EXPERIMENTAL INVESTIGATION OF BOND STRENGTH IN BITUMINOUS LAYERS

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Abstract-*The performance and durability of flexible pavements are highly dependent on the bond strength between successive bituminous layers. Poor interlayer bonding often results in structural distresses such as slippage cracking, rutting, and delamination, thereby significantly reducing pavement service life. This study presents a detailed experimental investigation of bond strength characteristics under varying tack coat materials and testing conditions. Laboratory experiments, including Direct Shear Test, Tensile Bond Strength Test, and Torque Resistance Test, were conducted on specimens prepared using VG-30 bitumen and Polymer Modified Bitumen (PMB). The results indicate that PMB demonstrates superior bonding performance, higher shear strength, and improved resistance to cyclic loading compared to conventional VG-30. Additionally, the study evaluates the influence of temperature, surface condition, and loading rate on interlayer bond strength. It was observed that bond strength decreases with increasing temperature, while proper surface preparation significantly enhances adhesion. The findings of this study highlight the critical role of tack coat material selection and application techniques in improving interlayer bonding, ultimately contributing to enhanced structural performance and extended service life of flexible pavements.*

Keywords: Interlayer Bond Strength, Bituminous Layers, Tack Coat, Polymer Modified Bitumen (PMB), Flexible Pavement Performance.

1. INTRODUCTION

Flexible pavements are widely used in road construction due to their cost-effectiveness, ease of construction, and ability to provide a smooth riding surface. These pavements are composed of multiple layers, namely the subgrade, sub-base, base course, binder course, and wearing course. Each layer is designed to perform a specific function, such as load distribution, structural support, and resistance to environmental and traffic-induced stresses. However, the overall structural performance of a flexible pavement system does not depend solely on the individual strength of each layer but also significantly on the quality of bonding between these layers.

The bonding between successive bituminous layers is achieved through the application of a tack coat, which is typically a thin film of bituminous material sprayed over the surface before laying the next layer. The primary function of the tack coat is to ensure proper adhesion between layers so that they behave as a monolithic structure under traffic loading. When adequate bonding is achieved, the pavement layers act together to distribute loads efficiently, thereby enhancing the load-carrying capacity and extending the service life of the pavement.

However, in practical construction scenarios, improper application of tack coat, contamination of the surface (due to dust, moisture, or debris), and unfavorable environmental conditions can lead to inadequate interlayer bonding. Poor bonding results in the independent movement of pavement layers under traffic loads, which induces shear stresses at the interface. This condition significantly weakens the structural integrity of the pavement and accelerates the development of various types of distresses. Common failures associated with poor interlayer bonding include slippage cracks, which appear as crescent-shaped cracks due to horizontal movement of the surface layer; rutting, caused by permanent deformation under repeated loads; fatigue cracking due to repeated tensile stresses; and delamination, where layers separate completely from each other.

In recent years, increasing traffic volumes and axle loads have further emphasized the importance of strong interlayer bonding. Conventional binders such as VG-30 bitumen have been widely used as tack coat materials; however, their performance under varying temperature and loading conditions is often limited. To address these challenges, modified binders such as Polymer Modified Bitumen (PMB) have been introduced, which offer improved adhesion, elasticity, and resistance to deformation.

Therefore, it becomes essential to experimentally evaluate the bond strength characteristics of bituminous layers under different conditions and with different materials. This study focuses on assessing the interlayer bond strength using laboratory-based experimental techniques such as Direct Shear Test, Tensile Bond Strength Test, and Torque Resistance Test. The study also aims to compare the performance of conventional and modified binders, and to investigate the influence of factors such as temperature, surface condition, and loading rate on bond strength. The outcomes of this research are expected to provide valuable insights into the mechanisms of interlayer bonding and contribute to the development of improved construction practices and material selection strategies for enhancing the performance and durability of flexible pavements.

2. LITERATURE REVIEW

Interlayer bonding between bituminous layers is a critical factor governing the structural performance and durability of flexible pavements. Over the years, several researchers have conducted experimental and analytical studies to evaluate the factors affecting bond strength, including tack coat type, surface condition, temperature, and loading characteristics.

Review 1: Polymer Modified Bitumen (PMB) Performance

Mohammad et al. (2025) carried out extensive research on the performance of tack coat materials and reported that Polymer Modified Bitumen (PMB) significantly enhances interlayer bonding compared to conventional binders such as VG-30. Their study concluded that PMB improves shear strength and adhesion due to its viscoelastic nature and polymer network structure. Furthermore, they observed that inadequate tack coat application can reduce pavement service life by 30–50%, leading to premature failures such as slippage cracking and rutting.

Review 2: Influence of surface roughness on interlayer bonding

Raab and Partl (2024) investigated the influence of surface roughness on interlayer bonding and concluded that increased surface texture enhances mechanical interlocking between layers. Their findings demonstrated that rougher surfaces provide higher resistance to shear stresses, thereby improving bond strength. However, they emphasized that proper tack coat application is still essential, as surface roughness alone cannot ensure adequate bonding.

Review 3: Effect of temperature on interlayer bond strength

Romanoschi and Metcalf (2020) conducted laboratory and field studies to evaluate the effect of temperature on interlayer bond strength. Their results indicated that bond strength decreases significantly with an increase in temperature due to reduced viscosity of the bitumen. At elevated temperatures, the binder softens, leading to reduced resistance against shear and tensile stresses, which ultimately affects pavement performance.

Review 4: Effect of tack coat on bond strength

West et al. (2015) studied the effect of tack coat application rate and uniformity on bond strength. Their research showed that both insufficient and excessive application of tack coat negatively affect bonding. An optimum application rate is necessary to ensure uniform adhesion between layers. They also highlighted that improper spraying techniques can result in non-uniform distribution, reducing the effectiveness of the tack coat.

Review 5: Polymer Modified Bitumen (PMB) Performance as a binder

Canestrari and Santagata (2013) focused on the performance of modified binders and reported that PMB exhibits superior bonding characteristics due to its improved elasticity and resistance to deformation. Their study concluded that PMB performs better under cyclic loading conditions, making it suitable for high-traffic pavements where repeated loading is a major concern.

Based on the present experimental study, it has been observed that PMB demonstrates higher tensile and shear bond strength compared to VG-30 bitumen. The findings are consistent with previous research, confirming that temperature, surface condition, and tack coat material significantly influence interlayer bonding.

3. OBJECTIVES

- To evaluate bond strength between bituminous layers
- To compare VG-30 and PMB tack coats

- To study effects of temperature and surface condition
- To analyze failure mechanisms

4. MATERIALS USED

4.1 Aggregates

- Crushed angular aggregates
- Properties tested: specific gravity, impact value

4.2 Bitumen

- VG-30 (Conventional)
- PMB (Polymer Modified)

4.3 Tack Coat

- Applied at controlled rates (0.2–0.4 kg/m^2)

5. METHODOLOGY

5.1 Sample Preparation

- Bituminous layers prepared using Marshall method
- Core samples extracted
- Tack coat applied between layers

5.2 Testing Methods

- Direct Shear Test
- Tensile Bond Strength Test
- Torque Test

6. RESULTS AND DISCUSSION

The results obtained from the experimental investigation clearly indicate that the bond strength between bituminous layers is significantly influenced by the type of tack coat material, temperature conditions, and surface characteristics. The laboratory tests, including tensile bond strength, direct shear, and torque resistance tests, were used to evaluate the interlayer bonding performance.

It was observed that specimens prepared using Polymer Modified Bitumen (PMB) exhibited higher bond strength compared to those prepared with conventional VG-30 bitumen. The improved performance of PMB can be attributed to its enhanced elastic properties and better adhesion capability, which allow it to resist shear and tensile stresses more effectively. In contrast, VG-30 showed comparatively lower bond strength and was more prone to adhesive failure at the interface. The effect of temperature on bond strength was also significant. As temperature increased, a noticeable reduction in bond strength was observed for both materials. This is mainly due to the decrease in viscosity of the bitumen at higher temperatures, which weakens the bonding between layers. However, PMB demonstrated relatively better performance even at elevated temperatures, indicating its suitability for varying climatic conditions.

Table 1: Tensile Bond Strength Results

Material	Bond Strength (MPa)
VG-30	0.31
PMB	0.47

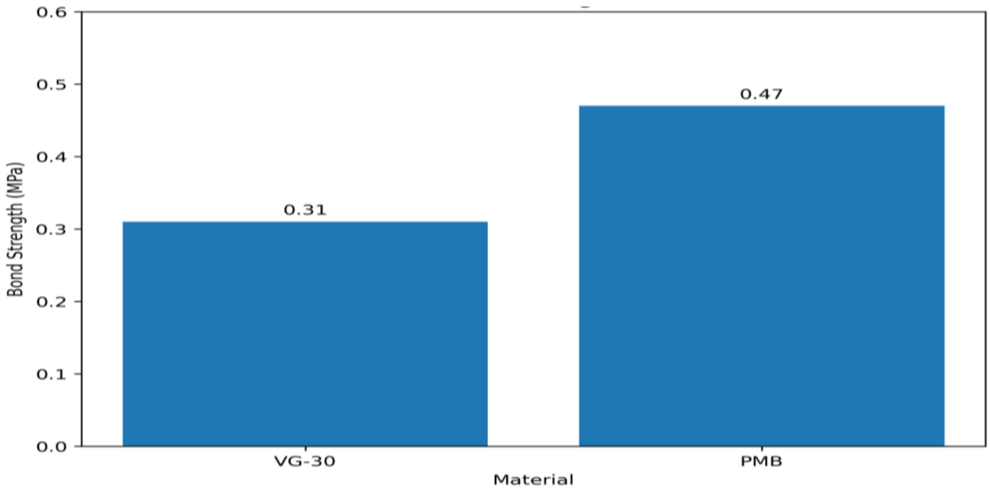

Figure 1: Tensile Bond Strength Results of VG-30 and PMB

Table 2: Effect of Temperature

Temperature (°C)	VG-30 (MPa)	PMB (MPa)
25	0.31	0.47
40	0.25	0.40
60	0.18	0.32

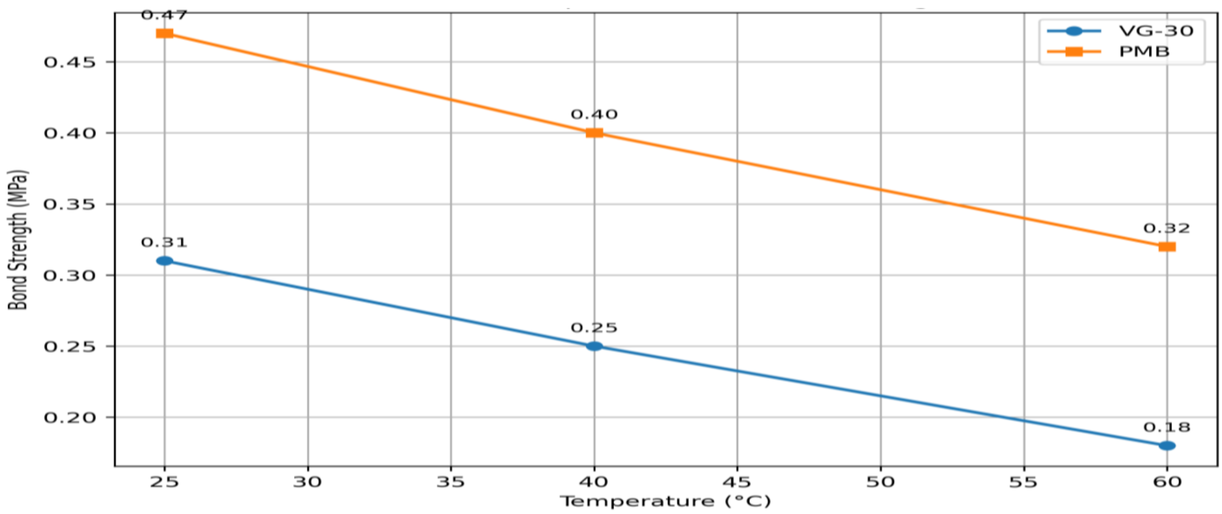

Figure 2: Effect of Temperature on Bond Strength of VG-30 and PMB

Table 3: Failure Mode Analysis

Material	Failure Type
VG-30	Adhesive
PMB	Adhesive + Cohesive

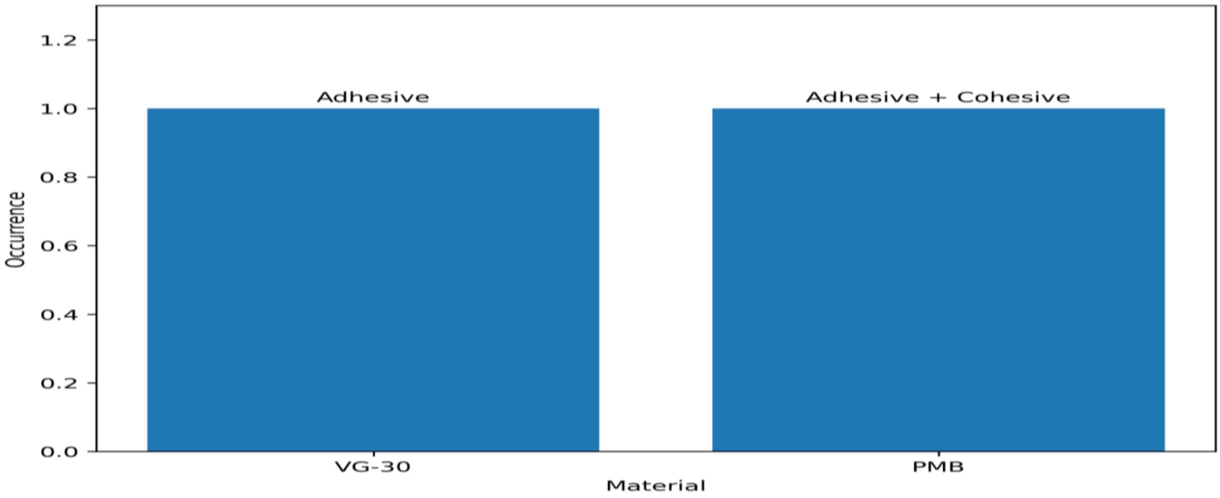

Figure 3: Failure Mode Analysis of VG-30 and PMB

7. DISCUSSION

- PMB shows better bonding due to elasticity and polymer network
- VG-30 fails mainly at interface (adhesive failure)
- Temperature significantly reduces viscosity → weaker bond
- Surface contamination reduces bonding by up to 50%

8. CONCLUSION

- PMB is superior to VG-30 in bond strength
- Proper tack coat application is critical
- Temperature and cleanliness must be controlled
- Improved bonding increases pavement life

9. RECOMMENDATIONS

- Use PMB for heavy traffic roads
- Ensure clean surface before tack coat application
- Apply tack coat uniformly
- Avoid construction at high temperatures

10. FUTURE SCOPE

- Study nano-modified bitumen
- Field performance validation
- Use of geosynthetics for bonding

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