

PPG Industries
Bringing innovation to the surface.™

Advanced Truck And Bus Radial Materials For Fuel Efficiency

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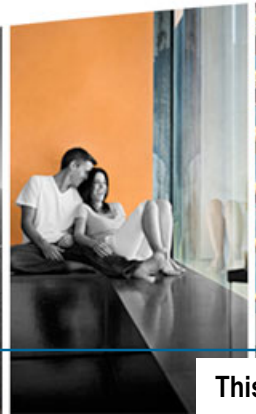


Overview

Timeline

- **Start: 10/01/2014**
- **End: 09/30/2017**

- **BP1 32% complete**
  - As on March 2015

Barriers

- **Technical Target**
  - 4-6% improved fuel efficiency of truck and bus radial tires
- **Technical Barriers**
  - Dispersion of fillers in natural rubber-based compounds
  - Natural rubber compound optimized for silica filler

Budget

- **Total project funding**
  - $1,253,269 (Total)
  - $939,950 (DOE)
- **Funding Obligated**
  - Fully funded

Partners

- **Bridgestone Americas Tire Operations**

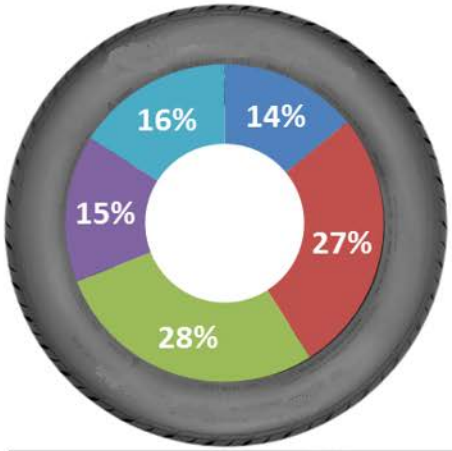
Relevance

- The goal of the project is to develop a novel surface-modified silica technology and demonstrate 4-6% improved fuel efficiency of truck and bus radial (TBR) tires built from the technology.
  - Maintaining or improving tear strength and tread wear over the state of the art carbon black-filled natural rubber-based TBR tread compound
  - A methodology to controllably and uniformly disperse silica fillers into the various phases of the rubber formula
  - A new surface modified silica technology that reduces the rolling resistance of a TBR tread compound by at least 60% in laboratory testing relative to carbon black technology
  - A new rubber blend for TBR compounds containing surface modified silica, optimized for on-tire rolling resistance, tear strength, and tread wear performance

Relevance

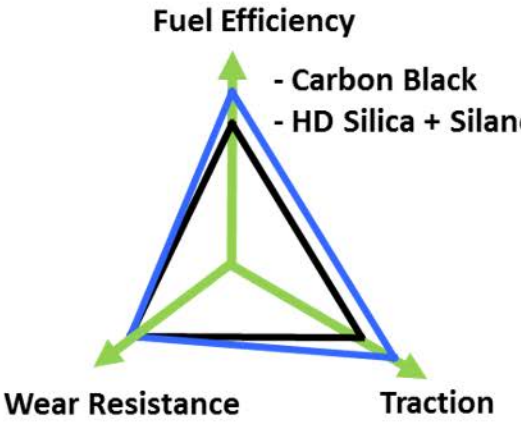
- Silica for passenger tires provides fuel-efficiency gains over carbon black, the traditional filler for tires
- In TBR tires predominantly comprised of natural rubber (NR), silicas no longer provide the same benefits
  - NR provides the chip and tear resistance essential for TBR applications
- NR contains proteins, organic matter, and metal ion contaminants
  - Contaminants are believed to interfere with the *in situ* coupling reaction required to effectively disperse silica in NR, yielding poor filler dispersion, tire performance, and processing

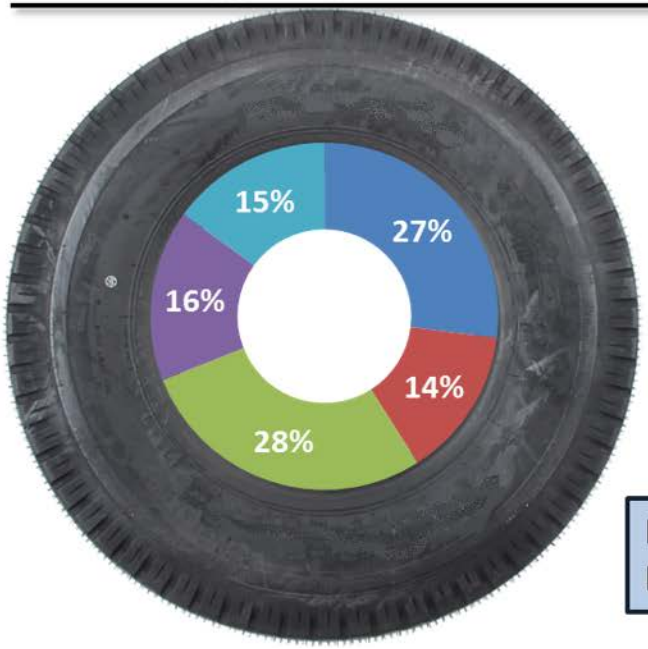
Passenger Tires & TBR Tires



Passenger Tire
(New wt. 25 lbs)

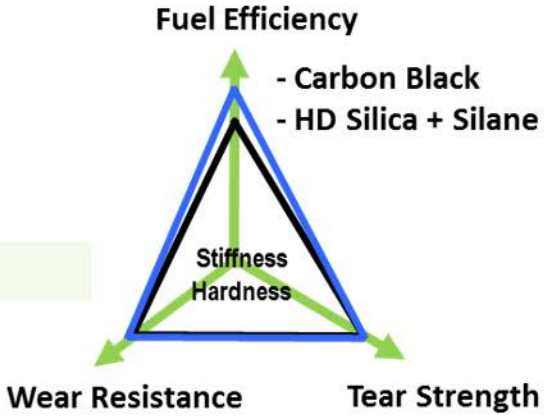
- Natural Rubber
- Synthetic Rubber
- Filler ~3 lbs filler in tread
- Steel
- Fabric, other fillers, etc





Truck Tire
(New wt. 120 lbs)

- Natural Rubber
- Synthetic Rubber
- Filler ~7 lbs filler in tread
- Steel
- Fabric, other fillers, etc



Most of the filler in truck tire treads is carbon black today. Like PC&LT tires, different criteria depending on end-use.

TBR Tire Challenge

- PPG investigated the ability of Agilon® passenger tire products to overcome the NR contaminant problem
- A high surface area Agilon was dispersible in NR and provided rolling resistance improvements over carbon black
  - Our work in this area has been published and presented in various industry magazines and conferences

"Innovating the silica surface for Improved NR truck tire vulcanisates" *Tire Technology International* 2/2014.

"Functionalized silicas for improved NR truck tire vulcanizates" *Rubber World* (2014) 249(2), 19-24.

"Bringing Innovation to the Surface: Functionalized Silicas for Improved Natural Rubber Truck Tire Vulcanizates," 184th Technical Meeting of the American Chemical Society Rubber Division, October 2013, #33.

"Agilon Performance Silicas in Natural Rubber Truck Tire Tread Compounds" 180th Technical Meeting of the American Chemical Society Rubber Division, October 2011, #70.

Milestones

Milestone	Plan * Updated - Actual Date	Status
0.1 Subcontract Executed	11/30/2014 – 12/11/2014	Completed
1.2.1 Microdispersion Technique Determined	1/30/2015 – 3/18/2015	Completed
1.2.2 Structure Determined	6/30/2015 * 9/18/2015	Underway
2.2.1 Surface Energy Effect Determined	9/30/2015	Planned
3.1 Tread Compound Determined	12/30/2015	
3.2 Tread Compound Formulas Selected	3/31/2016	
4.2.1 Experimental Trailer Tires Produced	4/15/2016	
5.1 Performance Gaps Identified	9/30/2016	
6.1 Tread Compound Formula Identified	12/31/2016	
6.2 Exp. Tread Compound Formula Selected	3/31/2017	
7.2.1 Experimental Tires Produced	4/15/2017	
8.1 Selection of Tire Technology for Testing	9/30/2017	
Final Report	12/30/2017	

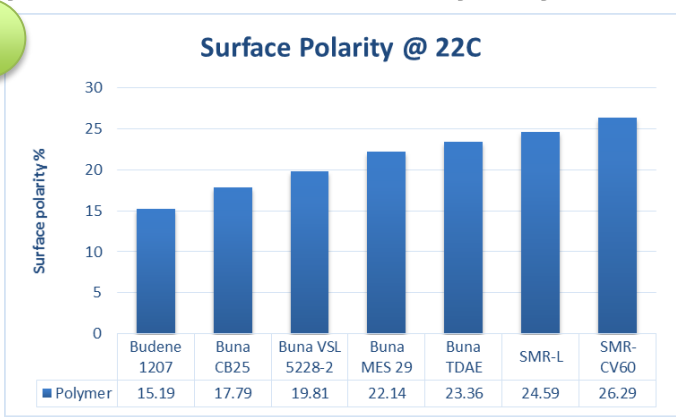
Programmatic Approach

- **Budget Period 1: CONTROLLING DISPERSION:**
  - Understand how different silica surface chemistries and surface areas are linked to dispersion performance in different rubber phases including both natural and synthetic rubbers
- **Budget Period 2: DEVELOP NEW TREAD COMPOUND:**
  - Use the design principles identified in BP 1 to reduce the rolling resistance of a TBR compound by at least 60% compared to carbon black with no decrease in hardness and equal or better tear strength and tread wear
- **Budget Period 3: OPTIMIZING FORMULA FOR ON-TIRE PERFORMANCE:**
  - Optimize the TBR compound performance and select the final rubber compound formulations for the tire builds that will be delivered to DOE for independent testing

Strategy

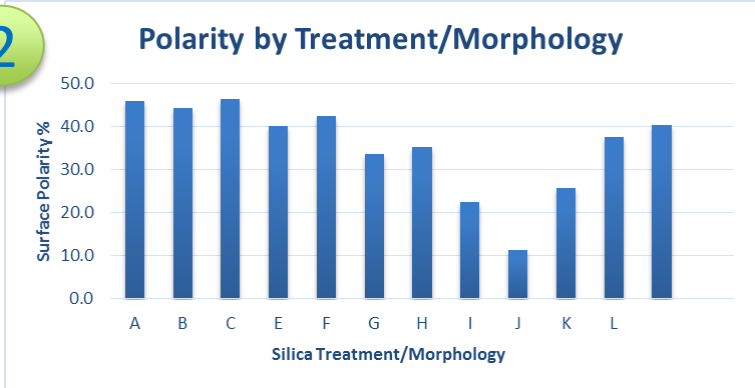
Identify Interfacial Behavior of Key Polymers

1



Identify Silica Morphologies/Treatments for Improved Wetting

2

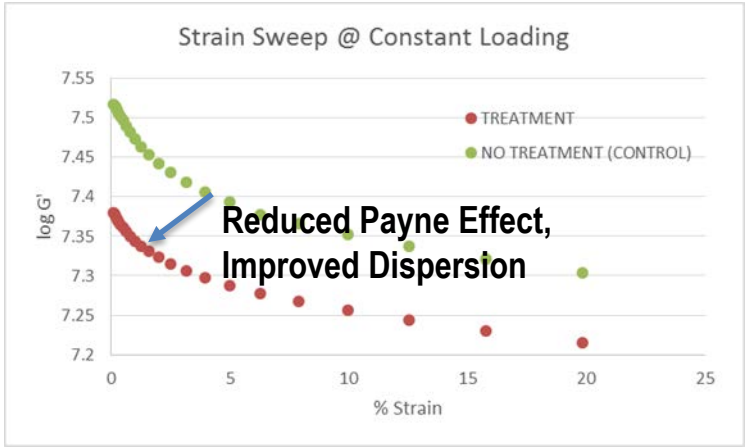


Select modifiers/morphologies that offer:

- Equal or better tread wear, tear strength
- 60% lower RR than carbon black control

Test Silicas in Single Polymer Model Formulations

3



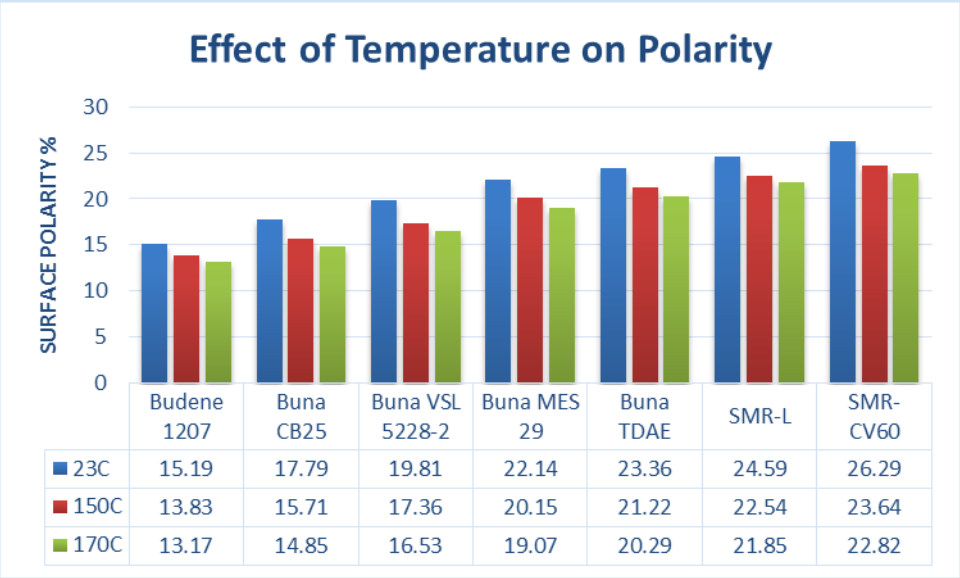
Polymer Blends for Optimized Wear, Tear, RR and Safety

4

Goal — **Optimized Tread Compound/Tires**

Accomplishments

- **Surface Energies of Key Rubbers Calculated at Room Temperature and at Typical Dump Temperatures/Silanization Hold Temperatures**

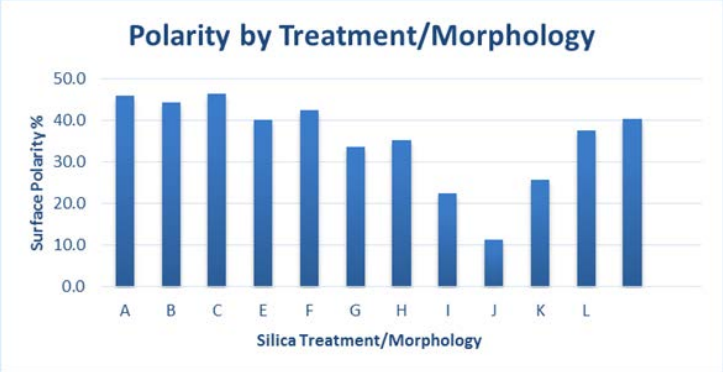


	Budene 1207	Buna CB25	Buna VSL 5228-2	Buna MES 29	Buna TDAE	SMR-L	SMR-CV60
23C	15.19	17.79	19.81	22.14	23.36	24.59	26.29
150C	13.83	15.71	17.36	20.15	21.22	22.54	23.64
170C	13.17	14.85	16.53	19.07	20.29	21.85	22.82

- **The surface energy/polarity measurement at actual conditions is critical to understanding how to disperse fillers in polymer blends**

Accomplishments

- **Silica Synthesis:**
  - 12 materials synthesized to date
    - 2 untreated controls, 10 treated silicas
  - Variety of Surface Energies Created



- **Rubber Compound Testing (Ongoing, Early Results)**

Property	Result
RR indicator	- 47%
Wear Resist.	+18%
Hardness	~ Equal

Difference between treated silica and silica control (NR)

Collaboration and Coordination with Other Institutions

- **Bridgestone Americas Tire Operations**
  - Working as advisor for the duration of the program
  - Will begin looking at polymer blends for optimization of tread properties

- **Augustine Scientific**
  - State of the art surface energy measurement laboratory
  - Conducted measurements of rubber surface tension using polar and non-polar liquids at room and molten-state temperatures
  - Conducted measurements of silica controls and treated silicas using polar and non-polar liquids
  - Will continue to test new silica treatments and any additional rubbers that are of interest during the program

Proposed Future Work

- **Silica Materials**
  - Develop understanding of how level of surface treatment should scale with surface area
  - Goal: Maximize tread wear, rolling resistance and tear strength
  - Optimize key metrics: processing, cure, dispersion, stress-strain, dynamic properties

- **Rubber Compounds**
  - Optimize single polymer formulations and study the effect the treated silicas have on key metrics
  - Begin to develop rubber blends for tread compound with optimized properties with silica

Remaining Challenges and Barriers/ Risk Management

- **Silicas that achieve a compatible polarity may not maintain wear and tear**
  - Continue to develop new ideas for surface modification of silicas
- **Rubber additives binding to silica in-situ may affect dispersion performance**
  - Study change of surface energy for control silicas in presence of known silica adsorbates if needed
- **Depending on the homogeneity of rubber blends, a single silica solution may not work**
  - Look at blends of treated silicas or additives that function as phase transfer catalysts
- **Optimization of single polymer model formulations**
  - Determine if the Payne effect remains the best way to quantify dispersion performance

Summary Slide

- **Objective**
  - Design, develop, and demonstrate fuel efficient and safety regulation compliant tire filler technologies
- **Expected Outcome**
  - A NR-based TBR tire with improved overall fuel efficiency by 4-6%
  - Maintaining or improving tear strength and tread wear
  - Complete Budget Period 1 on time
- **Silica Material**
  - Several silica surface chemistries have been created spanning a wide range of surface polarities
  - The presence of surface treatment in NR appears to show nearly a 50% reduction in RR indicators and an 18% improvement in abrasion compared to the untreated control
  - Single polymer model compounds are being optimized for BR, SBR and NR with silica chemistries being tested in each

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Questions and Answers

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