Improving Vehicle Fuel Efficiency Through Tire Design, Materials, and Reduced Weight

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Cooper Tire & Rubber Company

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Project ID: VSS083

Overview

Timeline

- Project start date: 10/1/2011
- Project end date: 9/30/2014
- Project complete: 10-15%

Barriers / Target

1) Cost / Premium Product

2) Risk Aversion / Equal Performance

Budget

- Total project funding: $3,294,693
  - DOE share: $1,500,000
  - Contractor share: $1,794,693
- Funding received in FY11 – $0
- Funding for all of FY12 - $548,000
- Funding up to March FY12 - $16, 531

Partners

- National Renewable Energy Lab
- Project Lead - Ray Grout

Project Objectives - Relevance

Overall Program Objective:

To develop a new class of tires in the replacement market that improves fuel efficiency by a minimum of 3% and reduces overall tire weight by 20%.

Project Objectives: (Oct. 2011 – Mar. 2012)

- Identify the features of each of the technology approaches to be used in future tire test programs:
  - Level (phr) of partial replacement of carbon black and silica with nano-fiber reinforcement in component natural rubber & SBR polymer compounds
  - Ultra-light weight tire bead bundle
  - Ultra-light weight tire belt package
  - Formulation options for ultra-long wearing and low hysteresis tread compound
  - New low hysteresis energy efficient tire profile design
  - Ultra-light weight inner liner (barrier film liner)
- Complete subcontract agreement with NREL

Approach 1: Nano-fiber Reinforcement

- **Strategy**

  Evaluate partial replacement (levels) of carbon black and silica with nano-fiber reinforcement in tire component compounds for optimum performance/cost opportunities:

  - Lower specific gravity – reduce component weight/volume/cost
  - Lower overall compound filler content to reduce hysteresis and improve fuel efficiency

- **Milestones - Status**

  - Develop masterbatch technology for nanofiber material in natural rubber and SBR polymer systems – 2nd Qt 2012
  - Develop and characterize nano-fiber natural rubber and SBR compound properties – 4th Qt 2012
  - Initiate 1st Tire Test Program – Dec. 2012

Approach 2: Light Weight Bead Bundle

- **Strategy**

  Alternate lightweight materials will be evaluated as replacements for standard steel beads and assessed for optimum performance/cost.

  - High strength fiber rings
  - Fiber-filled engineered plastic alternatives
  - Re-design a lighter, more compact steel bead

- **Milestones - Status**

  - Identify alternate materials that provide comparable strength and dimensional stability to traditional steel beads – 1st Qt 2012
  - Work with manufacturer to produce beads – 2nd Qt 2012
  - Schedule tire test programs of alternative beads – 3rd Qt 2012

Approach 3: Light Weight Belt Package

- **Strategy**

  Alternate lightweight materials will be evaluated as replacements for standard steel tire cord belts and assessed for optimum performance/cost.

  - High strength fiber cords
  - Belt combinations (i.e. combine steel and fabric belts)
  - Belt construction variations (epi, angles, etc.)

- **Milestones - Status**

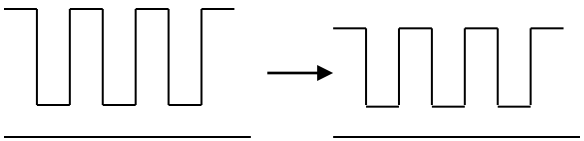
  - Evaluate alternative constructions / materials for suitability using FEA modeling of stiffness and dimensional stability – 1st & 2nd Qts 2012
  - Arrange meetings with lightweight cord makers to discuss development and trials of high strength cords – 1st Qt 2012
  - Arrange for a project trial of light weight belt materials in test tires to evaluate performance properties compared to steel belts - 2nd Qt 2012

Approach 4: Ultra-long Wearing Tread

- **Strategy:**

  Without sacrificing other tire performance parameters, develop an ultra-long wearing and ultra-fuel efficient tread to reduce tire weight by utilizing:

  - The latest low rolling resistance polymer technologies
  - Super abrasion fillers
  - New coupling agent
  - New processing aid and chemicals



Tread Non-Skid

- **Milestones – Status**
  - Complete compound studies of all of the above – 3rd Qt 2012
  - Complete 1st Tire Test Program – 4th Qt 2012

Approach 5: Low Hysteresis Tire Profile

- Strategy:
  - Use Finite Element Analysis (FEA) Modeling to predict Rolling Resistance (RR):
    - Evaluate Profile features in a Design Of Experiments (DOE)
      - Non-skid depth, Tread Width, Tread Radii,…….
      - Develop RR response to feature variation

- Milestones – Status:
  - Create FEA based RR Prediction – 1st Qtr 2012
  - Validate FEA based RR Prediction – 3rd Qtr 2012
  - Complete Profile DOE – 4th Qtr 2012

Approach 6: Barrier Film Liner

- **Strategy**

  A lightweight barrier film material will be evaluated as a replacement for standard halo-butyl inner liner for the tire.

- **Milestones - Status**
  - Lab test validation of the barrier film's air permeation resistance, fatigue resistance, and rubber adhesion – 4th Qt 2011
  - Completion of initial tire build for identification of any production process issues – 2nd Qt 2012

Accomplishments:

Approach 1: Nano-fiber Reinforcement

- Partial replacement of carbon black (65->25 phr) with nano-fiber (15 phr addition) demonstrated 30% hysteresis reduction in a tread compound.
- Nano-fiber significantly enhanced stiffness of a compound at low strain (~100%).
- Adhesion and tear strength needs to be validated.

Approach 2: Light Weight Bead Bundle

- Received a sample of light weight bead fabric ring and have held planning discussions with manufacturer on how to apply lightweight cord bead technology in tires.
- Designed a smaller, lighter steel bead construction.
- Investigated the potential of using fiber-reinforced thermoplastic polymers → it was determined that equivalent strength could not be achieved at a lighter overall weight and we have discontinued this approach for now.

Accomplishments:

Approach 3: Light Weight Belt Package

- FEA analysis of lightweight belt constructions suggested possibility of profile growth issues with traditional belt angles → Construction angles will be adjusted for planned tire trials.
- Fabric suppliers were contacted to discuss available lightweight products and to determine what new materials were available for optimum performance & cost.
- Lightweight belts were procured for an initial tire program to investigate plant processing and passenger tire performance.

Approach 4: Ultra-long Wearing Tread

- Through lab predictions, we have identified solution SBR polymer candidates comparing carbon & silica filler systems which could lower hysteresis as much as 50% and maintain or improve wet traction when compared to the current CS4 product.
- Due to issues with lab wear predictions, we have not demonstrated noticeable differences in tread wear resistance of candidate tread compounds. More work needs to be done in this area.

Accomplishments:

Approach 5: Low Hysteresis Tire Profile

- Created a Rolling Resistance (RR) prediction from static FEA models.
  - Generated RR predictions for the 225/60R16 CS4 in both the reference tire construction and four low weight constructions.
    - RR reduction up to 10 % with low weight belts in "production CS4 profile".
  - Generated RR prediction for a tire with a super-light weight construction in a low weight mold profile.
    - RR reduced by 27% over conventional 225/60R16 CS4.
- Initiated RR prediction validation program.
  - Test seven different sizes and tire types for RR & compare to FEA based RR prediction.
- Initiated Mold Profile design work for profile features of Design Of Experiments.

Accomplishments:

Approach 6: Barrier Film Liner

- Lab testing showed equal-to-improved air permeation resistance can be achieved with the barrier film
- Lab testing showed equal-to-improved flex fatigue can be achieved with the barrier film
- Arrangements for a roll of the barrier film for production trials were made; a small test roll was received
- A test program for tire building trials was issued and is planned for 1st Qtr 2012

Collaboration

National Renewable Energy Laboratory

- Subcontract agreement finalized in March 2012
- Initial meetings with NREL, (Terry Penney, Ray Grout, and Andreas Vlahinos)
  - Developed project specific focus & strategy, and detailed initial tasks
  - Developed initial procedures for Cooper supplied data
  - Outlined validation procedures for initial Cooper and NREL data
- New, simplified, independent rolling resistance algorithm developed by Cooper for the Design Of Experiment Project
  - Requires implementation within NREL procedures

Future Work FY12 & FY13

Approach 1: Nano-fiber Reinforcement

- Develop nano-fiber masterbatch methodology for commercialization - 2012
- Complete lab studies to develop reduced hysteresis compounds without sacrificing other compound performance criteria – 2012
- Conduct tire test programs to evaluate compound performance and initiate iterations (if needed) – 2013 through 2014

Approach 2: Light Weight Bead Bundle

- Working with our supplier & convertor, design and manufacture lightweight bead candidates for future tire evaluations – 2012
- Complete iterations (if needed) for tire evaluations of alternate light weight beads based on optimum tire performance and cost – 2013

Approach 3: Light Weight Belt Package

- Complete evaluation of initial light weight belt tire test program – 2012
  - Analysis and troubleshooting of any building process issues
  - Analysis and review of tire performance results
- Based on initial trial results, FEA design results, and discussions with material supplier, complete tire test program iterations if needed – 2012 & 2013

Future Work FY12 & FY13

Approach 4: Ultra-long Wearing Tread

- Complete lab studies of compound filler & polymer systems and identify candidate compounds – 2012
- Complete initial tire test program to evaluate tread performance – 2012
- Follow-up tire test program iterations (if needed) – 2013

Approach 5: Low Hysteresis Tire Profile

- Complete Rolling Resistance (RR) prediction validation program - 2012
  - Alter RR prediction method (if needed).
- Complete Mold Profile Design Of Experiments - 2012
  - Identify mold profile features conducive to low RR.
- Design mold profiles for alternate materials as required – 2013

Future Work FY12 & FY13

Approach 6: Barrier Film Liner

- Complete tire building evaluation of initial barrier film – 2012
  - Confirm sufficient and uniform stretching; consistency of barrier gauge
  - Analyze and troubleshoot any process issues
- Address any tire building process issues through discussion with barrier film producer and plant engineering – 2012
- Complete build and cure of trial tires for wheel testing and permeation verification – 2012
- Investigate barrier film application methods within the tire – 2013

Summary

- After six months of work, the initial features assessment of the six different technologies is on track except for nano-fiber reinforcement technology:
  - Issues:
    - Coupling agent identification and methodology for additional reinforcement is in progress.
    - Large scale coagulation system being constructed to produce sufficient quantities for future lab studies.
- Subcontract agreement with NREL finalized and work plan has been developed to initiate Design of Experiment project.