Optimized PI Compound Mixing Strategy

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Optimized PI Compound Mixing Strategy

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Chemical Engineering

Honors Research Project

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The Williams Honors College
The University of Akron

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THE GOODYEAR TIRE & RUBBER COMPANY

OPTIMIZED PI COMPOUND MIXING STRATEGY

FINAL REPORT

HONORS PROJECT

PLYS 497-803

Cecilia Mainzer

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Honors Faculty Advisor: Dr. Bi-min Newby
Readers: Jeremy Miracle, Dawn Johnson

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College of Engineering and Polymer Science
University of Akron
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Abstract

The project focuses on developing an optimal mixing strategy for a polyisoprene (PI) compound at the Goodyear Tire & Rubber Company. The aim is to optimize performance objectives of the compound. The project involved research, design iterations, mixing analyses, and performance evaluations, while adhering to engineering codes and standards.

The design process includes analyzing differences between two mixing technologies, intermesh and tangential rotors; altering mixing conditions; and exploring additional polymer systems and coupling technology of the compound.

Validation data confirms that the mixing technology and compound recipe meets all success metrics, including stiffness, hysteresis, adhesion, cure rate, and tear performance objectives, and ensures repeatability.

This project exemplifies innovation and engineering efforts by addressing compounding challenges and improving mixing processes within the tire and rubber industry.
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Introduction

The project’s purpose is to extend past efforts and develop an optimal mixing strategy for a compound that is 100% Polyisoprene (PI) with high levels of filler. This project is worthwhile as it establishes standard guidelines for mixing this type of compound. For this compound, the current mixing strategy includes three nonproductive (NP) passes and a productive (PR) pass with no heat tempering and either an intermesh rotor or tangential rotor. The current four-pass mixing strategy is non-optimum with the dispersion required of the PI rubber matrix. This project aims to improve compound properties without detrimental tradeoffs and increase dispersion and incorporation into the rubber matrix by outlining an optimal mixing strategy. An optimal mixing strategy would allow the company to streamline mixing by applying this strategy to other PI compounds, increasing performance indicators across the board, and minimizing redundancies.
Project Overview

The project’s overall purpose is to improve performance of PI compound products at The Goodyear Tire & Rubber company by optimizing mixing strategy solutions. The project’s scope was redefined throughout the design and testing portions and additional work streams were identified. Initiated in 2020, the project began exploring PI compound recipe and performance objects but proved to require a more complex mixing solution when challenges in polymer matrix dispersion occurred. The 2020-2023 efforts served as a base for the project outlined in this report.

Compounding is a complex combination of chemistry and physics that starts with selecting raw materials, formulating compounding recipes, adjusting mixing parameters for optimal dispersion during processing, collecting meaningful data through a plethora of test methods, as well as interpreting results, drawing conclusions, and identifying factors of improvement before the steps repeat (Barbin, 1994; Urbon, 1989).

The project addresses each step of compounding and divides them into the main areas, including research, design, testing, and validation. The scope of research included understanding the need for an optimized mixing strategy, evaluating current mixing conditions, identifying potential mixing conditions to be altered, outlining target performance objectives, and shadow off-site mixing with two types of rotors. The scope of design included adjusting mixing conditions, comparing ingredients, adding passes in the mixing process, and drafting new mixing strategies. The scope of testing included conducting mix attentions in the laboratory and evaluating new mixing condition performance. The scope of validation included conducting performance tests and collecting data on performance indicators to confirm results and ensure repeatability.

Due to the complexity of the project, an action plan was developed to manage the timeline of the project. The main steps described were broken down and completed each month. While the main monthly objectives outlined the core steps, it is valuable to note that many smaller tasks were completed to ensure each deadline was achieved.
Research

The Goodyear Tire & Rubber Company utilizes a variety of mixing strategies within their laboratories and plants to test and make rubber for tires. However, reducing complexity within the company is a necessity for mass production. Optimizing a single mixing strategy that results in ideal performance of products for a specific compound category will streamline mixing processes and save on costs, production, and time (Urbon, 1989).

The current mixing strategy utilized to process a main PI compound created challenges when the polymer matrix was not properly dispersing. To remedy this concern, all mixing conditions went under evaluation.

Processing includes a multitude of factors that affect the mix, such as what time and pass ingredients are added; mixing conditions such as duration, temperature, rotor speed, and heat tempering; and the types of rotors used whether it is tangential or intermesh (Urbon, 1989). Some factors are easy to alter between mixes, while others require time to reach steady state before a new mix. Specifically, if the chamber temperature of the mixer is altered, an additional time must be accounted for in set up for the chamber to come to the new steady-state temperature. Start-up and preparation time were factored into determining which mixing conditions would be further explored.

In addition to time, mixing condition changes needed to remain in compliance with company limits of each factor. Out of all the previously listed conditions, heat tempering produced the most viable option to better disperse filler into the polymer matrix. Heat tempering consists of keeping a target temperature constant for a selected duration of time to enable the coupling chemical reaction that occurs between the filler and the polymer (D. Johnson, personal communication, 2023). Heat treatment varies rotor speed to maintain a target temperature for a selected time.

These factors were seen in action when shadowing mix attentions in the laboratory. Learning about the current company’s practice consisted of reading about and observing mixes. To develop an understanding for scaled-up production, mixes at a third-party vendor were also evaluated. From the third-party vendor, a final mixing factor was determined for consideration.

Rotors are standard tools for the emulsification and mixing of materials inside a mixer (Urbon, 1989). There are many types of rotors, but tangential and intermesh were explored at the third-party vendor. Tangential rotors rotate independently and, therefore, can rotate at different speeds. **Figure 1** shows how neither rotor crosses the central line. Because of this, tangential rotors have a larger fill factor available in the mixer.
Intermesh rotors cross paths, like gear wheels. If both rotors are the same diameter, the rotors then must rotate at the same speed. **Figure 2** shows how each rotor crosses the central line and interferes with the other’s rotational path. Because of this, intermesh rotors create more dispersion while mixing the compound and therefore reduces the number of mix passes needed. Reducing mix passes can serve as a major benefit as it decreases the overall time of the mix.

Both tangential and intermesh rotors are utilized in the company’s laboratories and plant facilities, providing further reason to evaluate these two types of rotors and their effect on the PI compound.

After a mix, the newly made rubber compound is sent to the lab for testing and collection of performance data. With Goodyear being a global headquarters and an innovative company for over 125 years, the potential for scope creep could become very possible during testing. However, the main performance objectives for PI compounds for this project included stiffness, hysteresis, tear, and adhesion. Data for these performance indicators will make it clear if heat tempering will improve the performance objectives without significant tradeoffs.
**Design**

Heat tempering was investigated in a study consisting of six PI compounds. Between compounds, mixing pass conditions for NP1, NP3, and PR were kept consistent, except for NP2 which focused on heat tempering effects. When designing the study an additional factor for consideration presented itself.

The procurement team of the company continuously evaluates costs of supplies that are used in rubber recipes. Due to a push from company leadership, another factor needed to be incorporated into the study. This challenge exemplified the adaptations that occur in the design phase of a project in an engineering field. The compound recipes formulated in this section therefore also compared natural rubber grades and location due to the company’s emphasis on the conversion of Ingredient A to Ingredient B, which has comparable grade quality but lower costs. Table 2 showcases the differences explored in formulations and mix conditions. Missing information within the table was redacted following the company’s confidentiality policy.
Table 2: Heat tempering and different ingredient supplier study mixing conditions for six PI compounds.

<table>
<thead>
<tr>
<th>PI Compounds</th>
<th>Compound 1</th>
<th>Compound 3</th>
<th>Compound 3</th>
<th>Compound 4</th>
<th>Compound 5</th>
<th>Compound 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formulas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ingredient A</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Included</td>
<td>Included</td>
</tr>
<tr>
<td><strong>Ingredient B</strong></td>
<td>Supplier 1</td>
<td>Supplier 2</td>
<td>Supplier 1</td>
<td>Supplier 2</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

NP1

- **Rotor Temp (°C)**
- **Chamber Temp (°C)**
- **RPM**
- **Mix Time (min)**
- **Material Addition**
- **Mastication (sec)**
- **Material Addition**
- **RAM Raise 1 (°C)**
- **RAM Raise 2 (°C)**
- **Drop Temp (°C)**

NP2

- **Rotor Temp (°C)**
- **Chamber Temp (°C)**
- **RPM**
- **Mix Time (min)**
- **Material Addition**
- **Mastication (sec)**
- **Material Addition**
- **RAM Raise 1 (°C)**
- **Plateau (min)**
- **Mix (°C)**
- **Drop Temp (°C)**

NP3

- **Rotor Temp (°C)**
- **Chamber Temp (°C)**
- **RPM**
- **Mix Time (min)**
- **Material Addition**
- **Mastication (sec)**
- **Material Addition**
- **RAM Raise 1 (°C)**
- **Drop Temp (°C)**

**PR**

* Missing information within the table was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.

Tangential and intermesh rotors were investigated in a study consisting of eight control PI compounds and ten experimental PI compounds. Between compounds, mixing pass conditions for the PR passes were kept consistent. For NP1, NP2, and NP3 which focused on rotor effects,
including fill factor, ram raises, and mix time. Unfortunately, **Table 3** outlining the mixing conditions for each compound and rotors was not able to be published as it contained confidential information and violated the company’s confidentiality policy.

*Table 3: Tangential and intermesh rotor study mixing conditions for 18 PI compounds.*

* This table was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.
Testing

After the rubber recipes and mixing conditions were finalized in Table 2 and Table 3, the mixes were executed by a technician within laboratory facilities. For each mix, diligent notes and results were documented beyond the machine’s capabilities such as rubber appearance, loose filler, tackiness, and milling ability. However, for each mix, no significant difference resulted from these conditions and therefore were not further evaluated or compared.

The data from the mixers were also documented and the following mix curves for each study were produced. Due to The Goodyear Tire & Rubber Company’s confidentiality policy, only the temperature and ram position data was able to be shown on the graphs.

Figure 3 and Figure 4 show the resulting NP2 mix curves from the study that compared standard mixing and heat tempering. Figure 3 shows the standard mix with no heat tempering. For the standard mix, rotor speed is set as a constant while temperature steadily increases throughout the pass until the final drop temperature. Figure 4 shows the heat-tempered mix. For the heat-tempered mix, the rotor speed compensates by stopping and starting to keep the final target temperature constant for the selected duration of time.

Figure 3: Shows the standard mix mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
Figure 4: Shows heat tempered mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.

Again, due to The Goodyear Tire & Rubber Company’s confidentiality policy the NP1, NP2, and NP3 for the tangential and intermesh rotor study were not able to be published. The following mix curves in Figures 5, 6, 7, 8, 9, and 10 for these passes were redacted.

Figure 5: Shows the tangential rotor study NP1 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.

Figure 6: Shows the intermesh rotor study NP1 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.
Figure 7: Shows the tangential rotor study NP2 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.

Figure 8: Shows the intermesh rotor study NP2 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.

Figure 9: Shows the tangential rotor study NP3 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.

Figure 10: Shows the intermesh rotor study NP3 mixing curve for temperature in degrees Celsius and rotor speed in rotations per minute.
* This figure was redacted in compliance with The Goodyear Tire & Rubber Company’s confidentiality policy.
Validation and Repeatability

From each mix, data indicative of performance objectives was collected, including stiffness, hysteresis, tear, and adhesion. Table 4 displays the results of the standard mixing and heat-tempered mixing. Table 5 shows the results of the differences between the ingredient grade and suppliers. It is imperative to note the tables include normalized data to make better comparisons between the compounds and mixes. Higher normalized numbers indicate better results. From Table 4, significant improvement was seen in the tear of a heat-tempered mix compared to a standard mix without detriment to other properties. Substituting Ingredient B for Ingredient A gives higher tear with stiffness, hysteresis, and adhesion being minimal tradeoffs, as see in Table 5. There is no significant difference between the two Ingredient B suppliers.

Table 4: Standard mix versus heat tempered normalized performance objectives.

<table>
<thead>
<tr>
<th></th>
<th>Standard Mix</th>
<th>Heat Tempered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness (Mpa)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>100</td>
<td>101</td>
</tr>
<tr>
<td>Tear DTL (N/mm)</td>
<td>100</td>
<td>340</td>
</tr>
<tr>
<td>Adhesion (N)</td>
<td>100</td>
<td>98</td>
</tr>
</tbody>
</table>

Table 5: Ingredient grade and supplier normalized performance objectives.

<table>
<thead>
<tr>
<th></th>
<th>Original Ingredient A</th>
<th>Supplier 1 Ingredient B</th>
<th>Supplier 2 Ingredient B</th>
<th>Original Ingredient A</th>
<th>Supplier 1 Ingredient B</th>
<th>Supplier 2 Ingredient B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness (Mpa)</td>
<td>100</td>
<td>98</td>
<td>96</td>
<td>100</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>100</td>
<td>96</td>
<td>93</td>
<td>100</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Tear (N/mm)</td>
<td>100</td>
<td>108</td>
<td>148</td>
<td>100</td>
<td>118</td>
<td>109</td>
</tr>
<tr>
<td>Adhesion (N)</td>
<td>100</td>
<td>94</td>
<td>98</td>
<td>100</td>
<td>94</td>
<td>98</td>
</tr>
</tbody>
</table>

Table 6 displays the results of the tangential versus intermesh rotor mixing. From Table 6 the following was seen:

- No impact on stiffness.
- Hysteresis is better with intermesh.
- Tear from Machine 1 was lower, but higher when tested with Machine 2, deeming the results inconclusive and the need to improve tear-testing methods.
- Adhesion was a slight trade off being worse for intermesh, but still falling within acceptable limits.
- Because of the higher efficiency nature of intermesh rotors, it is vital to note in the table that the number of mix passes were decreased from 4 to 3, which is significant in time and cost savings.
Table 6: Tangential versus intermesh rotor mixing normalized performance objective results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tangential</th>
<th>Intermesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness (Mpa)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>Tear Machine 1 (N/mm)</td>
<td>100</td>
<td>88</td>
</tr>
<tr>
<td>Tear Machine 2 (N/mm)</td>
<td>100</td>
<td>143</td>
</tr>
<tr>
<td>Adhesion (N)</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>Passes</td>
<td>4*</td>
<td>3*</td>
</tr>
</tbody>
</table>

*Indicates values that are not normalized.
Conclusions

The design and implementation of an optimized mixing strategy for PI compounds at The Goodyear Tire & Rubber Company has yielded significant improvements in process efficiency and polymer matrix dispersion. The project set out to address the inefficiencies of the current mixing strategy.

Through meticulous research, design iterations, and performance evaluations, an optimized mixing strategy was developed to handle complex PI compound mixes. The new optimized mixing strategy with heat tempering produced a significant improvement of tear results without compromising the other properties. Heat tempering significantly benefits the tear of the compound, proving that mixing has a direct impact on compound performance.

In addition to heat tempering, intermesh rotors also had a significant impact on hysteresis, with only minimal known tradeoffs. The utilization of intermesh rotors also decreased the number of passes of the mixing strategy from four to three passes, resulting in huge time and cost savings.

In conclusion, this project represents an advancement for The Goodyear Tire & Rubber Company, enhancing their mixing strategies for PI compounds. Having an optimized mixing strategy for PI compounds minimizes redundancies, increases repeatability, and significantly improves performance objectives.
References
