, the rheological properties of the components and in-situ compatibilized blends will be determined using Mooney viscometer and Advanced Polymer Analyzer (APA 2000) available in our laboratory. The blends will be prepared by using a Banbury mixer. The above mentioned blends will be compounded with curatives on two-roll mill and their vulcanization behavior will be measured using APA 2000. The blend compounds will compression molded and cured using a compression molding press. Mechanical properties and hysteresis of various vulcanized blends will be measured using an Instron Tensile Tester. In addition, the abrasion resistance of these vulcanizates will be measured using DIN Abrader. The storage modulus and tan delta as a function of temperature will be determined using DMA. Based on tan delta values of vulcanizates at low temperatures and 60^oC comparative analysis will be made concerning expected effects on the traction and rolling resistance of future tires made with inclusion of recycled tire rubber.

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Schedule

Year One of the project:

(1) Experiments on in-situ compatibilization of unfilled and carbon black- and silica-filled BR/NR blends of various ratios using the ultrasonic reactor and measurements of die characteristics and ultrasonic power consumption;
(2) Measurements of molecular characteristics using GPC and morphology and its stability under annealing using optical microscopy, AFM and SEM of the prepared untreated and ultrasonically treated blends;
(3) Study of rheological behavior of these blends as affected by ultrasonic process conditions using Mooney viscometer and APA 2000;
(4) Evaluation of vulcanization behavior of these blends of various ratios and measurements of the crosslink density and gel fraction of vulcanized blends;

(5) Preparation of moldings of blends and measurements of their mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(6) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(7) Preparation of the annual report.

Year Two of the project:

(1) Experiments on in-situ compatibilization of unfilled and carbon black- and silica-filled BR/SBR blends of various ratios using the ultrasonic reactor and measurements of die characteristics and ultrasonic power consumption;
(2) Measurements of molecular characteristics using GPC and morphology and its stability under annealing using optical microscopy, AFM and SEM of the prepared untreated and ultrasonically treated blends;
(3) Study of rheological behavior of these blends as affected by ultrasonic process conditions using Mooney viscometer and APA 2000;
(4) Evaluation of vulcanization behavior of these blends of various ratios and measurements of the crosslink density and gel fraction of vulcanized blends;
(5) Preparation of moldings of blends and measurements of their mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(6) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(7) Preparation of the annual report.

Year Three of the project:

(1) Experiments on in-situ compatibilization of unfilled and carbon black- and silica-filled SBR/NR blends of various ratios using the ultrasonic reactor and measurements of die characteristics and ultrasonic power consumption;
(2) Measurements of molecular characteristics using GPC and morphology and its stability under annealing using optical microscopy, AFM and SEM of the prepared untreated and ultrasonically treated blends;
(3) Study of rheological behavior of these blends as affected by ultrasonic process conditions using Mooney viscometer and APA 2000;
(4) Evaluation of vulcanization behavior of these blends of various ratios and measurements of the crosslink density and gel fraction of vulcanized blends;
(5) Preparation of moldings of blends and measurements of their mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(6) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(7) Preparation of the annual report.

Deliverables

New knowledge-based in-situ ultrasonic compatibilization technology of rubber blends will be developed. Novel in-situ compatibilized unfilled and carbon black- and silica-filled BR/NR, BR/SBR and SBR/NR blends with enhanced performance properties and stable morphology will be obtained and available for testing by various tire companies.

Budget

Continuous ultrasonic in-situ copolymerization of rubber blends suitable in tire applications

	Year 1	Year 2	Year 3	Total
Avraam I. Isayev, PI (about 1 month summer salary)	$15,000	$15,500	$16,000	$46,500
PhD Graduate Student	$25,000	$26,000	$27,000	$78,000
Supplies and Services	$10,000	$10,500	$11,000	$31,500
Travel	$3,000	$3,500	$4,000	$10,500
Direct Cost	$53,000	$55,500	$58,000	$166,500

Grand Total (direct cost only) **$166,500**

Rolling Resistance of Smart Nanofabrics

PI: Shing-Chung Josh Wong

Department of Mechanical Engineering

University of Akron, Akron OH 44325-3903.

Email: swong@uakron.edu

Executive Summary

This project aims to evaluate and quantify the rolling resistance of a variety of nanoscale and nanostructured yarns and fabrics that can be applied for tire applications. The yarns and fabrics can be made smart and responsive to stress and environmental factors by incorporating a self-actuating and functional component or components in the design. Rolling resistance contributes to 6-10% of the overall fuel consumption of vehicles. The capability of differentiating and thus managing the contributing factors, which include but are not exclusive to, fiber adhesion, viscoelastic deformation and drag frictional force, to rolling resistance will determine the future success of a smart tire design. The project will make use of an oscillated pendulum and acoustic emission devices in the Department at the University of Akron. It will leverage on the existing resources in advanced materials characterization and thus the materials research hub at Akron. The project will be expanded to a complete bottom-up design for smart tires when funding conditions permit.

Budget Request: $40,000/year for 2 years.

EXPERIMENTAL AND NUMERICAL HYDROPLANING AND EXPERIMENTS FOR RAPID EVALUATION OF TIRE DESIGNEXPERIMENTAL WORK:

M.J. Braun
Mechanical Engineering, University of Akron, Akron, OH 44325
Email: mjbraun@uakron.edu, Tel:330-972-7734

The proposed work concerns an experimental and numerical fundamental study of the causes and processes of hydroplaning for an automotive tire

GOALS:

Experimental Work

1. Determination of the fundamental mechanism by which water lifts a rotating and rolling tire off the road, including the effects due to tire deformation
2. Determination of the mechanism by which the water is “pushed” out from under the tire.
3. Determination of the interaction (causes and effects) between the compliant surface of a tire and the rigid surface on which it rotates/rolls.
4. Determination of the contribution of the tire surface profile, road texture and the interaction between the two of them to the process of hydroplaning.

Numerical Work

1 Use of a commercial code that integrates solid/fluid interaction for full transient simulation
2 Construct model consistent with the experimental simulation
3 Use database obtained from the experimental track for validation of numerical model

OUTCOMES:

1. ***Construct a coherent scenario ,*** backed by experiments and numerics as to the initiation, development and cessation of the process of hydroplaning**.**
2. ***Create an extensive, validated database*** of tire profiles and their performance
3. ***Validated*** numerical model
4. ***Establish a streamlined procedure*** based on items 1) and 2) for rapid evaluation of proposed tire tread performance :
   -- construct and test prototype to verify findings
   -- apply procedure to actual design and implement in production
   -- provide experimental data that can be directly used in the validation process for the interested user

DELIVER experimental test section, methodology, database,
DELIVER validated code, method and input files

TASKS

Based on the scope of work detailed above we propose the following tasks:

(a) complete literature search regarding previous experimental work and numerical work.
(b) Design in detail the test installation. This will include
--design and construction of the annular rotating track for the tire and its guiding supports.
--design and construction of the loading mechanism, its control and instrumentation. The loading mechanism will contain a hydraulic cylinder, load cell, spring and damper assembly.
--design and construction of the water feed and scavenge loop. This will form a closed loop water circuit that will feed the water under the tire at variable rates, and have on the downstream of the tire a scavenge pump that will allow to fully control the level of wetness of the "pavement". A flowmeter and pressure gauges will allow control of the mass flow rates.
--customization of the vision system for fluid flow tracking and quantification under the tire footprint.
--design and installation of the pressure sensing system. This system will include specially designed pressure taps connected to miniature pressure transducers. They will be installed both in the "road" and tire.
--customization of the data acquisition system for 32 high speed differential channels (LabView software). A National Instruments system will be used. For low frequency or steady state a 200 channels NEFF data acquisition system will be used. (*These systems are available at UA)*
--choose variable speed electric motor (75 HP) and controls, and design motor train for entraining the tire. In this design we will incorporate a torque sensor that will monitor the torque on the tire and be a good indicator for hydroplaning incipience. *(These systems are available at UA)*
(c) Assembly and debug the test installation
(d) Prepare a variety of tire tread profiles for testing
(e) Testing for different tread profiles. For every tested profile the following parameters will be varied.
-- angular speed of the tire
-- loading of the tire
-- mass flow of water feed and scavenge
-- profile of the "road"

(f) ***Experimental work***. The scope of work here will be partitioned in two categories.
(I) Flow visualization. Within this category we will obtain fundamental information regarding the flow patterns at circumferential inlet and exit of the tire as well as the flow under the footprint and its configuration as it exit axially the tire pattern. In this context we will try to obtain both qualitative and quantitative results that can be directly used in the improvement of the tire pattern design and validation of numerical codes.
(II) Pressure and torque mapping. These numerical measurements will be used for the creation of a database to study the incipience and development of hydroplaning, and give a coherent image and guidance for design improvements. We intend to create an extensive database that can also be used as a basis for numerical validation of simulation algorithms.
(III) Correlation of flow patterns with pressure and torque measurements. The data obtained at items (I) and (II) will be corroborated and arranged in a library of images with the corresponding pressure and torque measurements.

DELIVER experimental test section, methodology, database,

(g) Numerical Work

I. Tire material and construction. Obtain from the sponsor appropriate information regarding material constitutive equations and structure as a composite material

II. Test-model deformation of the material under load w/o any interaction with a second body

III. First generation model for solid-fluid-solid interaction (road-fluid-tire). In this context we will model exactly the experimental installation described above.

IV. Validation of the model using the experimental data

V. *Second generation model: combination of the model from items (I to III) with thermal equation for temperature evaluation. (This item is proposed for continuation past the second year)*

DELIVER validated code, method and input files

TIMETABLE

Tasks	Month 1-3	Month 4-7	Month 8-12	Month 13-24
Literature review for both experimental and numerical work	♦-------------♦			
EXPERIMENTAL				
Installation design	♦---------------♦			
Review meetings	♦			
Construction		----♦---------------♦		
Review meeting			♦	
Debugging			♦--♦	
Experimental work			----- ♦------------------------------------♦	
Review meetings				♦ ♦ ♦
Database construction				♦----------------------♦
Review meetings				♦
NUMERICAL				
Tire material and construction		♦------♦		
Test-model of the material under load w/o any interaction with a second body		♦-------------♦		
First generation model for solid-fluid-solid interaction			♦----------------------♦	
Validation of the model using the experimental data				♦-------------♦
DELIVER validated code, method and input files				♦-♦

BUDGET

Year 1: $80,000

Included:	PI salary for 2 summer month + fringes and overhead Construction of the test section
Costshared:	1 grad student

YEAR 2:	**60,000**

Included:	PI salary for 2 summer month+ fringes and overhead Supplies, maintenance and running the test section
Costshared:	1 grad student

Development of a Computational Tool for Optimization of Steel Cord Construction

Xiaosheng Gao
University of Akron

Rapid advance in computational technology (both hardware and software) has made computer simulation an integrated part of the tire development process. Comparing to building and testing physical prototypes, computer simulation provides a means which is quicker to identify faults and optimize design so that time-to-market and development costs can be drastically reduced. Due to the complexity of tire structure, tire analysis often requires multi-scale modeling. The global analysis considers the full assembly featuring cord laminae as shell with rebar, and subcomponents with minimal representation. It provides stresses and deformation at the global level, which can be used to prescribe boundary conditions for the local analysis. In local analysis, detailed material and structural features and mechanism based failure models can be included. This project aims to develop a computational tool for optimization of tire steel cord construction.

Goal: to develop a computational tool that can be used to select more economical and durable cord construction

Objectives:

1) To modify a previously developed steel cord mesh generator to enhance mesh quality around the contact areas
2) To investigate on how to account for the interaction between the steel cord and the surrounding rubber in the local analysis
3) To conduct multi-scale analysis of a tire and to evaluate the fatigue life of the steel cord

Duration: 2 years

Budget: $30k/year

Deliverables: computer program and written report

1) First year: a mesh generator that automatically generates finite element meshes for various cord construction
2) Second year: multi-scale analysis of a tire

Development of an Irreversible Cohesive Zone Model for Prediction of Tire Belt Fracture and Separation

Xiaosheng Gao
University of Akron

Rapid advance in computational technology (both hardware and software) has made computer simulation an integrated part of the tire development process. Comparing to building and testing physical prototypes, computer simulation provides a means which is quicker to identify faults and optimize design so that time-to-market and development costs can be drastically reduced. Due to the complexity of tire structure, tire analysis often requires multi-scale modeling. The global analysis considers the full assembly featuring cord laminae as shell with rebar, and subcomponents with minimal representation. It provides stresses and deformation at the global level, which can be used to prescribe boundary conditions for the local analysis. In local analysis, detailed material and structural features and mechanism based failure models can be included. Tires are subjected to cyclic loading and fatigue cracks often initiate in the belt edge area. These fatigue cracks then propagate and lead to belt separation. But up until now, prediction of fatigue failure remains an empirical art. Despite the widespread use of the Paris law (including the various modified forms), it is worth noting that it provides a data correction scheme rather than a predictive capability primarily because it does not capture the physics of fatigue crack growth. This project aims to develop an irreversible cohesive zone model that can be used to predict tire belt fracture and separation.

Goal: to develop a computational tool that can be used to predict tire durability and reliability

Objectives:

1) To expand the applicability of the irreversible cohesive zone model we developed for predicting crack initiation and propagation in metals and composites so that it can be used to analyze tires
2) To calibrate the model parameters using experimental data obtained from coupon specimens
3) To conduct multi-scale analysis of a tire and to predict crack initiation and propagation at the belt edge area

Duration: 3 years

Budget: $30k/year

Deliverables: computer program and written report

1) First year: development of the irreversible cohesive zone model and implementation of the model into a finite element code
2) Second year: calibration of the material specific model parameters
3) Third year: prediction of the crack initiation and propagation at the belt edge area of a given tire

Constitutive Modeling of Rubber

PI: Professor Michelle S. Hoo Fatt
Dept. of Mechanical Engineering
The University of Akron
(330) 972-6308 (office)
hoofatt@uakron.edu (email)

Summary

Accurate constitutive models for rubber compounds are essential for predicting the behavior and performance of tires. Such constitutive models must be derived from consistent and repeatable test data. This project consists of two parts: (1) an experimental phase in which hysteresis and temperature data are acquired and (2) an analytical/numerical phase in which a constitutive model is developed and incorporated in finite element analysis. Thermo-mechanical material characterization of the cyclic behavior a filled rubber compound will be done with an MTS 831 servo-hydraulic machine and a FLIR Infra-red camera. The constitutive model and FEA code would be of substantial value and importance to the tire industry since it would allow them to examine the response and performance of tires without costly and time-consuming field tests.

The technical approach is as follows:

- Run cyclic material tests and biaxial, hole-in-sheet tests under controlled ambient temperature. Track specimen force, deformation and temperature with time.
- Develop 3D constitutive model based on test results.
- Extract material parameters from tests.
- Simulate uniaxial material response and compare to test data.
- Write UMAT subroutines for FEA.
- Simulate hole-in-sheet experiments using FEA to validate 3D constitutive model.

This research offers new and innovative test methods for characterizing tire rubbers. Such test methods could eventually become rubber test standards, thereby enhancing the pool of existing test standards for rubbers. The research will involve undergraduate students in the mechanical-polymer engineering program, who will aid in the design of experiments (both apparatus and methodologies), as well as graduate students, who will be trained in rubber mechanics through their thesis and dissertation research.

Specific outcomes of this research project are as follows:

1. New experimental technique to address *actual* behavior of tire rubber.
2. Stress-strain-temperature data from MTS servo-hydraulic machine.
3. Thermo-mechanical, rate-dependent constitutive model for filled rubber.
4. User-defined material sub-routine (UMAT) for FEA.
5. More accurate simulated tire response in FEA.

Benefits of the outcomes to tire industry include (1) better predictive capabilities of tire performance, including safety, reliability and mileage; (2) new constitutive models for rubbers under dynamic loading; and (3) trained professionals in the tire mechanics field with BS, MS and PhD degrees.

Timeline & Deliverables

Year 1: Experimental method/test plan. Temperature/strain-rate controlled hysteresis data from MTS servo-hydraulic machine.
Year 2: Constitutive model/equations.
Year 3: FEA user-material subroutine for tire simulation.

Budget

The total three-year budget for this project is $253,000, excluding 48.5% University of Akron Overhead. The Overhead on this project is an additional $71,780 (Overhead is not charged on equipment exceeding $5K). A breakdown of costs per year is as follows:

Year 1: Costs = $153,450

Equipment – FLIR IR camera system, $90K
MTS Fixtures – Retrofitted Germanium window panel for heat chamber, $15K
Materials - $5K
PI Summer – $13.95K (including benefits)
Grad Student – $20K
Undergrad Student – $6K
Travel - $3.5K

Year 2: Costs=$49,150

Materials - $5K
PI – $14.65K (including benefits)
Grad Student – $20K
Undergrad Student – $6K
Travel - $3.5K

Year 3: Costs =$50,400

Materials - $5K
PI – $15.4K (including benefits)
Grad Student – $20
Undergrad Student – $6K
Travel - $4K

GREEN(ER) TIRE TECHNOLOGY
EXECUTIVE SUMMARY

TRTC Tire Center Proposal
Judit E. Puskas

PROJECT DESCRIPTION

The magic triangle of rolling resistance, traction and wear is the Holy Grail of tire technology. Decreased rolling resistance without sacrificing wear and traction would reduce green house gas emission. We propose to investigate two new polymers that may break the magic triangle: A: randomly branched SBR; B: new biodegradable disulfide polymers.

1. Background. The Puskas group developed new, greener technologies for the synthesis of new polymers that have the potential of breaking the magic triangle. **A:** High molecular weight randomly branched polymers with controlled multimodal/broad distribution via *inimer*-type Reversible Addition-Fragmentation-Transfer (RAFT) polymerization, the most versatile of the controlled radical polymerization techniques. This method uses an initiator-monomer (inimer) that will produce a branched polymer without the risk of crosslinking. The technique was demonstrated to work in the bulk polymerization of styrene. We also developed methods for branching analysis based on high resolution Size Exclusion Chromatography SEC. **B:** novel high molecular weight biodegradable disulfide polymers and networks. This method uses water, hydrogen peroxide and air. The University of Akron filed patent applications for both technologies.

2. Objectives: A: Synthesize and characterize randomly branched SBR; B: Synthesize and characterize disulfide polymers and networks; C: investigate filler interaction with both polymers.

3. Methodology and Approaches. A: Synthesize and characterize randomly branched emulsion SBR using the RAFT inimer technology, and provide samples to the industrial partners to compare the performance of the polymer with regular emulsion SBR. B: synthesize and characterize disulfide polymers and networks and provide samples to the industrial partners; C: Provide samples to the industrial partners to investigate filler interaction with the novel polymers.

4. Project Management: Progress will be actively followed throughout the project to maximize the chance of success & allow adjustments in the plan as needed to respond to results/discoveries/knowledge found as the project unfolds. If changes in plan are required, for example as shown by the deliverable falling below the target, or no deliverable made (e.g. a report), then one of the options below will be chosen:

- Option to adjust timing
- Option to pursue a new approach (hypothesis) to meet the final deliverable

5. Annual budget

A: $52,500 One student ($25,000); chemicals ($10,000); Overhead 50% ($17,500)
B: $52,500 One student ($25,000); chemicals ($10,000); Overhead 50% ($17,500)
C: Industrial partner in kind contribution.

6. Service. We are happy to provide SEC services to the industrial partners using our high resolution system: 5 detectors, 6 columns. We were able to correlate Mooney viscosity of butyl rubber with MW data using this system.

Continuous ultrasonic processes for devulcanization of rubbers suitable for incorporation in new tires

Avraam I. Isayev
Department of Polymer Engineering
The University of Akron
Akron, OH 44325-0301
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330-972-6673

Background

A continuous process for devulcanization of rubbers, developed in our laboratory, is by the application of high power ultrasound in the presence of pressure and heat. By using this technique the three-dimensional structure of crosslinked rubbers rapidly breaks down making them reprocessable and curable again. Various devulcanization reactors were developed and extensive data were accumulated on limited number of rubbers along with attempts to develop mechanisms of devulcanization and models to theoretically describe the process and a possibility of the process scale up [1, 2]. So far a comparative analysis of process characteristics, rheological and mechanical properties, structural transformations, curing behavior and NMR relaxation and diffusion processes in unfilled and filled rubbers during their ultrasonic treatment were carried out in laboratory environment. Properties of blends of devulcanized and virgin rubbers were also studied. Sulfur and peroxide cured rubbers were investigated along with details of degradation mechanisms of the rubber network by ultrasonic waves.

In 2007, a company, Avraam Corporation, was created in Akron, Ohio, with aim to design and manufacture industrial devulcanization reactors for recycling various rubbers, including tire rubber. The first 3.5 inch ultrasonic devulcanization extruder was manufactured, tested and shipped to a foreign country.

Ultrasonic devulcanization of rubbers is a new technology. Presently, it is in infancy stage and it is not fully understood and optimized. Limited experimental results, that were obtained, show that each rubber, due to its different molecular structure and compounding recipe, behaves differently during ultrasonic devulcanization. So far, information on ultrasonic devulcanization of only a few different types of rubbers has been obtained [1, 2].

Further work was directed towards ultrasonic devulcanization of various existing rubbers used in tires in order to find optimal conditions for their devulcanization and subsequent use in tires. Moreover, the models of ultrasonic devulcanization, that have been put forward so far, use simplified approaches to a very complex phenomena taking place during devulcanization. Therefore, significant challenges exist in the development of a suitable theory for the description of the devulcanization process due to the complexity of the processes occurring simultaneously during ultrasonic devulcanization. Future studies have to be directed to solve these problems.

Proposal

The present proposal outlines experimental research efforts to be undertaken to further develop ultrasonic technology for recycling ground tire rubber (GTR) by carrying out targeted experiments to study the ultrasonic devulcanzation process, fabrication, structure and properties of the new tire materials by incorporating devulcanized GTR rubbers. The proposed research will be conducted on the GTR rubbers of various mesh sizes as provided by manufacturers and/or by tire companies. Devulcanization experiments will be carried out using a coaxial ultrasonic extruder at a frequency of 20 kHz and various ultrasonic amplitudes. Experimental studies will include an extensive investigation of the effect of varying barrel temperature, flow rate and ultrasonic parameters on the crosslink density and gel fraction of devulcanized rubbers. Pressure at the entry to the devulcanization zone, output and the power on the screw extruder and the power on the ultrasonic generators will be measured. Based on these measurements the energy balance will be made to find the efficiency of the process concerning the total and specific energy consumption.

The die characteristics and their dependence on processing parameters will be established. In addition, the rheological properties of the devulcanized rubbers, blends of virgin tire compounds with devulcanized GTR rubbers and blends of virgin tire compounds with GTR rubbers of various meshes will be determined using Mooney viscometer and Advanced Polymer Analyzer (APA 2000) available in our laboratory. The blends will be prepared by using a Banbury mixer. The devulcanized GTR rubbers and the above mentioned blends will be compounded with curatives on two roll mill and their vulcanization behavior will be measured using APA 2000. The compounds will compression molded and cured using a compression molding press. Mechanical properties of the revulcanized GTR rubbers and various blends will be measured using an Instron Tensile Tester. In addition, the abrasion resistance of these vulcanizates will be measured using DIN Abrader. The storage modulus and tan delta as a function of temperature will be determined using DMA. Based on tan delta values of vulcanizates at low temperatures and 60^{o}C comparative analysis will be made concerning expected effects on the traction and rolling resistance of future tires made with inclusion of recycled tire rubber.

References

1. A. I. Isayev and Sayata Ghose, "Ultrasonic Devulcanization of Used Tires and Waste Rubbers", in book Rubber Recycling, S. K. De, A. I. Isayev and K. Khait, eds., CRC Press, Boca Raton, Chapter 9, pp. 311-384, 2005.

2. A. I. Isayev and J. S. Oh, "Tire Materials: Recovery and Re-use", in book The Pneumatic Tire, Eds. A. N. Gent and J. D. Walter, NHTSA U.S. Department of Transportation, Washington, DC, Chapter 18, pp. 670-691, 2005.

Schedule

Year One of the project:

(1) Experiments on devulcanization of GTR of various meshes, including 10-16, 30, 60 and 90 mesh, using the ultrasonic reactor with measurements of die characteristics and ultrasonic power consumption;
(2) Measurements of the gel fraction of GTR of various meshes and devulcanized GTR of various meshes;
(3) Study of rheological behavior of devulcanizied GTR as affected by devulcanization process conditions;
(4) Evaluation of revulcanization behavior of devulcanized GTR of various meshes and measurements of the crosslink density and gel fraction of revulcanized rubbers;

(5) Preparation of moldings of devulcanized GTR of various meshes and measurements of mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(6) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(7) Preparation of the annual report.

Year Two of the project:

(1) Compounding of devulcanized GTR of various meshes with virgin tire rubbers at concentrations 5, 10, 30 and 60 phr;
(2) Study of rheological behavior of virgin tire rubber compounds and mixtures of devulcanizied GTR with virgin tire rubbers;
(3) Investigation of vulcanization behavior of virgin tire rubbers and mixtures of devulcanizied GTR with virgin tire rubbers and measurements of the crosslink density and gel fraction of vulcanizates;
(4) Preparation of moldings of mixtures of devulcanized GTR of various meshes with virgin tire rubbers and measurements of mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(5) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(6) Preparation of the annual report.

Year Three of the project:

(1) Compounding of GTR of various meshes with virgin tire rubbers at concentrations 5, 10, 30 and 60 phr;
(2) Study of rheological behavior of mixtures of GTR of various meshes with virgin tire rubbers;
(3) Investigation of vulcanization behavior of mixtures of GTR of various meshes with virgin tire rubbers and measurements of the crosslink density and gel fraction of vulcanizates;
(4) Preparation of moldings of mixtures of GTR of various meshes with virgin tire rubbers and measurements of mechanical properties (including the stress-strain behavior and hysteresis) and abrasion resistance of moldings;
(5) Measurements of the storage modulus and tan delta of moldings as a function of temperature;
(6) Comparison of properties of compounds and vulcanizates of virgin tire rubbers, devulcanized GTR of various meshes, mixtures of devulcanized GTR of various meshes with virgin tire rubbers and mixtures of GTR of various meshes with virgin tire rubbers;
(7) Preparation of the final report.

Deliverables

New knowledge-based devulcanization technology will be developed. New tire rubber compounds with suitable contents of recycled tire rubber will be developed and suggested for implementation in manufacturing new tires by various tire companies.

Budget

Continuous ultrasonic processes for devulcanization of rubbers suitable for incorporation in new tires

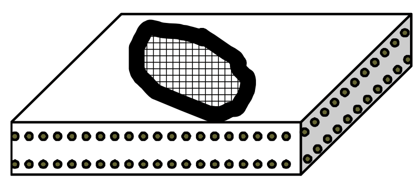
	Year 1	**Year 2**	**Year 3**	**Total**
Avraam I. Isayev, PI (about 1 month summer salary)	$15,000	$15,500	$16,000	$46,500
PhD Graduate Student	$25,000	$26,000	$27,000	$78,000
Supplies and Services	$10,000	$10,500	$11,000	$31,500
Travel	$3,000	$3,500	$4,000	$10,500
Direct Cost	$53,000	$55,500	$58,000	$166,500
Grand Total (direct cost only)				**$166,500**

HYSTERESIS BEHAVIOR OF FULL TIRE AND COMPOSITES AS A FUNCTION OF MODULUS and GEOMETRY of REINFORCEMENT

Dr. T. S. Srivatsan and Dr. A. Prakash
Department of Mechanical Engineering
The University of Akron, Akron, Ohio 44325-3903

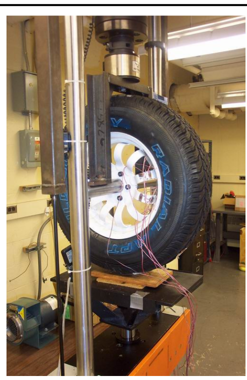
A tire structure comprises of a reinforcement fiber (wire) in a polymer / elastomer matrix. The energy consumed by the tire is related to this complex structure of the composite, which develops a hysteresis during the loading and unloading cycle. Hypothetically if the structure is fully elastic like metals and their alloy and composite counterparts, the tire can be run on any inflation without drastically affecting the vehicle's fuel economy [MPG (Miles per Gallon)].

A tire composite is made of rubber / elastomer reinforced with a high strength cord. The modulus of the reinforcing cord ranges from 15 GPa for Polyester, 70 GPa for Aramid to 200 GPa for high strength steel cords. The size and distribution of the reinforcement does exert a profound influence on the energy absorption capability of the composite under various modes of loading.

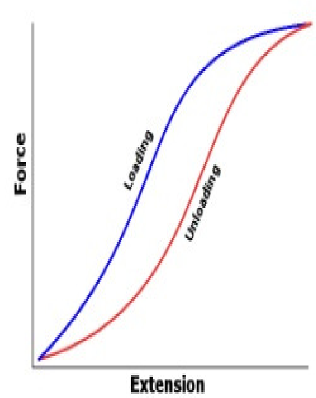


A two ply reinforced composite

In our earlier research work, we have studied and documented the hysteresis behavior of wire-reinforced rubber matrix composites. We have also done a detailed study of cord mechanics where structure of a cord (cable) is analyzed for stress distribution and inter filament friction when subject to loading. The work was further carried on a full tire, where strain gauges were mounted on the reinforcement at various key locations and the resultant strain behavior was recorded under different loads. This provided a good mapping of the deformation behavior of a tire at critical locations. Due to noticeably significant non-linearity in material properties, we believe that the best characterization of the tire structure is by a laboratory test method as briefly outlined below. We currently have the facilities to mount strain gauges at various locations of a tire or a composite and to effectively and efficiently conduct both static and dynamic tests under various loads.



Whole tire load deflection with mounted strain gauges



The proposed program

(a) To characterize the side wall, a single ply composite will be studied. For a given fixed tensile strength of the composite, three cords of different diameters and constructions will be used. The cords will be of steel, aramid or polyester or a combination. The resulting thickness will depend upon the cord diameter. Load, deflection and hysteresis will be studied using strain gauges.

(b) Simulation of tread area, a composite having one 90 degree ply and two- plies at bias angles will be examined. Three cord densities as outlined in (a) above will be examined.

(c) Similar to the study delineated in (b), four plies of the 'belt' at bias angles will be used.

THE HYSTERESIS BEHAVIOR of FULL TIRE and COMPOSITES as a FUNCTION OF MODULUS and GEOMETRY of REINFORCEMENT

►	**DIRECT COSTS**	**January to December (12 months)**
	Personnel	
●	**Faculty:**	
	♣ **Dr. T.S. Srivatsan**	**Nil**
	♣ **Dr. Amit Prakash (2 summer months)**	**10,000.00**
●	**Post Doctoral Research Associate (One)**	**34,000.00**
●	**Graduate Student (One)**	**14,000.00**
	Fringe Benefits [29% faculty + 0.7% students]	**12,858.00**
	Total Wages: Salaries + Fringe Benefits	**70,858.00**
►	**INDIRECT COSTS**	
◘	**Permanent Equipment (Test fixtures, specimen support and loading attachments)**	**4,000.00**
◘	**Mechanical testing (machine use and modification)**	**4,000.00**
◘	**Material Cost (to include supplies)**	**1,000.00**
◘	**Machine Shop Costs**	**950.00**
◘	**Travel Costs**	**Nil**
	Total Other Costs	**9,950.00**
►	**TOTAL DIRECT COSTS**	**80,808.00**
►	**INDIRECT COSTS**	**39,192.00**
	Total DIRECT plus INDIRECT COSTS	**$ 120,000.00**

A NOVEL DESIGN FOR MANUFACTURING EFFICIENT AND LOW WEIGHT RUN-FLAT TIRES USING COMPOSITE TOROIDAL SPRINGS

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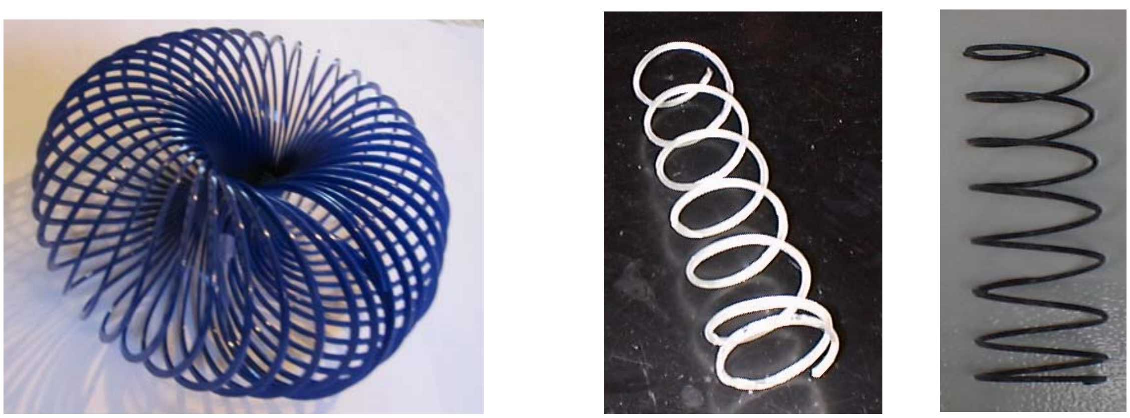
http://www2.uakron.edu/cpspe/dpe/web/sancaktar.htm

Executive Summary

We aim to reduce tire weight and increase tire performance including its service length in comparison to current sidewall-strengthened or rubber-filled run-flats by using toroidal (Figure 1A) composite helical springs (Figure 1B, 1C) placed over the rim in a manner similar to Michelin's PAX system (Figure 2).

We propose a three-year R&D activity with specific objectives and deliverables for each year.



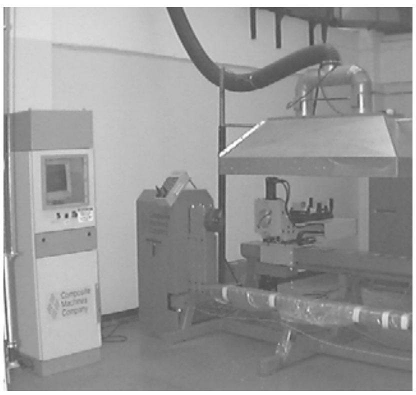
(A) **(B)** **(C)**

Figure 1. Illustrations of toroidal geometry with circular cross-section (torus) (A), and glass fiber (B), and carbon fiber (C) reinforced epoxy-matrix composite helical springs.

Figure 2. Michelin PAX run-flat design.

General Goals

Our general goal for the proposed three-year R&D activity is to reduce tire weight and increase tire performance including its service length in comparison to current sidewall-strengthened or rubber-filled run-flats by employing toroidal composite helical springs produced using the composites manufacturing equipment already available in Dr. Sancaktar's research laboratory as described below and shown in Figure 3.



(A)

(B)

Figure 3. CMC computer controlled filament winding machine (A), and 3 ft diameter graphite-epoxy cylinder manufactured using it (B).

A Model MD **CMC Computer Controlled Filament Winding Machine and its associated filament winding software are available at our research laboratory** (Figure 3). The filament winder is a single spindle, 4-axis machine with computerized motion control. Filament and/or ribbon winding capability are 41 in part diameter; 120 in part length; 2,000 lb mandrel weight; 0 to 90 degrees winding angles; 8 in 3- jaw chuck headstock, and tailstock; pattern linking capability. Cad wind process simulation system for filament winding is available to automatically create the mandrel model, to calculate the winding and to generate the part program.

We also have a **Despatch Digitally Controlled, Walk-in Thermal Curing Chamber** with inside dimensions of 68 in deep X 68 in wide X 71 in high, 120 in inside diagonal length, depth increase capability and 750 °F (400 ^{o}C) heating capacity.

An **Advanced Vacuum Systems Autoclave** with 12 in x 18 in area at 650 ^{o}F, 300 psig gas charging capability is also available.

Objectives and Deliverables

YEAR 1

Objectives: To use our existing Micro-Macro (Mic-Mac) composites design software and the ANSYS FEA software to arrive at alternative designs with the necessary toroidal cross section geometries, coil dimensions and wire diameters and the number of turns needed for run-flat composite support spring for service in a tire for a given period of time. Based on these calculations, to use our existing CMC computer controlled filament winding machine to manufacture a toroidal composite helical spring to be cured in-situ over a rim commercially available or to be suggested by sponsor(s) to fit on a current year model car. This assembly will be fitted with a commercially available tire of sponsor's preference and mounted on a rental car. The designed wheel will first be inflated with air and driven for a specified time for evaluation. It will then be deflated and driven for a specified time for evaluation.
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed run-flat design.

YEAR 2

Objectives: Based on the design calculations performed during Year 1, we will use our existing CMC computer controlled filament winding machine to manufacture toroidal composite helical springs of at least 3 additional and different cross sectional geometries, coil dimensions and wire diameters and the number of turns to be cured in-situ over a rim commercially available or to be suggested by sponsor(s) to fit on a current year model car. Each design will be manufactured using glass, carbon and glass/carbon hybrid fiber reinforcements. These assemblies will be fitted with a commercially available tire of sponsor's preference and mounted on a rental car. The designed wheels will first be inflated with air and driven for a specified time for evaluation. They will then be deflated and driven for a specified time for evaluation in sequence.
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed run-flat design.

YEAR 3

Objectives: Design for adaptation of the toroidal composite helical run-flat system process to industrial manufacturing environment. Design the necessary equipment with the necessary safety and efficiency considerations.
Deliverables: Design plan for the adaptation of the toroidal composite helical run-flat system process to industrial manufacturing environment.

Budget: $ 50K/Year in direct costs.

UV LASER TREATMENT OF TIRE REINFORCING (CORD/BELT /FABRIC) FIBERS FOR IMPROVED ADHESION TO RUBBER

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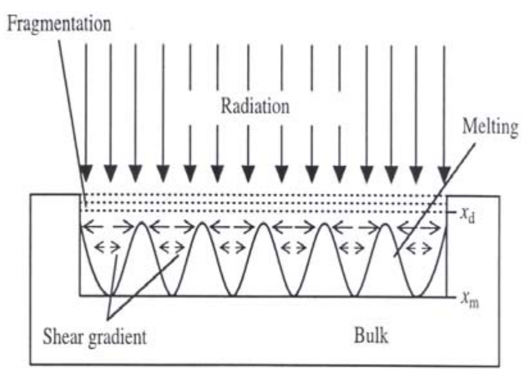
Executive Summary

We aim to obtain stronger and durable reinforcement adhesion by using the laser irradiation method. For this purpose, we propose an excimer laser-based process (Figure 1A) to create surface topography (Figure 1B) on tire reinforcing (cord/belt/fabric) fibers conducive to mechanical adhesion. This process can be coupled with any existing chemical surface treatment process. We propose a three-year R&D activity with specific objectives and deliverables for each year.



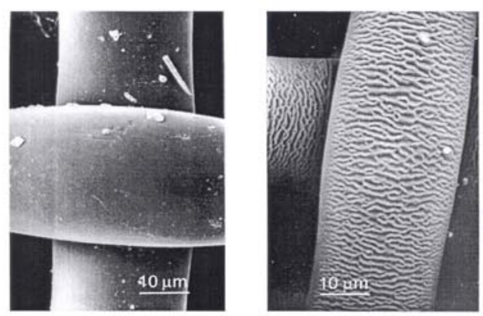


Figure 2. Scanning electron micrographs of PET fibers before (left) and after (right) UV-laser irradiation (248 nm, 10 pulses).

(A) **(B)**

Figure 1. Illustrations of methods of increasing mechanical adhesion by UV laser induced process (A), to create surface topography conducive to mechanical adhesion (B) (A.N. Netravali, T. Bahners, J. Adhesion Sci. Technol. 24, 45 2010).

General Goals

Our general goals for the proposed three-year R&D activity are as follows:

1- Reduction in premature tire failures due to reinforcement separation.

2- Increase in tire performance limits due to stronger and durable reinforcement adhesion.

Figure 2. Lambda Physik excimer LPX 2401 pulse laser

Our Lambda Physik excimer LPX 2401 pulse laser (Figure 2) with 157 to 351 nm wavelength range (F2, ArF, KrF, XeC1, XeF), and the related optics, and accessories were purchased with a National Science Foundation award (Award Number: 9724185). The maximum pulse energy of the laser is 300 mJ (KrF), the minimum pulse duration is 18 ns (F_2), and the maximum repetition rate is 400 Hz (KrF, XeC1, XeF). The acquired high repetition rate laser with high-energy delivery capacity (2 X 10^9 W/cm^2 with KrF) allows accomplishing engineering tasks which require larger volumes to be treated. The maximum pulse energy of 300 mJ available with the acquired laser is sufficient to evaporate aluminum, titanium and copper for adhesion pretreatment ablation purposes as well as other surface treatment tasks. The excimer laser beam is aligned with the help of a diode laser assembled onto the back frame, and focused by ARC (Acton, MA) convex lens(es) made of Suprasil 2® UV grade fused silica with 775 mm (or other) focal distance and 90% transmission efficiency. The samples can be aligned so that the laser beam is perpendicular on them. Irradiation can be performed at the focal point (maximum energy concentration), or different distances and with different masks for less and shaped energy delivery. The output energy can be monitored using a joule meter.

This excimer laser is available in Dr. Sancaktar's research laboratory.

Figure 3 illustrates UV laser irradiation effects on adhesion of PET as an example.

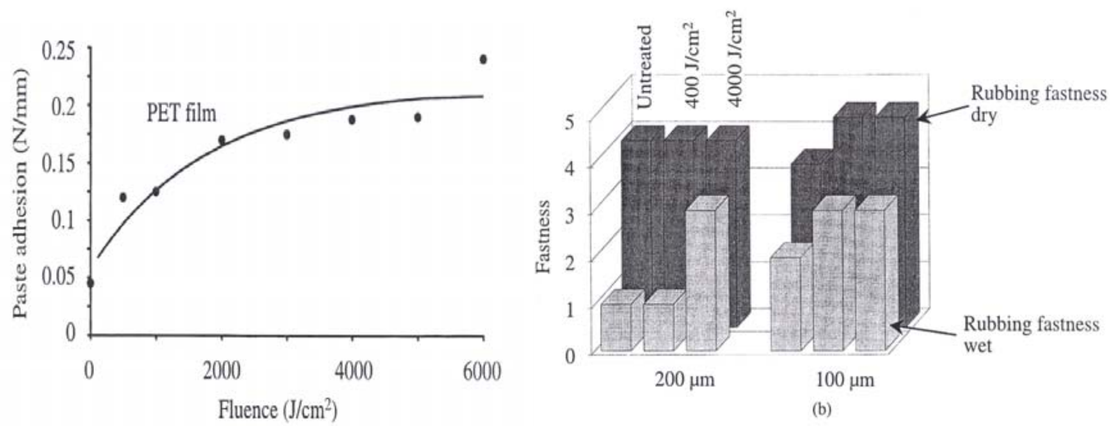


Figure 3. Effect of UV lamp generated photo-oxidation on the adhesion of binding paste as used for pigment printing and dyeing. (a) Binding paste adhesion to a UV treated PET film as a function of fluence — energy per unit area — as measured by Praschak *et al*. and (b) dry and wet rubbing fastness of pigment prints on UV treated PET fabrics. The rubbing fastness is characterized by a grading from 0 (worst) to 5 (best). The latter

experiment was performed for two different paste thickness (100 and 200 μm) and two different lamp fluences. (A.N. Netravali, T. Bahners, J. Adhesion Sci. Technol. 24, 45 2010).

Objectives and Deliverables

YEAR 1

Objectives: To use our multi-gas excimer laser to irradiate commercially available and/or sponsor(s) tire reinforcing fibers to obtain stronger and durable reinforcement adhesion to rubber. The experimental parameters will include the following laser parameters: Laser gas (wavelength), fluence, number of pulses, pulse frequency. We will perform the following tests with the irradiated reinforcement fibers: FT-IR; Tensile and fatigue tests. Single fiber fragmentation tests on irradiated fibers embedded and adhering to rubber will also be carried out. Sponsor(s) preferred chemical process will be applied for specimen preparation for these tests if requested by the sponsor(s).
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method.

YEAR 2

Objectives: To use our multi-gas excimer laser to irradiate commercially available and/or sponsor(s) tire reinforcing cord/belt/fabric bundles to obtain stronger and durable reinforcement adhesion to rubber. The experimental parameters will include the following laser parameters: Laser gas (wavelength), fluence, number of pulses, pulse frequency. We will perform the following tests with the irradiated reinforcement bundles: FT-IR; Tensile and fatigue tests. Fatigue tests on irradiated bundles embedded and adhering to rubber will also be carried out. Failed fatigue samples will be examined using optical and Scanning Electron microscopy. Sponsor(s) preferred chemical process will also be applied for specimen preparation for these tests if requested by the sponsor(s).
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method.

YEAR 3

Objectives: Testing of tires manufactured by the sponsor(s) using the reinforcement processed as described in Year (2) objectives above, as mounted on a car and driven on sponsor's or TRTC members test track. Design for adaptation of the laser-based adhesion improvement process to industrial manufacturing environment. Design the necessary equipment with the necessary safety and efficiency considerations.
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method. Design plan for the adaptation of the laser-based adhesion improvement process to the industrial manufacturing environment.

Budget: $ 50K/Year in direct costs.

LASER-BASED PROCESS FOR NOVEL DESIGNS TO CREATE IMPROVED TREAD PERFORMANCE

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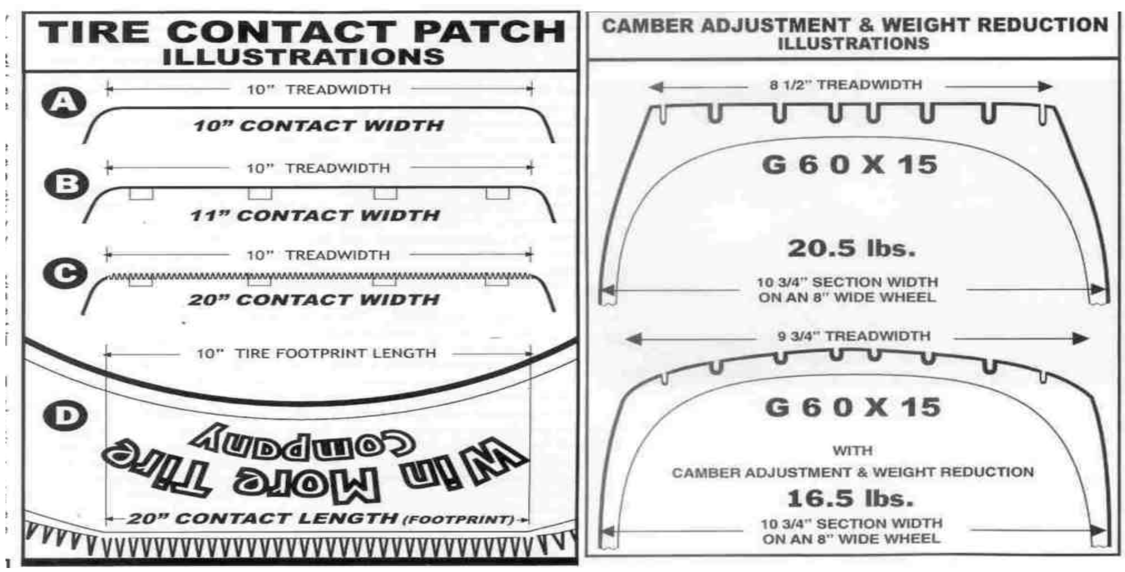
Executive Summary

We propose an excimer laser-based end-of-manufacture process to create patterns with specific area-size, depth, shape, orientation, distribution density and irradiated area material stiffness on tire tread surfaces to improve tire performance (Figure 1A). We also propose to investigate feasibility and efficacy of tire surface trimming by excimer laser as an alternative to mechanical surface grinding to reduce tire weight while improving tire traction (Figure 1B). We propose a three-year R&D activity with specific objectives and deliverables for each year.



(A) **(B)**

Figure 1. Illustrations of methods of increasing tire contact patch (A), and reducing tire weight by camber adjustment (B) (http://www.mrt-wheels.com).

General Goals

Our general goals for the proposed three-year R&D activity are as follows:

1- Increasing surface traction while maintaining current design tread patterns required for wet and/or muddy road surfaces.

2- Creating a capability to tune tread stiffness and to have varying stiffness regions on tire surfaces. The laser process for this goal is the same as that for goal (1) above, and therefore goals (1) and (2) represent a coupled process set to increase tire traction.

Figure 2. Lambda Physik excimer LPX 2401 pulse laser

Our Lambda Physik excimer LPX 2401 pulse laser (Figure 2) with 157 to 351 nm wavelength range (F2, ArF, KrF, XeC1, XeF), and the related optics, and accessories were purchased with a National Science Foundation award (Award Number: 9724185). The maximum pulse energy of the laser is 300 mJ (KrF), the minimum pulse duration is 18 ns (F_2), and the maximum repetition rate is 400 Hz (KrF, XeC1, XeF). The acquired high repetition rate laser with high-energy delivery capacity (2 X 10^9 W/cm^2 with KrF) allows accomplishing engineering tasks which require larger volumes to be treated. The maximum pulse energy of 300 mJ available with the acquired laser is sufficient to evaporate aluminum, titanium and copper for adhesion pretreatment ablation purposes as well as other surface treatment tasks. The excimer laser beam is aligned with the help of a diode laser assembled onto the back frame, and focused by ARC (Acton, MA) convex lens(es) made of Suprasil 2® UV grade fused silica with 775 mm (or other) focal distance and 90% transmission efficiency. The samples can be aligned so that the laser beam is perpendicular on them. Irradiation can be performed at the focal point (maximum energy concentration), or different distances and with different masks for less and shaped energy delivery. The output energy can be monitored using a joule meter.

This excimer laser is available in Dr. Sancaktar's research laboratory.

Figure 3 and 4 illustrate UV laser irradiation effects on silicone rubber as an example.

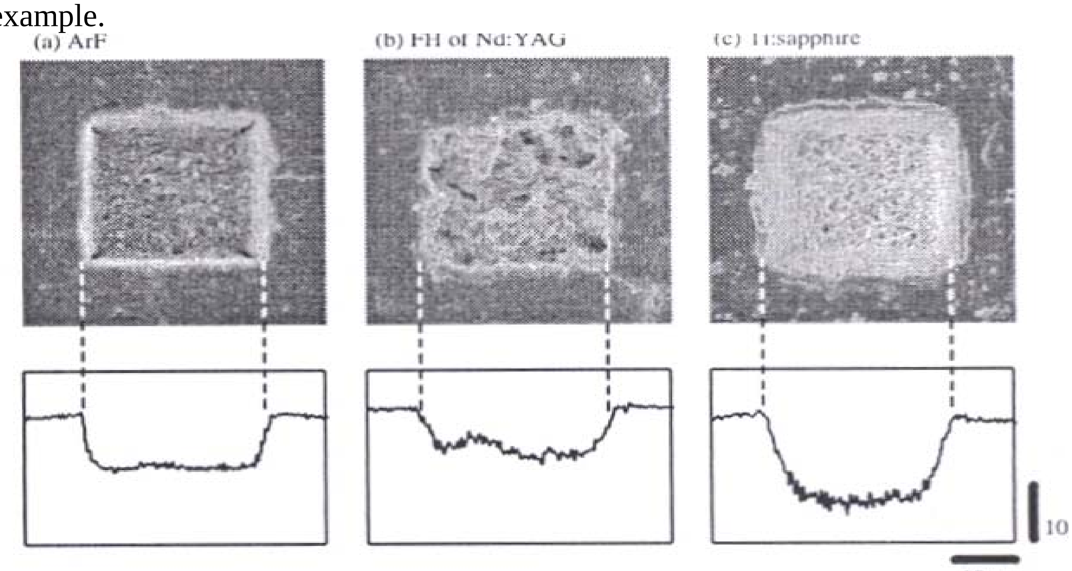


Figure 3. SEM images and cross-sectional plots of the ablated patterns on silicone rubber by different UV lasers using 50 pulses with 1.0 J/cm^2 in fluence (Y. Fukami, M. Okoshi, N. Inoue, Jpn. J. Appl. Phys.43, pp. 4240-1, 2004).

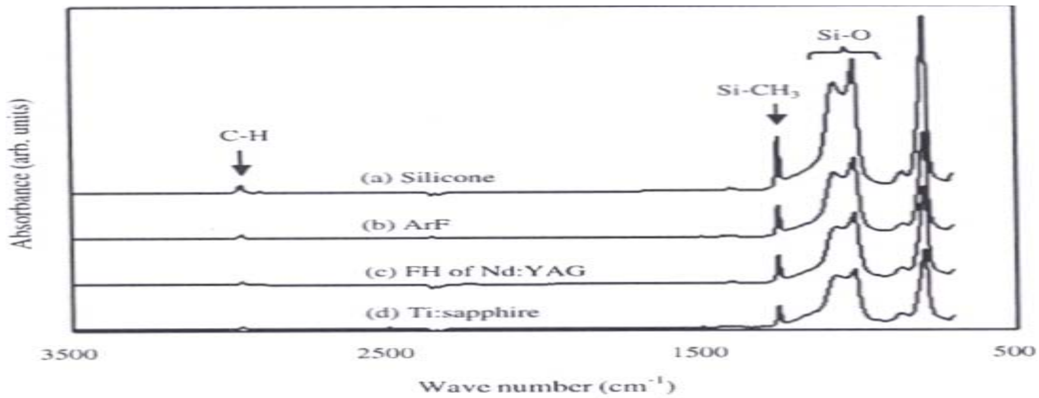


Figure 4. Chemical changes induced on silicone rubber by UV irradiation as measured using FT-IR (Y. Fukami, M. Okoshi, N. Inoue, Jpn. J. Appl. Phys.43, pp. 4240-1, 2004).

Objectives and Deliverables

YEAR 1 ***Objectives:*** To use our multi-gas excimer laser to ablate specific geometric patterns of varying depths on commercially available tires and/or sponsor(s) tires and/or tire rubber to be provided by sponsor(s). The experimental parameters will include the following laser parameters: Laser gas (wavelength), fluence, number of pulses, pulse frequency. We will perform the following tests on ablated areas: FT-IR; Durometer (hardness); Tensile and fatigue tests on strips excised from ablated areas. ASTM friction tests on tread sections containing ablated patterns with specific area-size, depth, shape, orientation, distribution density and irradiated area material stiffness.

Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method.

YEAR 2 ***Objectives:*** To use our multi-gas excimer laser to surface trim commercially available tires and/or sponsor(s) tires as an alternative method to mechanical surface grinding to reduce tire weight while improving tire traction as shown in Figure 1B. The experimental parameters will include the following laser parameters: Laser gas (wavelength), fluence, number of pulses, pulse frequency.

We will perform the following tests on ablated areas: FT-IR; Durometer (hardness); Tensile and fatigue tests on strips excised from ablated areas. ASTM friction tests on trimmed tread sections.

Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method.

YEAR 3 ***Objectives:*** Testing of commercially available tires and/or sponsor(s) tires processed as described in Years (1) and (2) objectives above, as mounted on a car and driven on sponsor's or TRTC members test track. Design for adaptation of the laser-based end-of-manufacture process to industrial manufacturing environment. Design the necessary equipment with the necessary safety and efficiency considerations.

Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed laser method. Design plan for the adaptation of the laser-based end-of-manufacture process to the industrial manufacturing environment.

Budget: ***$ 50K/Year in direct costs.***

REDUCTION IN TREAD SURFACE WEAR BY THE INCLUSION OF MAGNETIC NANOFIBERS

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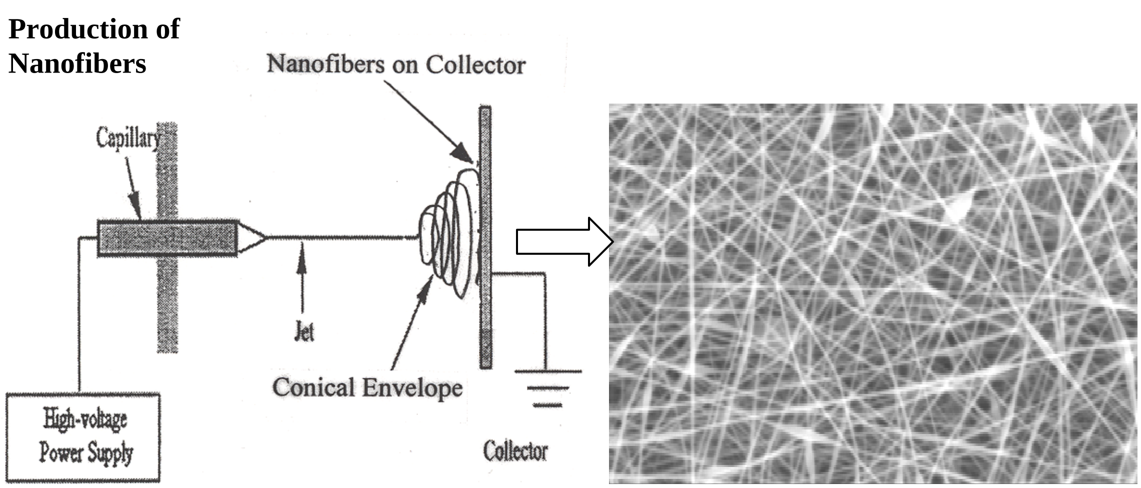
Executive Summary

We propose incorporation of electrospun (Figure 1A) nanofiber mats (Figure 1B, 2) directly on tread surfaces during the molding operation to reduce tread surface wear by the resulting reductions in micro tear and fibrillation in rubber tread.
We propose a three-year R&D activity with specific objectives and deliverables for each year.



(A) **(B)**

Figure 1. Illustrations of the electrospinning method (A), and the nanofiber mat obtained (B).

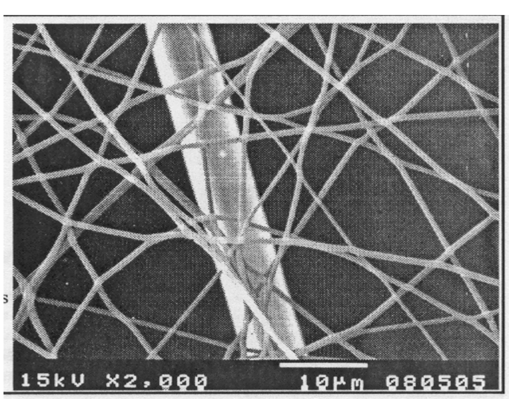


Figure 2. Comparison of traditional carbon fibers with electrospun carbon nanofibers.

General Goals

Our general goals for the proposed three-year R&D activity are as follows:

1- To reduce tread surface wear by the resulting reductions in micro tear and fibrillation in rubber tread.

2- Easy incorporation of electrospun magnetic nanofibers directly from magnetized mold surfaces onto the tread surfaces during the tire molding operation.

3- Increased heat transfer and the resulting increase in durability of the tread rubber due to the presence of highly heat conducting metal (Nickel, Figure 3) or metalized nanofibers.

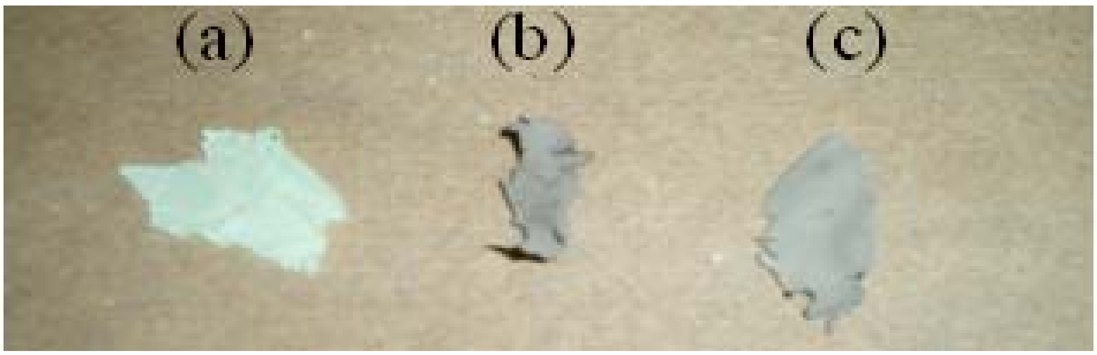


Figure 3. Nanofiber mats for: (a) PVP/Ni acetate formulation, (b) NiO after calcination of PVP/Ni acetate at 700^{o}C, and (c) metallic Ni after reduction of NiO with H_2.

Objectives and Deliverables

YEAR 1

Objectives: To use the electrospinning method to produce magnetic nickel nanofiber mats as shown in Figures 3 and 4, and in sufficient quantities for proof of concept experiments.

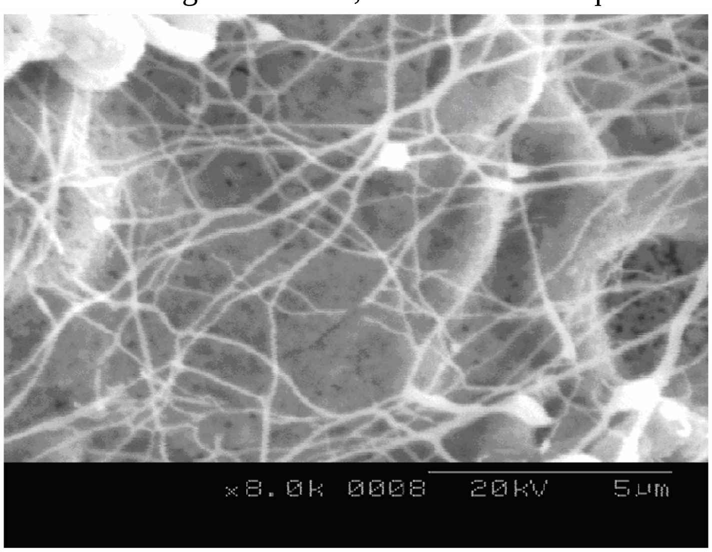


Figure 4. SEM photographs of Ni nanofibers prepared by Dr. Sancaktar's group.

Perform experiments to illustrate the capability to successfully transfer nickel nanofiber mats from a magnetized mold onto a curing rubber substrate during compression molding. Perform optical and scanning electron microscopy on the samples molded with the nanofiber mats to assess incorporation of the nanofiber, its depth and distribution as functions of molding conditions and mat density and thickness. Explore feasibility of electrospinning other magnetic nanofibers such as magnetite and coatability of carbon and/or other nonmagnetic nanofibers with magnetic surface layers. We have already illustrated successful coatability of nanofibers by silver for electric conduction purposes.
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed method for nanofiber incorporation into rubber tread surfaces.

YEAR 2
Objectives: Perform tensile loading/unloading and fatigue experiments on strips excised from the tread areas containing the incorporated nanofiber mat. Assess delay or avoidance of micro tearing activities in comparison to control samples not containing microfiber. Perform frictional rubbing experiments on strips excised from the tread areas containing the incorporated nanofiber mat to assess delay or avoidance of fibrillation activities in comparison to control samples not containing microfiber.
Deliverables: Results of the experiments summarized in objectives above to reveal the efficacy of the proposed method for nanofiber incorporation into rubber tread surfaces.

YEAR 3
Objectives: Testing of sponsor(s) tires processed as described in Year (1) objectives above, as mounted on a car and driven on sponsor's or TRTC members test track. Design for adaptation of the nanofiber process to industrial manufacturing environment. Design the necessary equipment with the necessary safety and efficiency considerations.
Deliverables: Design plan for the adaptation of the nanofiber incorporation process to the industrial manufacturing environment.

Budget:* *$ 50K/Year in direct costs.