Flow Polymers

Tire Durability
Importance of Innerliner Performance

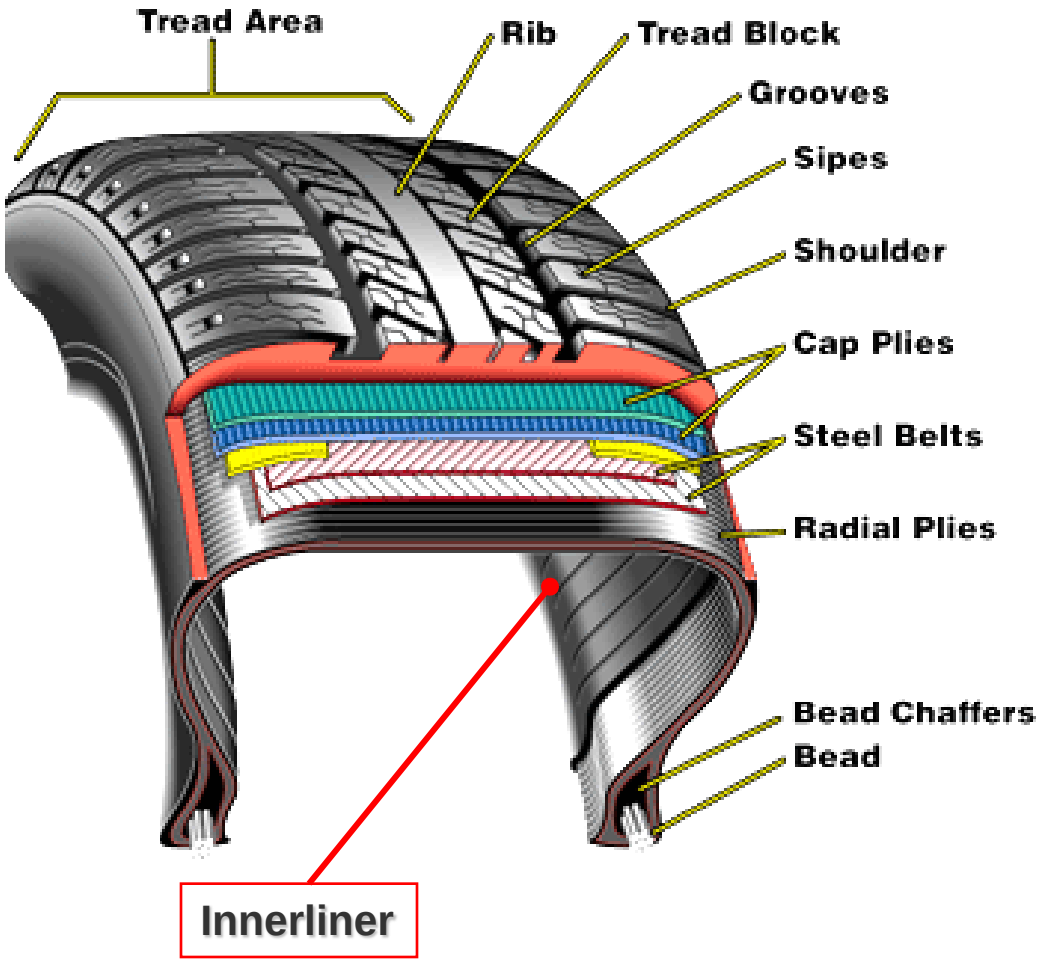
Contents

- **Tire Innerliner Function and Performance**
- **Importance of Bromobutyl Rubber in Tire Innerliner**
- **Promix® 400 Homogenizing Agent Performance in Tire Innerliner Formulations**

Tire Innerliner
Function and Performance

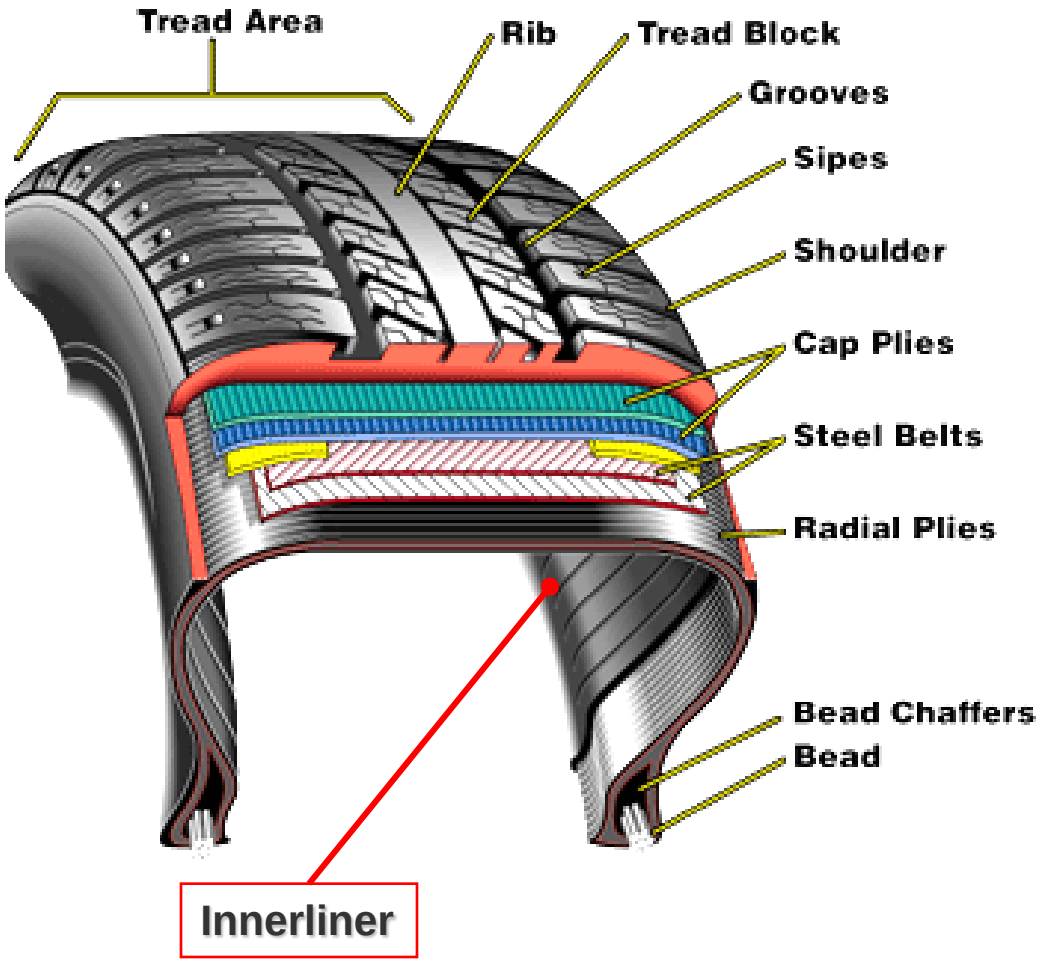
Tire Innerliner Functions and Performance

- Air inside the tire is 21% Oxygen, O_2. O_2 is the enemy of rubber as it causes degradation and loss in physical properties.
- The innerliner provides a barrier that helps prevent O_2 from entering the tire structure and degrading the tire rubber.
- When innerliner performance is not adequate, through appropriate compounding, oxidative degradation can be a primary cause of tire failure.



Tire Innerliner Functions and Performance

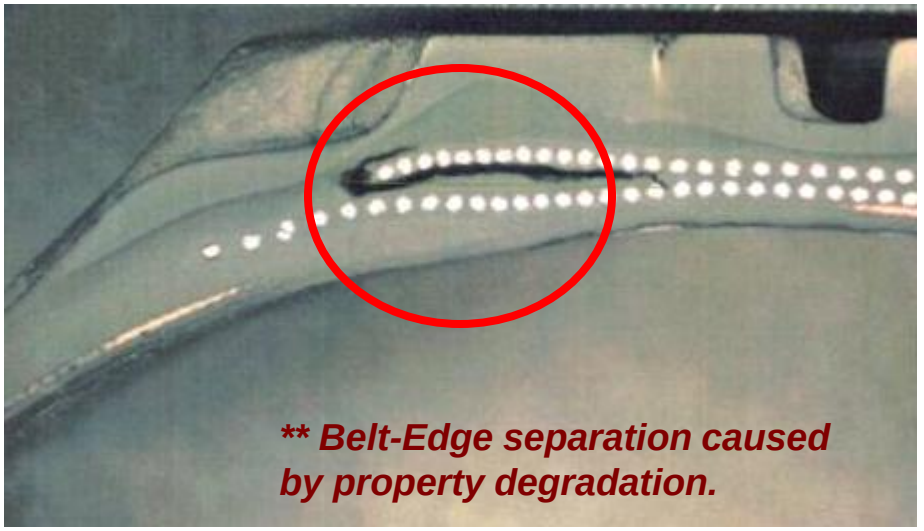
- **Careful innerliner formulation can help ensure proper performance. Use of bromobutyl rubber provides the required O2 barrier properties while maintaining needed flexibility and adhesion.**
- **A poor innerliner formulation can result in higher levels of O2 and increased degradation of internal components.**



Tire Innerliner and Belt-Edge Durability

- The tire belt-skim and wedge are subjected to very high interlaminar shear forces.
- A high O_2 level in the belt skim rubber from poor innerliner barrier performance can result in property degradation and a belt-to-belt separation.
- Low air pressure from poor innerliner performance can cause excessive tire deflection, higher heat generation and acceleration of oxidative property degradation.

Belt-Edge Separation from Property Degradation



*** Belt-Edge separation caused by property degradation.***

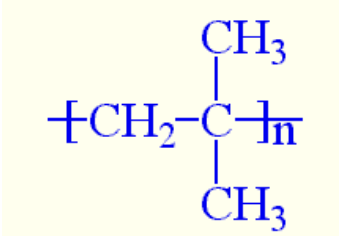
Proper innerliner formulation can help prevent oxidative property degradation.

Importance of Bromobutyl Rubber in Tire Innerliner

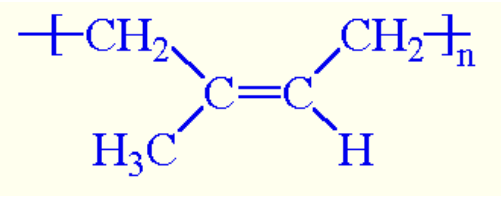
Bromobutyl Rubber – Properties

- The performance of butyl rubber is driven by its structure. The Pendant methyl groups of polyisobutylene create a closely packed polymer structure that provides superior barrier to O_2.
- Halogenation of butyl rubber (i.e., bromobutyl) provides faster cure and improved adhesion to natural rubber.
- While butyl rubber is nearly 18 times less permeable to O_2 than natural rubber, it still has very good low temperature flexibility.

Molecular Structure



Polyisobutylene



Polyisoprene

O_2 Permeability and Diffusivity

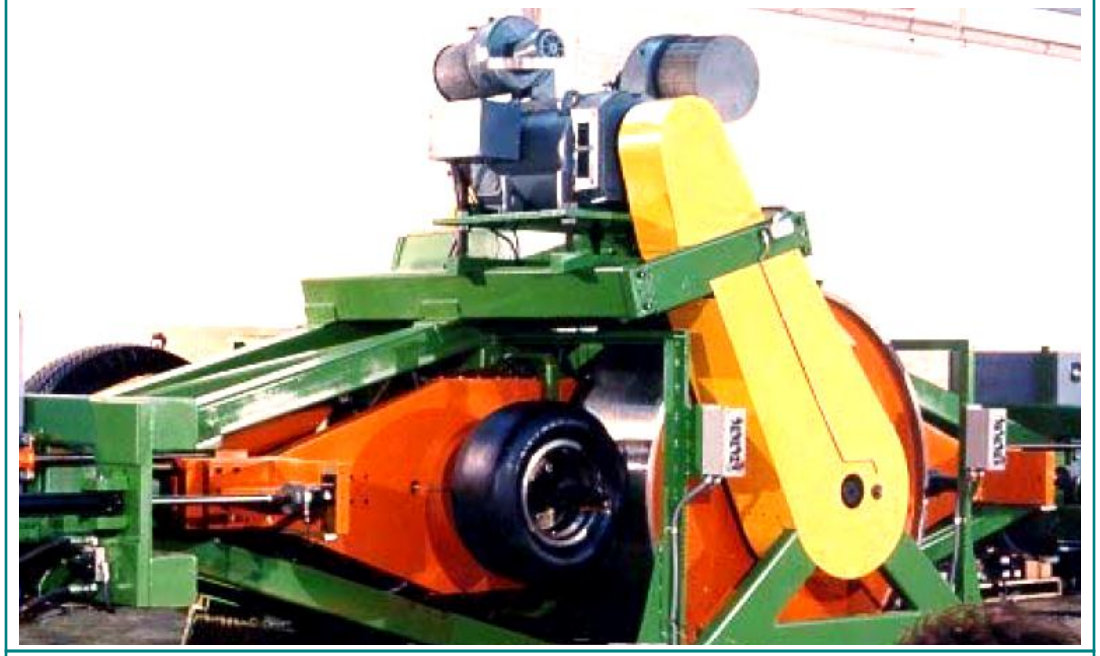
	Permeability ($10^{-8}cm^2s^{-2}atm^{-1}$)		Diffusivity ($10^{-6}cm^2s^{-1}$)	
	25°C	50°C	25°C	50°C
Natural Rubber	17.7	47	1.58	4.7
Butyl Rubber	0.99	4.03	0.081	0.384

Journal of Polymer Science, vol. 5, issue 3, pp. 307-332

Bromobutyl and Tire Durability

- **The benefits of butyl rubber in innerliner were demonstrated by Waddell *et. al.* using the durability test method required by the United States Federal Motor Vehicle Safety Standard (FMVSS) 139.**
- **While FMVSS 139 endurance is a passenger tire test, high O_2 level in the belt coat rubber are as much or more of a concern for commercial truck tires due to the higher inflation pressures and higher loads experienced by commercial tires in service.**

Testing Tire Durability

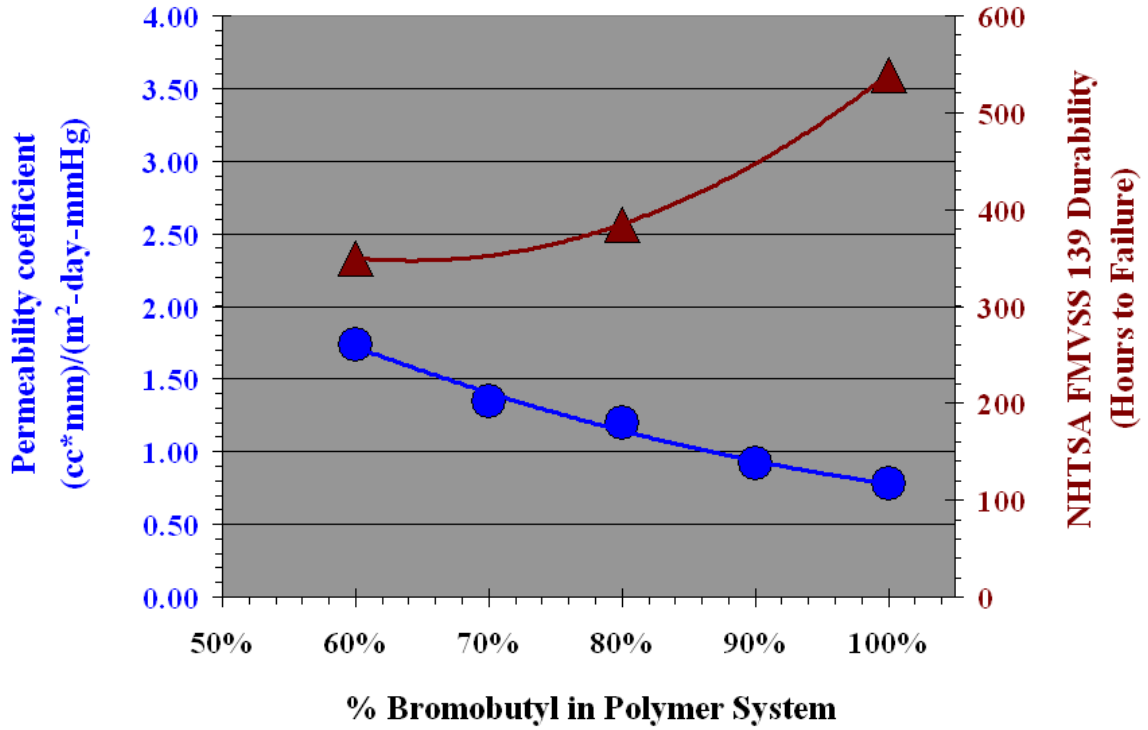


The benefits of bromobutyl O_2 barrier properties are evident through tire endurance testing.

Bromobutyl – Barrier Properties and Tire Durability

- A 100% Bromobutyl polymer system provides the lowest O_2 permeability.
- Lower O_2 permeability leads to higher durability due to a reduction in oxidative property degradation.
- Addition of Natural Rubber results in higher O_2 permeability which negatively affects tire durability.

Bromobutyl Affect on O_2 Permeability & Durability

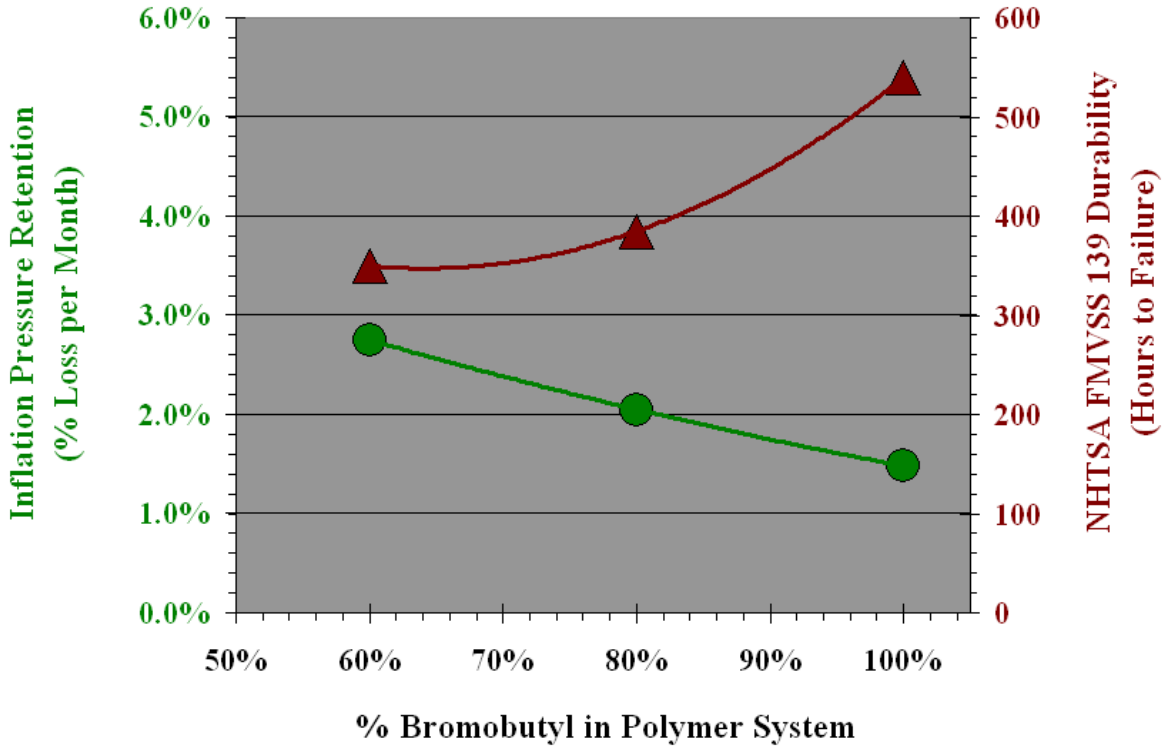


Rubber World, Volume 234, Number 3, pp. 36-41 (June 2006)

Bromobutyl – IPR and Tire Durability

- A 100% Bromobutyl polymer system provides the best Inflation Pressure Retention (IPR).
- Better IPR leads to higher durability as excessive tire deflection and heat generation is avoided.
- Addition of Natural Rubber results in higher Inflation Pressure loss rates which negatively affects tire durability.

Bromobutyl Affect on IPR & Durability

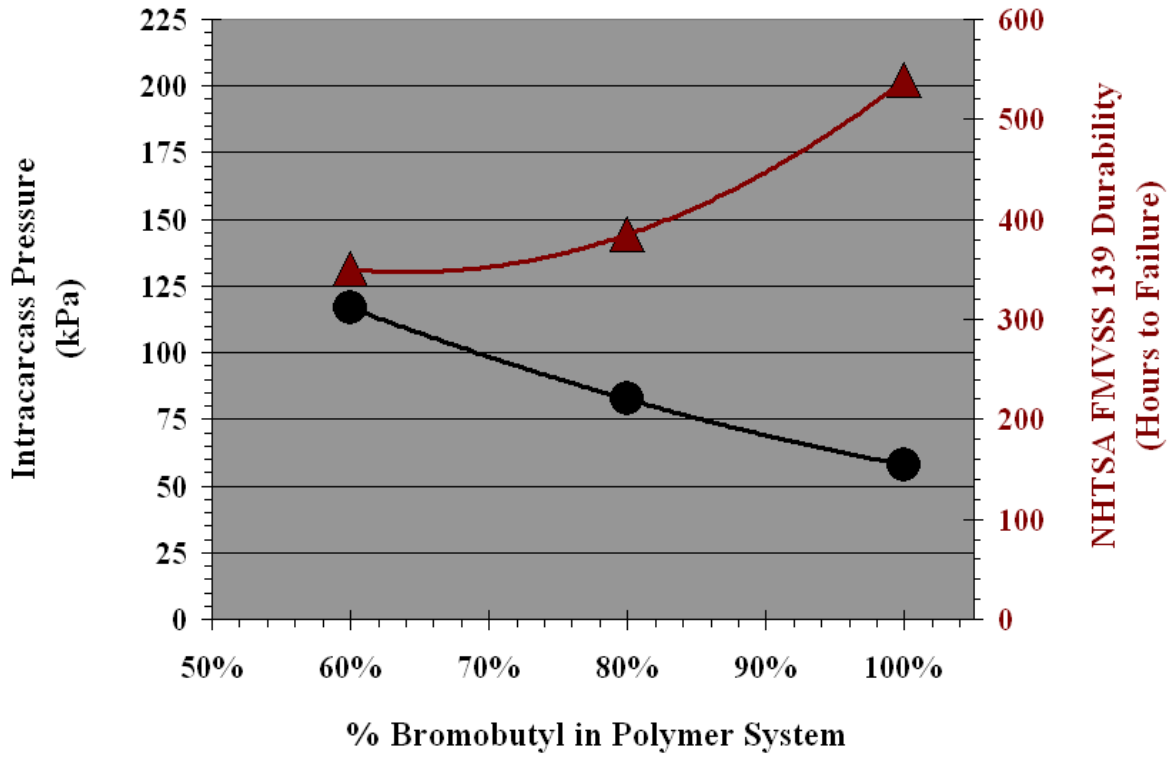


Rubber World, Volume 234, Number 3, pp. 36-41 (June 2006)

Bromobutyl – Intracarcass Pressure and Tire Durability

- **A 100% Bromobutyl polymer system provides the lowest Intracarcass Pressure.**
- **Lower Intracarcass Pressure leads to lower levels of dissolved O_2 and reduced oxidative property degradation.**
- **Addition of Natural Rubber results in increased Intracarcass Pressure which negatively affects tire durability.**

Bromobutyl Affect on Intracarcass Pressure & Durability



Rubber World, Volume 234, Number 3, pp. 36-41 (June 2006)

Bromobutyl Rubber – Summary

- **High Bromobutyl content provides lower O_2 Permeability, better Inflation Pressure Retention and lower Intracarcass Pressure which result in better tire durability.**
- **Addition of Natural Rubber reduces the barrier performance of the Bromobutyl but provides improved physical properties and carcass adhesion.**
- **As with most polymer blends, homogenization of a mixed polymer system to a finer morphology can minimize challenges while maintaining or improving advantages.**
- **Promix® 400 is a homogenizer for the Bromobutyl/NR system!**

Bromobutyl Content Considerations

	100% Bromobutyl	80% Bromobutyl
300% Modulus (psi)	491	469
Tensile Strength (psi)	1337	1480
Elongation (%)	684	683
Carcass Adhesion (lbf/in)	187	212
Oxygen Trasmission Rate (cc/100 in2 day)	9.9	27.9

Advantages to High Bromobutyl Content

- Improved barrier to O_2
- Improved Inflation Pressure Retention
- Reduced Intracarcass Pressure
- Improved Tire Durability

Challenges of High Bromobutyl Content

- Reduced Tensile Strength
- Reduced Adhesion to Carcass
- Difficult processing
- Increased cost

Promix® 400 Homogenizing Agent Performance in Tire Innerliner Formulations

Promix® 400 – Introduction

- **Increased Bromobutyl content provides better Inflation Pressure Retention, lowest Intracarcass Pressure and better durability.**
- **Addition of Natural Rubber reduces the barrier performance of the Bromobutyl but improves physical properties and carcass adhesion.**
- **As with most polymer blends homogenization can help minimize challenges and maintain advantages.**
- **Promix® 400 is a homogenizer for the Bromobutyl/NR system.**

Promix® 400 Features and Benefits

Features of Promix® 400

- Copolymerized hydrocarbon resin
- Contains aromatic, naphthenic and aliphatic components
- Compatible with many elastomers
- Homogenizer for the Bromobutyl/NR polymer system
- Compliant with European PAH regulation

Benefits of Promix® 400 in Tire Innerliner

- Reduced O_2 Permeability
- Improved innerliner adhesion to carcass
- Improved fatigue properties
- Improved blending and processing
- Improved barrier even in 100% Bromobutyl systems
- Cost control through use of Bromobutyl with Natural Rubber and potential for gauge reduction.

Promix® 400 – Tire Innerliner Formulation

- **Polymer system is typically 100% Bromobutyl or a blend of Bromobutyl (BIIR) and Natural Rubber (NR).**
- **Naphthenic oil is added for improved processability but decreases barrier properties.**
- **Promix® 400 Homogenizing Agent provides improved barrier properties, better adhesion, improved resistance to fatigue and improved processability.**

Typical Tire Innerliner Formulations

Bromobutyl	**80 – 100 phr**
Natural Rubber	**0 – 20 phr**
N660	60.00
Naphthenic Oil	**0-15**
Promix® 400	**0-15**
Tackifying Resin	4.00
Stearic Acid	2.00
Magnesium Oxide	0.15
Zinc Oxide	1.00
Sulfur	0.50
MBTS	1.20

Promix® 400 in Bromobutyl/NR Innerliner

Example: BIIR/NR Innerliner

- **Polymer system is 80phr Bromobutyl with 20phr Natural Rubber.**
- **Oil was reduced as Promix® 400 was added to maintain constant modulus.**
- **Addition of Natural Rubber made possible by Promix® 400 helps control cost.**

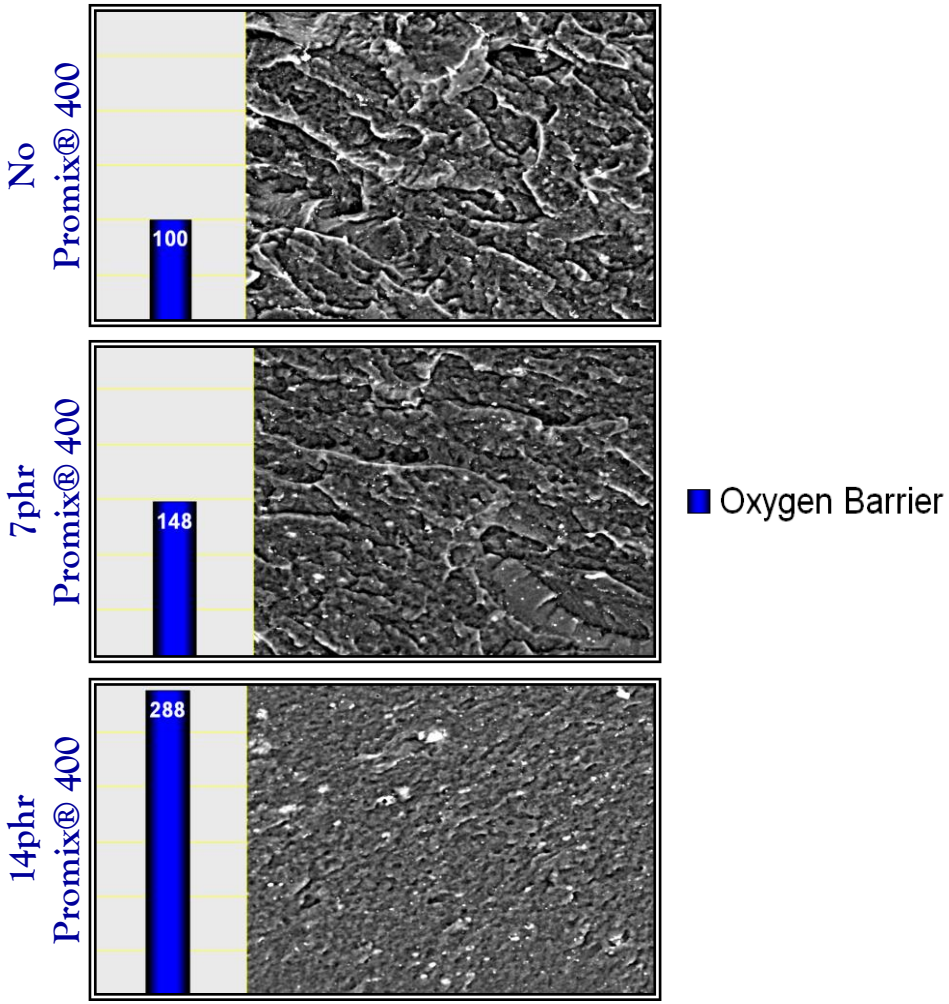
Bromobutyl/NR Innerliner Formulations

	No Promix® 400	7phr Promix® 400	14phr Promix® 400
Bromobutyl	80	80	80
Natural Rubber	20	20	20
N660	60	60	60
Naphthenic Oil	**16.5**	**8.0**	**1.0**
Promix® 400	**0.0**	**7.0**	**14.0**
Tackifying Resin	4.0	4.0	4.0
Stearic Acid	2.0	2.0	2.0
MgO	0.15	0.15	0.15
ZnO	1.0	1.0	1.0
Sulfur	0.5	0.5	0.5
MBTS	1.2	1.2	1.2

Promix® 400 in Bromobutyl/NR Innerliner

Example: BIIR/NR Innerliner

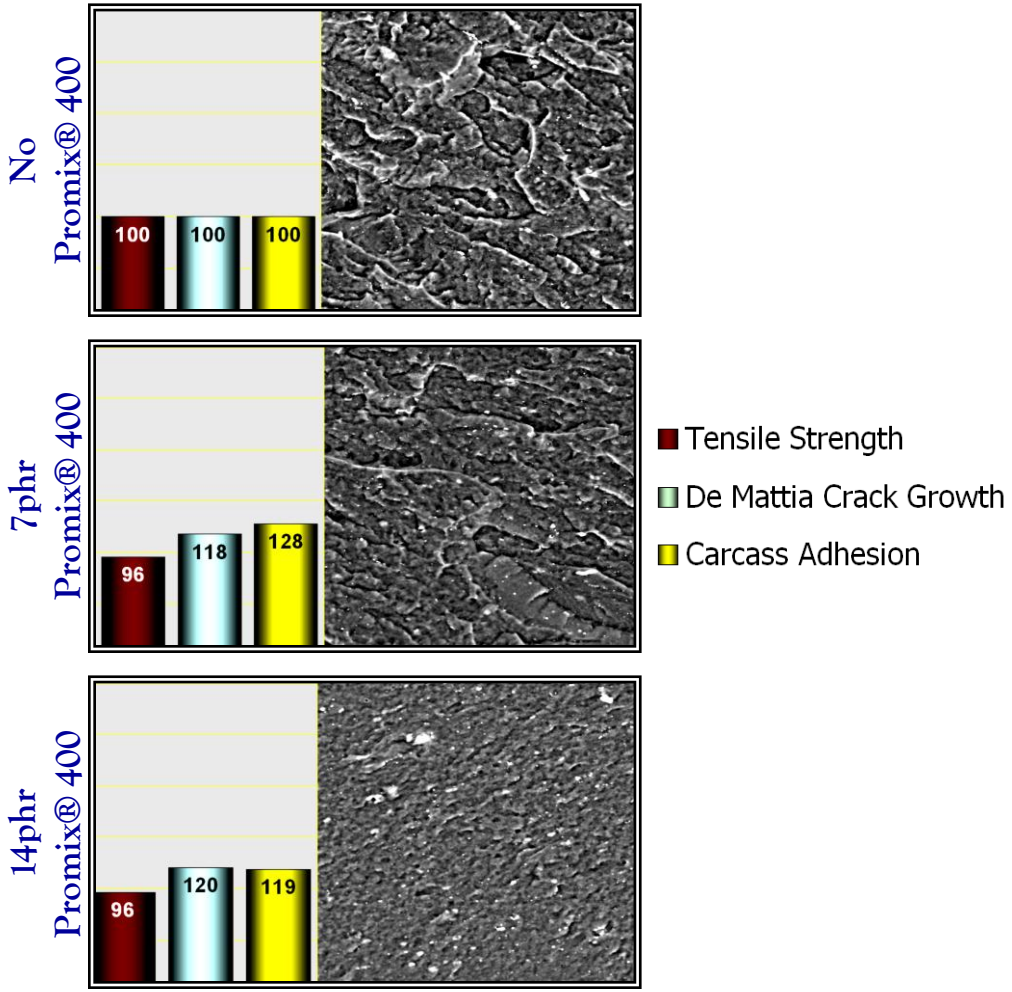
- **Promix® 400 Homogenization**
- **In an innerliner formulation containing a 80% Bromobutyl, 20% Natural Rubber system, polymer phase morphology is clearly visible via microscopy.**
- **Use of Promix® 400 visibly improves polymer morphology and dramatically improves O2 barrier. Opportunity for improved performance and cost control through gauge reduction.**



Promix® 400 in Bromobutyl/NR Innerliner

Example: BIIR/NR Innerliner

- **Promix® 400 Homogenization**
- **Improved performance:**
  - **Equivalent tensile strength**
  - **~20% improvement in De Mattia Crack Growth Rate**
  - **~20% improved Carcass Adhesion with mode changed from smooth to cohesive**



Promix® 400 in Full Bromobutyl Innerliner

Example: Full BIIR Innerliner

- **Polymer system is 100phr Bromobutyl without Natural Rubber.**
- **Promix® 400 in-place-of Naphthenic Oil**
- **Naphthenic oil was reduced as Promix® 400 was added to maintain constant modulus.**

Full Bromobutyl Innerliner Formulations

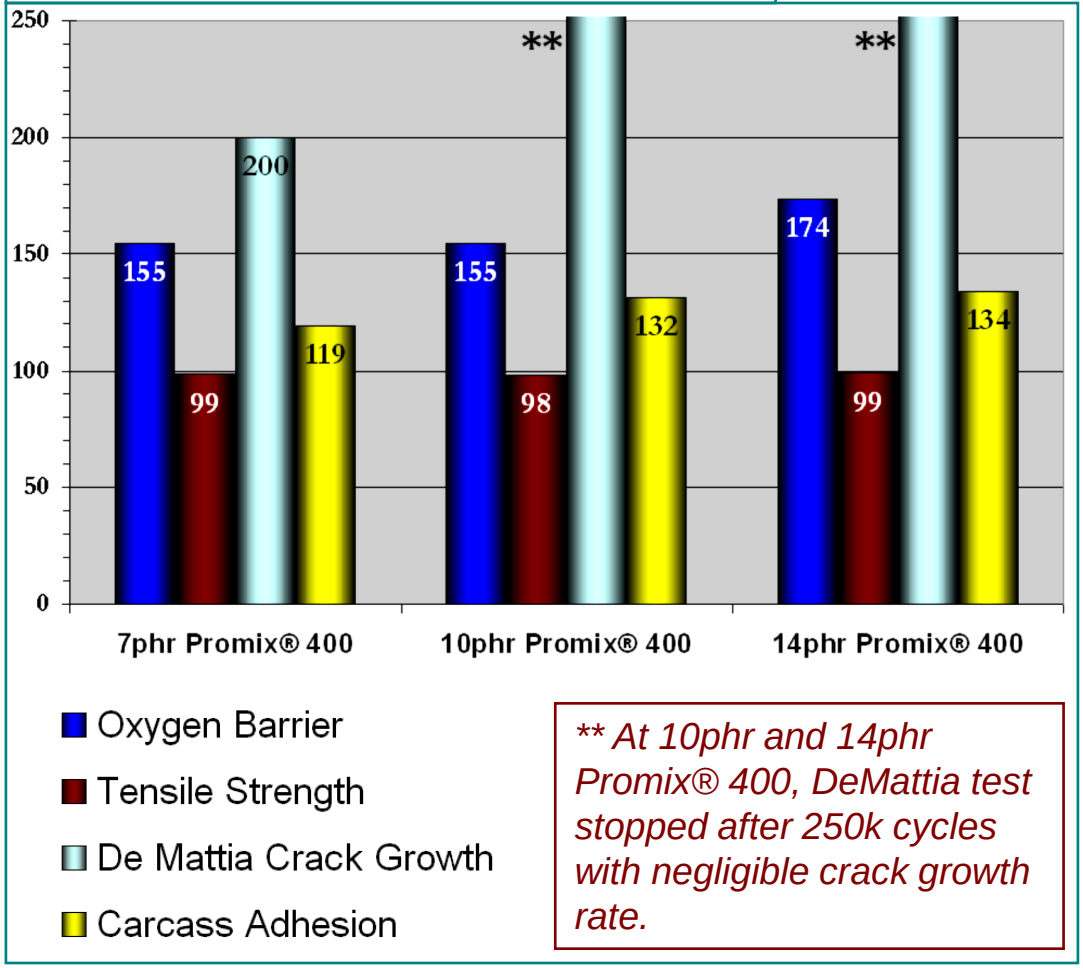
	No Promix® 400	7phr Promix® 400	10phr Promix® 400	14phr Promix® 400
Bromobutyl	100	100	100	100
N660	60	60	60	60
Naphthenic Oil	**16.5**	**8.0**	**5.0**	**1.0**
Promix® 400	**0.0**	**7.0**	**10**	**14.0**
Tackifying Resin	4.0	4.0	4.0	4.0
Stearic Acid	2.0	2.0	2.0	2.0
MgO	0.15	0.15	0.15	0.15
ZnO	1.0	1.0	1.0	1.0
Sulfur	0.5	0.5	0.5	0.5
MBTS	1.2	1.2	1.2	1.2

Promix® 400 in 100% Bromobutyl Innerliner

Example: Full BIIR Innerliner

- **Promix® 400 in-place-of Naphthenic Oil**
- **Improved performance:**
  - **Equal tensile strength**
  - **Dramatic improvement in DeMattia Crack Growth Rate**
  - **50%+ Improvement in Oxygen Barrier**
  - **~20%+ improved Carcass Adhesion with mode changed from smooth to cohesive**

Promix® 400 in Bromobutyl Innerliner

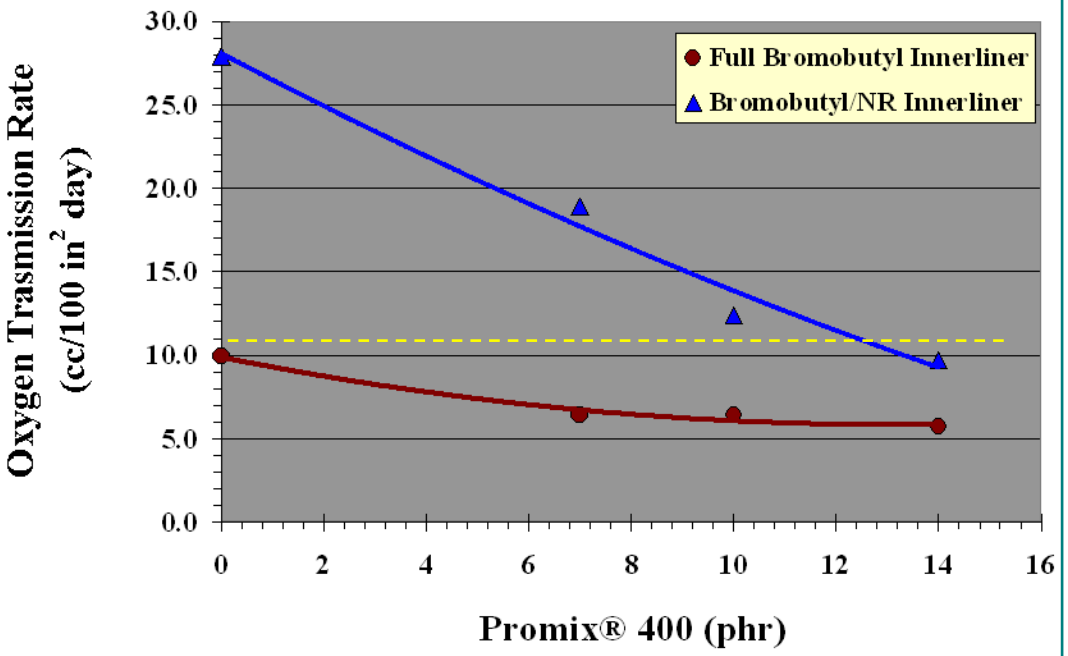


*** At 10phr and 14phr Promix® 400, DeMattia test stopped after 250k cycles with negligible crack growth rate.*

Promix® 400 in Bromobutyl Innerliner

- **Promix® 400 in Bromobutyl Innerliner**
- **Use of Promix® 400 in Bromobutyl innerliner in-place-of Naphthenic oil results in improved O_2 barrier.**
- **Improved barrier performance using Promix® 400 allows flexibility in use of Natural Rubber for enhanced physical properties and cost control.**

Promix® 400 in Bromobutyl Innerliner



***** 80% Bromobutyl Innerliner with 14phr Promix® 400 has equivalent O2 barrier to Full Bromobutyl Innerliner. (MOCON OTR at 25°C)***

Promix® 400 in Innerliner – Summary

Features of Promix® 400

- Copolymerized hydrocarbon resin
- Contains aromatic, naphthenic and aliphatic components
- Compatible with many elastomers
- Homogenizer for the Bromobutyl/NR polymer system
- Compliant with European PAH regulation

Benefits of Promix® 400 in Tire Innerliner

- Reduced O_2 Permeability
- Improved innerliner adhesion to carcass
- Improved fatigue properties
- Improved blending and processing
- Improved barrier even in 100% Bromobutyl systems

Promix® 400 provides opportunity to reduce tire oxidative degradation for improved tire durability.