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Industrial Solutions to Enhance Adhesion Strength of Metal to Rubber Bonding in Press on Tire

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Abstract. Failures in metal-to-rubber bonding (MTRB) represent a significant quality challenge in the tire manufacturing industry. This study investigates the root causes of MTRB failures in press-on (PON) tires and proposes optimized methods to mitigate these issues. Key factors such as surface preparation, adhesive and rubber layer thickness, and the effects of aging were analysed. Results reveal that adhesion strength is significantly influenced by surface treatment parameters, adhesive coat uniformity, and compound thickness. Aging studies demonstrate the detrimental effects of prolonged exposure to heat. Practical suggestions, including grit blasting parameter optimization and automation of adhesive applications, are provided to enhance production efficiency and product quality.

Keywords: Metal-to-rubber bonding, adhesion strength, industrial optimization, adhesive thickness, aging effects

1 Introduction

Metal-to-rubber bonding (MTRB) is a critical component in the manufacturing of PON tires, which are widely used in high-performance and heavy-load vehicles (Langenohl, 2004). These tires often experience failures at the MTRB interface due to inadequate adhesion, surface contamination, or mechanical stress (Achary, Gouri, & Ramaswamy, 2001).

The adhesion between metal and rubber plays a crucial role in ensuring the durability and performance of tires, especially for industrial applications. Rubber and metal have fundamentally different chemical and physical properties, which can lead to weak bonding if not properly addressed. This is further compounded by the operational conditions of PON tires, such as exposure to high temperatures, dynamic loads, and environmental factors like humidity and corrosive elements (Souid, Sarda, Deterre, & Leroy, 2014).

Failures in the metal-to-rubber bond (MTRB) manifest as delamination, cracking, or loss of adhesion, often leading to costly downtime and product recalls (Chemistry, 2017). For instance, weak adhesion can result in the separation of the tread layer from the steel band core, severely affecting the tire's structural integrity and performance. Studies have shown that inadequate surface preparation, improper adhesive application, and variations in curing parameters are some of the leading causes of MTRB failure (Bonding, 2014; Ismail, Harun, & Yahya, 2015)

To address these challenges, manufacturers have turned to advanced bonding techniques, surface treatment methods, and stringent quality control protocols. Surface preparation methods such as grit blasting, chemical treatments, and primer applications have been explored to enhance the metal's surface energy and ensure better adhesion with the rubber layer (Ali, Hosseini, & Sahari, 2010). Similarly, optimizing the thickness of adhesive and rubber layers has been shown to significantly improve the bonding strength, while also minimizing production defects (Achary et al., 2001).

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This study, conducted in collaboration with Michelin Lanka, aims to identify the root causes of MTRB failures in PON tires and propose industrially viable solutions. The research focuses on optimizing key process parameters, including surface treatment methods, adhesive and rubber thicknesses, and curing conditions. By addressing these factors, this study seeks to enhance the overall quality and reliability of PON tires, thereby meeting the demands of high-performance industrial applications.

2 Materials and Methods

Between the general methodology and the specific materials used, it is important to establish a clear connection. The choice of materials directly influences the performance and reliability of MTRB in industrial applications. By carefully selecting rubber compounds, adhesives, and primers tailored to operational conditions, this study ensures the relevance and applicability of the findings.

2.1 Materials

The materials selected for this study were chosen based on their proven effectiveness in MTRB applications within the tire manufacturing industry. The primary adhesive rubber compound used was B-6113, which is designed for high adhesion strength and durability. For the primer and adhesive layers, Chemlok 205 and Chemlok 220 were employed, both of which are widely recognized for their compatibility and strong bonding properties with steel substrates. The metal substrate used was steel bands with predefined dimensions, ensuring uniformity across all samples. These materials form the backbone of the bonding system analyzed in this research, and their selection was based on industrial best practices and availability.

2.2 Methodology Overview

The methodology for this study involved a series of systematic steps designed to evaluate the factors influencing MTRB performance. First, the surface preparation of the metal substrates was conducted using grit blasting, followed by de-greasing to remove contaminants and ensure a clean bonding surface. Next, primer and adhesive coats were manually applied to the prepared metal surfaces, ensuring consistency in thickness. The coated samples were then subjected to curing at a temperature of 150°C under a pressure of 30 kg/cm² for 45 minutes to achieve optimal bonding. Testing procedures included adhesion strength measurements using ASTM D429 (Methods, n.d.)and hardness evaluations using ASTM D2240 (Vian & Denton, 2018). Additionally, aging studies were performed on selected samples, where they were exposed to a temperature of 70°C for 72 hours to assess the effects of prolonged heat exposure on adhesion strength and mechanical properties. This comprehensive methodology ensured a thorough evaluation of the key parameters affecting MTRB performance.

3 Results and Discussion

3.1 Optimization of Surface Preparation

Grit blasting significantly impacts adhesion strength (Bonding, 2014). An optimal grit blasting time of 8 minutes was identified as a practical compromise between adhesion performance and production efficiency (See Fig.1) (Ismail et al., 2015).

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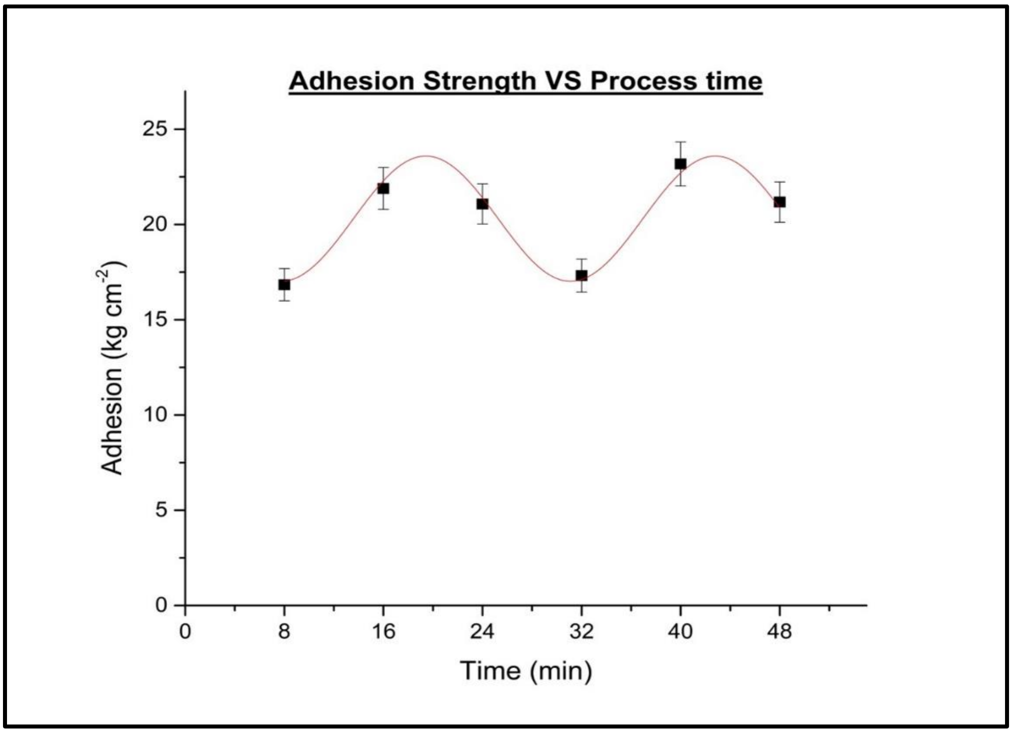

Fig. 1. The graph of Adhesion strength vs Grit blasting time

3.2 Influence of Adhesive and Rubber Thickness

Adhesion strength varied with adhesive coat and rubber thickness (Seen Fig.2 and Fig.3) (Chemistry, 2017). A 2 mm thick rubber layer exhibited the highest adhesion strength, while excessively thin or thick adhesive coats led to suboptimal bonding. The tensile properties of the rubber specimens used are presented in Table 1, and the tensile strength was calculated using the following equation:

$$\boldsymbol{Tensile\ Strength}\left(\frac{\boldsymbol{kg}}{\boldsymbol{cm^2}}\right)=\frac{Breaking\ Force\ (kg)}{Cross\ Section\ Area\ (cm^2)}\ (1)$$

Table 1. Tensile strength, Modulus, Elongation results for different thickness rubber specimens

Sample	Thickness (cm)	Width (cm)	Load 1(kg)	100% Modulus (kg cm^{-2})	Load 2(kg)	300% Modulus (kg cm^{-2})	Load 3(kg)	Tensile (kg cm^{-2})	Elonga-tion at break %
1	0.217	0.6	3.1	23.8	13	99.8	29.4	225.8	520
2	0.225	0.6	2.6	19.3	13.6	100.7	28.74	212.9	510
3	0.185	0.6	2.5	22.5	10.5	94.6	25.6	230.6	540
4	0.195	0.6	2.5	21.4	10.9	93.2	25.02	213.8	520

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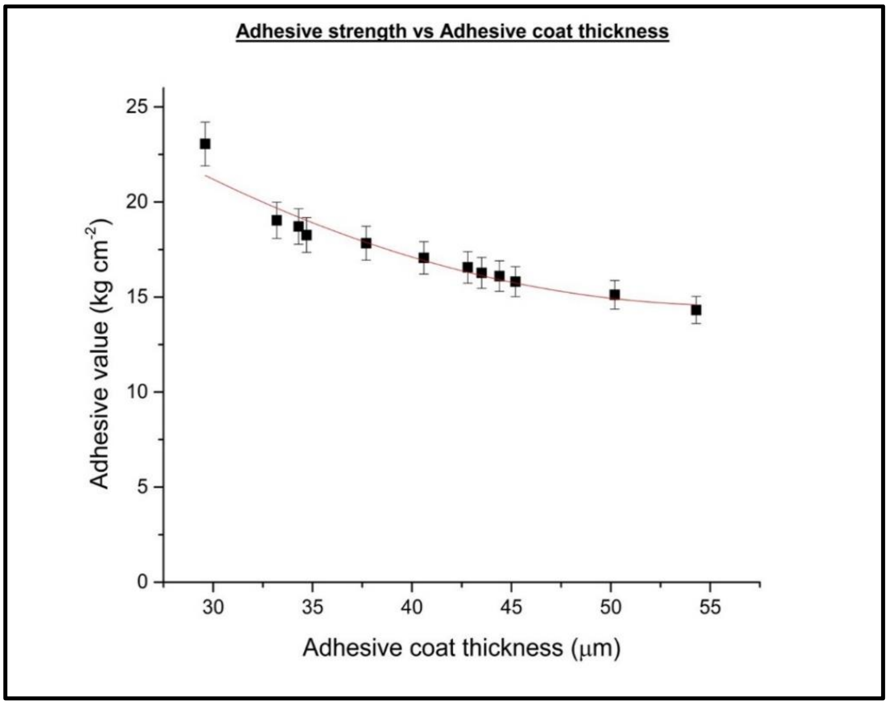

Fig. 2. The graph of Adhesion strength vs adhesive coat thickness

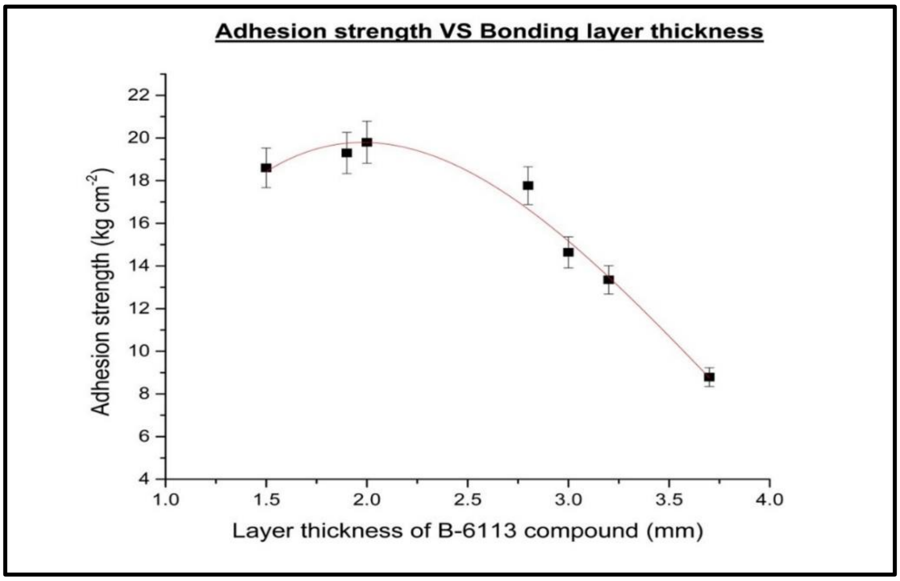

Fig. 3. The graph of adhesion strength vs bonding layer thickness

3.3 Effects of Aging on Adhesion

Aging reduced adhesion strength, tensile properties, and hardness (See Fig.4 and Fig.5) (Ali et al., 2010). FTIR analysis (See Fig 6) showed no significant chemical changes in the rubber compound due to aging, indicating that mechanical property degradation was the primary cause of reduced bonding (Souid et al., 2014). Table 2 provides an adhesion strength comparison under different primer and adhesive thicknesses. Adhesion strength was calculated using the equation:

$$\boldsymbol{Adhesion\ Strength}\ (\boldsymbol{kg/cm^2}) = \frac{Load\ (kgcm^{-1})}{Width\ (cm)} \quad (2)$$

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Table 2. Adhesion Strength Comparison

Sample	Time (min)	Adhesion Value (kg/cm²)	Primer Thickness (μm)	Adhesive Thickness (μm)
1	15	16.84	10	30
2	17	21.89	10	30
3	21	21.08	10	30
4	25	17.32	10	30

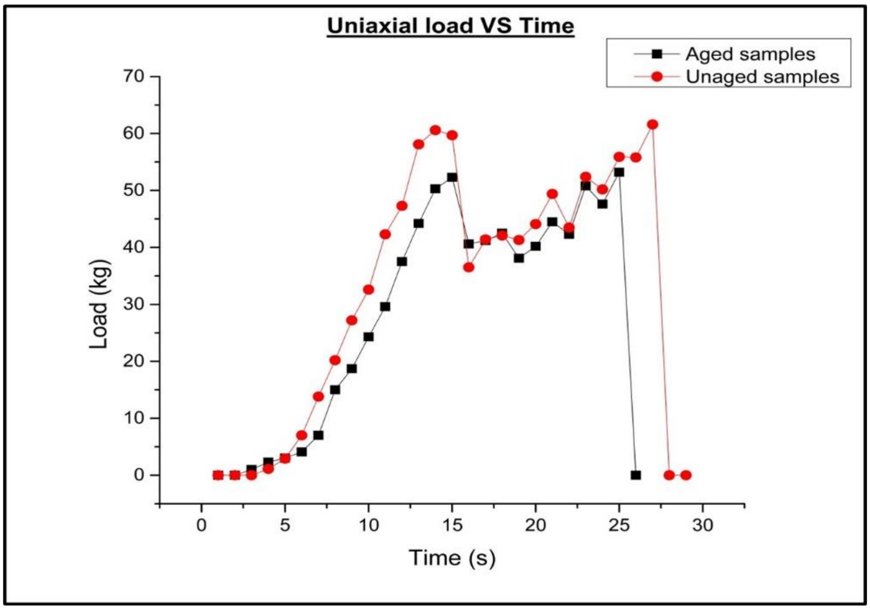

Fig. 4. Adhesion force comparison of aged and unaged MTRB samples with respect to time

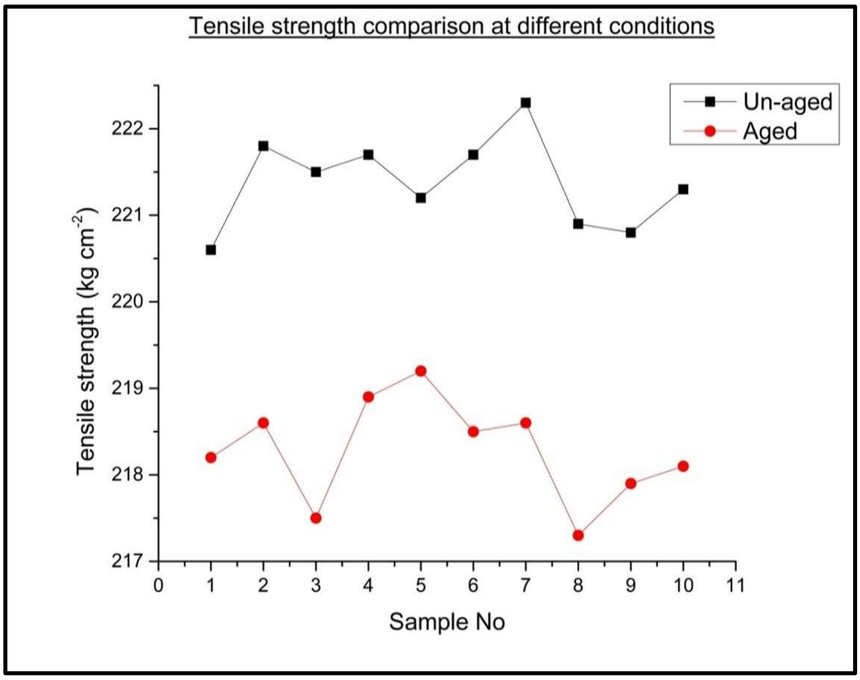

Fig. 5. Tensile strength variation at aged and unaged conditions

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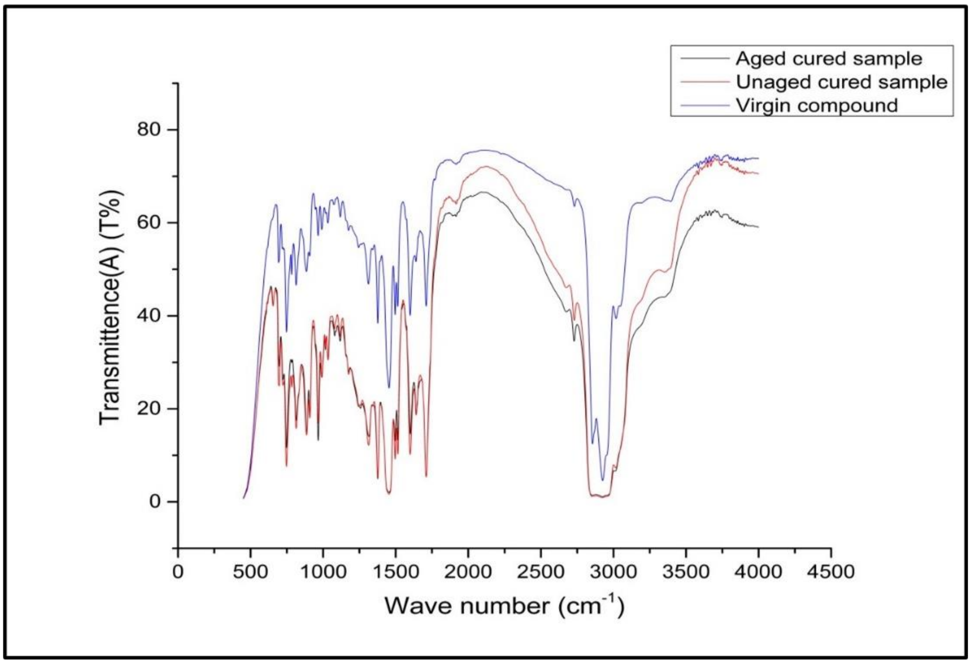

Fig. 6. The graph of FTIR spectrum comparison

3.4 Process Variations in Production

Non-uniform thickness of adhesive coats and rubber layers in the production process significantly affected adhesion strength (*INTERFACIAL WATER AND ADHESION LOSS OF POLYMER COATINGS ON A*, n.d.) . Tables 3 and Table 4 highlight these variations, with only 24% of adhesive coats meeting specification standards (Chemistry, 2017).

Table 3. Adhesive coat thickness variation in actual process

Status	Percentage
Within specification value	24%
Greater than upper specification value	32%
Less than lower specification value	44%

Table 4. Adhesive rubber thickness variation in actual process

Status	Percentage
Within specification value	67%
Greater than upper specification value	8%
Less than lower specification value	25%

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4 Conclusion and Recommendations

This study identifies critical parameters affecting MTRB in PON tires and provides actionable recommendations to enhance product quality and manufacturing efficiency. The findings highlight the importance of systematic surface preparation, where grit blasting and degreasing play a pivotal role in ensuring optimal bonding conditions. Furthermore, the controlled application of primer and adhesive coats is essential to achieve uniform adhesion strength across the substrate.

Aging studies revealed that prolonged exposure to heat significantly weakens the bonding strength, emphasizing the need for materials and processes that can withstand high-temperature conditions. The analysis also underscored the detrimental effects of non-uniform adhesive and rubber thicknesses in the production process, which can be mitigated through the adoption of automated coating systems and rigorous quality control measures.

- To reduce MTRB failures and enhance performance, the following key recommendations are proposed:
- Standardize Grit Blasting Parameters: Implement precise control over grit blasting time and intensity to achieve consistent surface roughness.
- Optimize Adhesive Application: Transition to automated or semi-automated adhesive coating methods to ensure uniform layer thickness.
- Enhance Quality Control: Introduce real-time monitoring systems for adhesive and rubber layer thicknesses to minimize production variations.

- Material Innovation: Explore advanced adhesive and primer formulations with improved thermal resistance and mechanical properties.
- Continuous Process Improvement: Develop an integrated feedback mechanism to adapt and optimize production parameters based on real-time performance data.

By addressing these areas, manufacturers can significantly enhance the durability and reliability of PON tires, meeting the demands of industrial applications while minimizing production costs and customer complaints. Future research could focus on developing predictive models to further understand the long-term performance of MTRB under various operational conditions.

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