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

PI: Tim Donley

Cooper Tire & Rubber Company

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Project ID: VSS083

Overview

Timeline

- Project start date: Oct. 1, 2011
- Project end date: Sept. 30, 2014
- Project complete: 85%

Barriers

1) **Cost / Premium Product**
2) **Manufacturability**

Budget

- Total project funding: $3,679,309
  - DOE share: $1,500,000
  - Contractor share: $2,179,309
- Funding received in FY11 – $ 0
- Funding received in FY12 - $ 422,591
- Funding received for FY13 - $ 529,546
- Funding up to April FY14 - $ 173,478

Partners

- Teijin: Project Lead – Botond Szalma

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%.

- Phase I
  - Evaluate the following six technologies individually for contribution to fuel efficiency and/or weight savings:
    1) Partial replacement of carbon black and/or silica with nano-fiber materials
    2) Ultra-light weight tire bead bundle
    3) Ultra-light weight tire belt package
    4) Ultra-light weight inner liner (barrier film liner)
    5) Formulation options for ultra-long wearing and low hysteresis tread compound
    6) New design of low hysteresis, energy efficient tire profile
  - Each technology will be assessed for manufacturability throughout the development process.
- Phase II
  - Combine technologies that show potential to meet program goals.

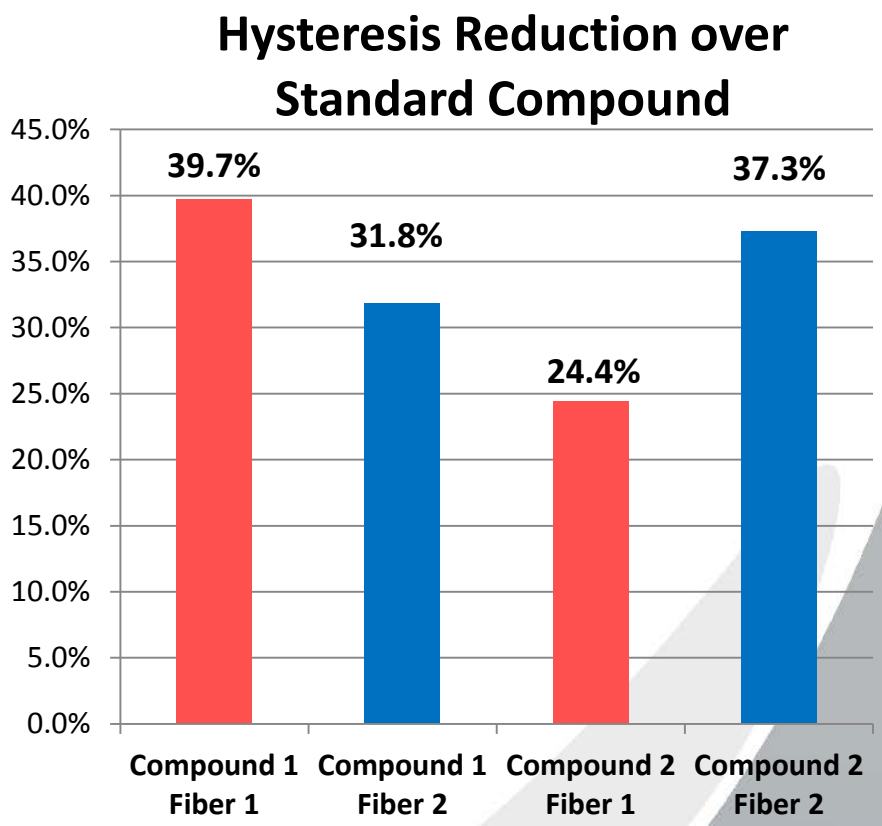
Approach 1: Nano-fiber Reinforcement

- **Strategy**
  - Evaluate nano-fiber reinforcement materials as a partial replacement for carbon black and/or silica to lower compound hysteresis.
    - Investigate nano-fiber in masterbatch to improve dispersion.
    - Identify fiber materials to use directly into compound mixing.
- **Milestones - Status**
  - Develop tire compounds from fiber materials that provided lower hysteresis – 3rd Qtr 2013 (Completed)
  - Conduct 1st tire test program – 4th Qtr 2013 (Completed)
  - Identify compounds with lower hysteresis for Phase II - 1st Qtr 2014 (Completed)
  - Execute Phase II tire program – 2nd Qtr 2014 (In Progress)
  - Identify coupling agent to improve properties of nano-fiber masterbatch 3rd Qtr 2014 (In Progress)
- **Go/No-Go**
  - Demonstrate lower hysteresis tire compounds contribute to lower rolling resistance tires – 1st Qtr 2014. (Completed)

Accomplishments – Fiber Reinforcement

Approach 1: Fiber Reinforcement

- Identified two fiber materials that could partially replace carbon black and/or silica to reduce compound hysteresis.
- Produced and tested tires to verify rolling resistance reduction.
- Identified low hysteresis compounds for Phase II.



Tire Rolling Resistance/Weight Results				
	Wt	RRc	% Wt	% RR
Tire w/Standard Compounds	23.33	9.34		
Tire w/Fiber 1 Compounds	22.77	8.68	2.40%	7.00%
Tire w/Fiber 2 Compounds	22.87	8.81	1.97%	5.62%

Approach 2: Light Weight Bead Bundle

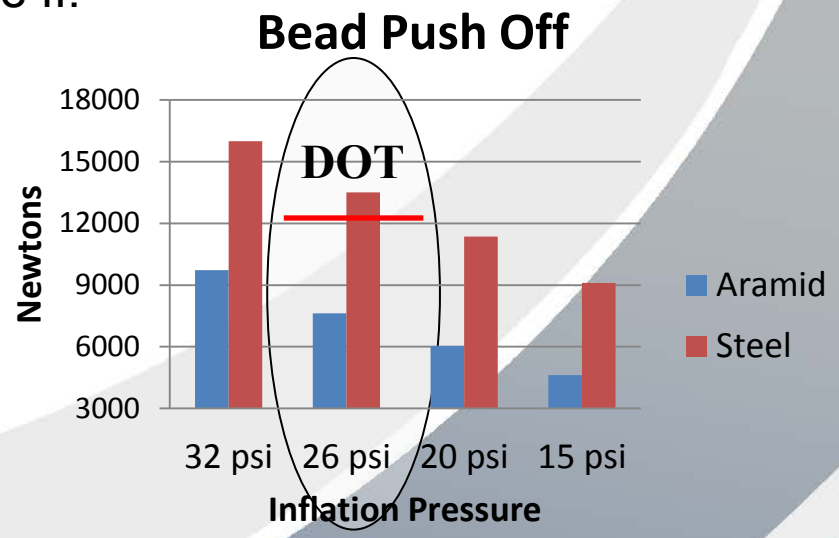
- **Strategy**
  - Investigate alternate light weight materials as replacements for standard steel beads.
    - High strength pre-manufactured aramid bead rings.
    - Aramid cord utilizing the same bead manufacturing process as steel cord.
- **Milestones - Status**
  - Conduct a tire program with 2nd generation aramid beads with similar strength to steel beads – 1st Qtr 2013 (Completed)
  - Perform additional tire tests with the 2nd generation aramid beads – 3rd Qtr 2013 (Completed)
  - Execute another tire program with 2nd generation aramid beads – 4th Qtr 2013 (Completed)
- **Go/No-Go**
  - Evaluate tire performance and manufacturing feasibility in comparison to steel beads – 1st Qtr 2014 (Completed)

Accomplishments

Approach 2: Light Weight Bead Bundle

- Completed two test programs using aramid beads from both manufacturing processes.
  - Tested and passed Burst Strength testing.
  - Tested and passed high speed and endurance wheel testing.
  - Tested and passed Rim Slip testing.
  - Bead Push off testing did not meet DOT requirements.
  - Handling was not acceptable.
  - Limited tire testing planned for Phase II.

- Technology needs further development before being a viable candidate.
  - Limited tire testing planned for Phase II.



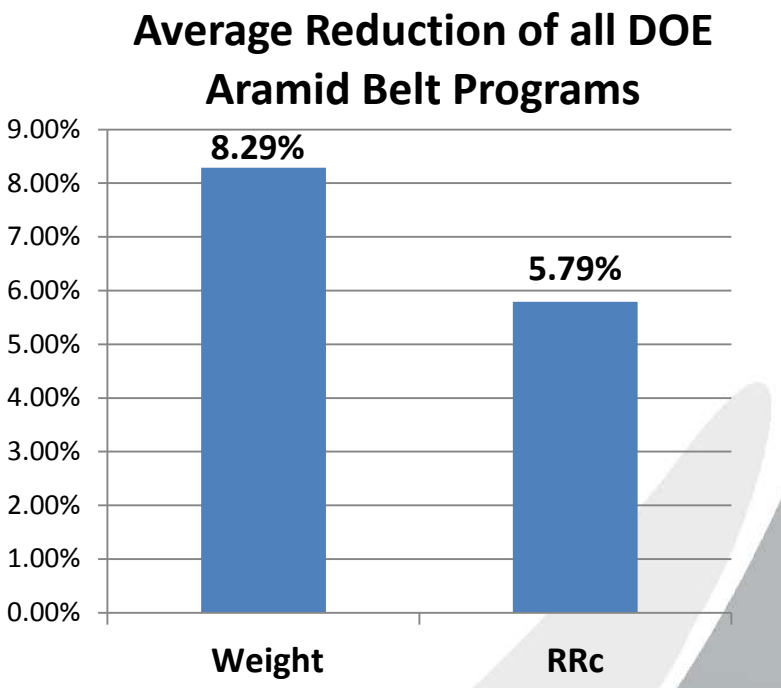
Approach 3: Light Weight Belt Package

- **Strategy**
  - Evaluate alternate light weight materials as replacements for standard steel belts.
- **Milestones - Status**
  - Conduct 3rd tire test program with some design changes to improve performance. – 4th Qtr 2013 (Completed)
  - Evaluate aramid belts in program outside the DOE development. – 2nd Qtr 2014 (Completed)
  - Execute Phase II tire program – 2nd Qtr 2014 (In Progress)
- **Go/No-Go**
  - Aramid belts pass all DOT requirements - 1st Qtr 2013 (Completed)

Accomplishments

Approach 3: Light Weight Belt Package

- Completed five tire programs using aramid belts.
  - Three as part of DOE development.
  - Two as part of other development work.
- Aramid belt construction chosen for Phase II.



3rd Tire Program: "BG" Mold Profile		
	Weight Savings	RR Savings
Control - Steel Belt		
Aramid Belt	9.0%	6.7%
Aramid Belt – Overwrap Change	8.4%	6.4%
Aramid Belt - Belt Angle Change	9.0%	7.4%
Aramid Belt - Monoply	13.7%	8.0%

Approach 4: Barrier Film Liner

- **Strategy**
  - Evaluate a light weight barrier film material as a replacement for standard halo-butyl inner liner.
- **Milestones - Status**
  - Conduct 2nd tire program to further evaluate production process issues and to evaluate film performance. – 1st Qtr 2013 (Completed)
  - Build 3rd tire program to evaluate film performance. – 1st Qtr 2014 (Completed)
  - Test tires from 3rd tire program – 2nd Qtr 2014 (Completed)
- **Go/No-Go**
  - Determine if film can meet manufacturing and performance requirements needed to meet program goals. – 2nd Qtr 2014 (Completed)

Accomplishments

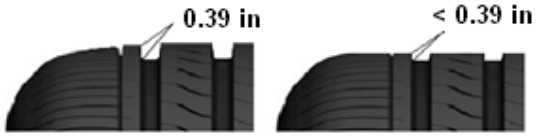
Approach 4: Barrier Film Liner

- Completed 3 tire builds investigating 3 different versions of barrier film material.
  - Failed aggressive endurance test with fatigue cracking in the shoulder.
  - Observed improvement from version 1 to version 2 barrier film.
  - Lab data indicated version 3 would out perform version 2.
  - Wheel testing resulted in worse fatigue cracking with version 3 than version 2.
  - Barrier Film has resulted in poorer rolling resistance.
- Technology needs further development before being a viable candidate.
  - Limited tire testing planned for Phase II.

	Endurance Test	Liner Cracking	Weight (lbs)
Rubber liner	100%	None	2.1
Version 1	53%		0.6
Version 2	100%	Moderate	0.6
Version 3	74%		0.6

Approach 5: Ultra-long Wearing Tread

- **Strategy:**
  - Develop technologies for an ultra-long wearing and ultra-fuel efficient tread compound to reduce tire weight and rolling resistance.



Reduced Tread Depth

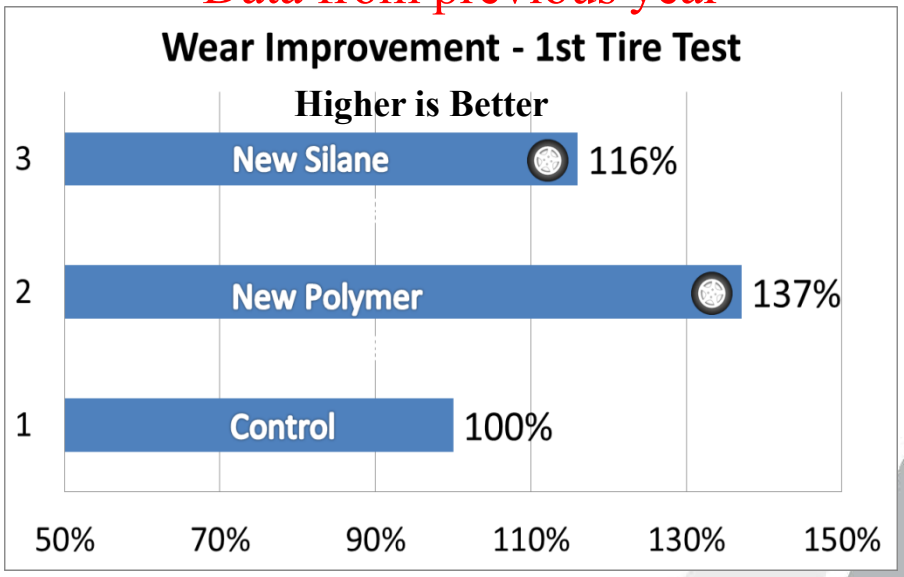
- **Milestones – Status**
  - Perform lab compound studies to balance traction, wear and rolling resistance – 2nd Qtr 2013 (Completed)
  - Carry out lab compound studies combining the new polymer and new silane technologies from the 1st tire program – 3rd Qtr 2013 (Completed)
  - Conduct 3rd tire test program to evaluate the combination of new polymer and new silane technologies – 3rd Qtr 2013 (Completed)
  - Execute Phase II tire program – 2nd Qtr 2014 (In Progress)
- **Go/No-Go**
  - Determine if compound formulation is optimized to meet all tire performance goals. – 1st Qtr 2014 (Completed)

Accomplishments

Approach 5: Ultra-long Wearing Tread

- Investigated 4 tread compounds in a 3rd tire program.
- Compound EX #2 chosen for the Phase II.

Data from previous year



Compound Evaluation 3rd Tire Program					
Mold Profile	**Compound**	**RR***	**Wet Traction**	**Snow Traction**	**Wear**
CS4 - 12/32"	Control	---	---	---	---
New Profile - 9/32"	Ex #1	**16%***	**2.5%**	**-4.8%**	**7.3%**
New Profile - 9/32"	Ex #2	**20%***	**2.5%**	**4.0%**	**5.3%**
New Profile - 9/32"	Ex #3	**19%***	**4.0%**	**2.0%**	**-6.8%**
New Profile - 9/32"	Ex #4	**16%***	**3.0%**	**-9.5%**	**0%**

* RR change only includes compound difference

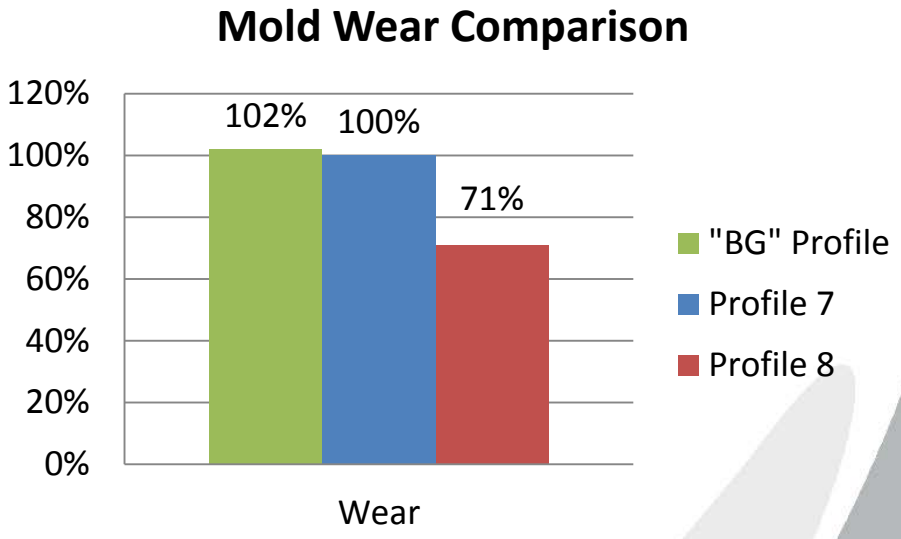
Approach 6: Low Hysteresis Tire Profile

- **Strategy:**
  - Develop and use new Finite Element Analysis (FEA) Model to predict Rolling Resistance (RR)
- **Milestones – Status:**
  - Perform design of experiments on tire profile – 1st Qtr 2013 (Completed)
  - Design and build new mold using results from design of experiments – 2nd Qtr 2013 (Completed)
  - Build and test tires from new mold profile in conjunction with tread compound evaluation – 3rd Qtr 2013 (Completed)
  - Execute Phase II tire program – 2nd Qtr 2014 (In Progress)
- **Go/No-Go**
  - Determine if mold profile is fully optimized and meets required performance criteria. – 4th Qtr 2013 (Completed)

Accomplishments

Approach 6: Low Hysteresis Tire Profile

- Using the new FEA rolling resistance model, two additional molds were developed for tire testing.
  - Model predicted a slight improvement over “BG” Profile.
- Identified mold profile for Phase II.



Rolling Resistance/Weight Results			
Mold Profile	**Tread Compound**	**RR % Improvement**	**Wt. % Improvement**
CS4 - 12/32"	control	0.0	0.0
“BG” Profile - 9/32“	control	11.6%	10.2%
Profile 7 - 9/32“	control	8.9%	10.0%
Profile 8 - 8/32“	control	14.5%	14.9%

Collaboration

National Renewable Energy Laboratory:

- Subcontract agreement finalized in March 2012 to collaborate on light weight tire FEA model.
- As a result of advancements in Cooper's FEA capabilities, collaboration with NREL was completed in 2013.

Teijin:

- Collaboration is ongoing with Teijin to develop aramid belts and aramid beads.

Other:

- Cooper continues to collaborate with multiple material manufacturers to develop and improve tread, fiber and inner liner technologies.

FY2013 Reviewer's Comments

Reviewer comment: "the project could benefit from collaboration in the area of material development, consumer feedback, and other areas."

Response: Throughout the program there has been collaborations with many others companies as Cooper strives to develop new technology to meet the goals of this program.

Reviewer comment: "it seemed that the decision points were not followed in the development of some of these technologies and planning for future work."

Response: Each of the technologies has gone through a rigorous stage gate process and decision points were used to ensure the success of the program.

Future Work FY14

Approach 1: Fiber Reinforcement

- Continue to investigate nano-fiber masterbatch technology.
  - Continue to develop coupling agent technology.
  - There is still the potential for a meaningful hysteresis improvement.

Approach 3: Light Weight Belt Package

- Conduct follow up tire program to improve aramid belt performance.
  - Investigate construction changes to improve performance.
  - The belt coat compound is also under development as part of the investigation.

Future Work FY14

Phase II Tire Program

- Build 3 sets of projects to combine the technologies.
- A small amount of tires will be procured with Barrier Film and Aramid Beads for limited testing to investigate material interactions.

	RRC*	Weight Reduction	Tire Weight	Δ WT %	Δ RR % *	Commercial Risk	Performance Risk
CS4 Control	10.8		26.0				
Mold/Tread	7.85 *	2.5	23.5	9.6%	27.3%	Low	Low
Fiber Reinforced Compounds	7.35 *	0.5	23.0	11.5%	31.5%	Low	Low
Aramid/Monoply	6.90 *	3.2	19.8	23.9%	34.3%	Med	Low
Barrier Film	7.25 *	1.5	18.3	29.6%	32.9%	High	High
Aramid Bead	7.25 *	0.4	17.9	31.2%	32.9%	High	High

*** Estimated Results**

Achieve Program Objectives

Summary

- Testing conducted to date indicates Cooper is on track to meet the goals of 20% weight reduction and 3% fuel savings.
- Phase II is on track for evaluation during 2nd Quarter of 2014.

Features	Contribution To Weight Reduction	Contribution To Low RR
Light weight Nano-fiber	1%-2%	5%
~~Light weight Bead~~	~~2% - 4%~~	~~Minimal~~
Light weight Belt	8%-14%	4%-6%
~~Light weight Inner Liner~~	~~8%~~	~~- 5% to -10%~~
Ultra-Long Wearing & Ultra-Low RR Tread	1%-2%	15%-20%
Low RR Tire Profile	8%-10%	10%-12%
Total	**~20%**	**~ 30%**