Research Feature https://doi.org/10.31705/BPRM.v6(1).2026.1



Paving the Future: Transforming Waste Tires into High-Performance Roads with Pyrolysis Carbon Black

Road infrastructure is crucial for economic growth. But maintaining durable roads in tropical climates remains a significant challenge [1]. In Sri Lanka, high temperatures and heavy traffic accelerate asphalt deterioration, leading to frequent maintenance and increased costs [2]. However, conventional asphalt modifiers in Sri Lankan practice, such as polymer additives, are often expensive and environmentally unsustainable. Addressing this issue, researchers at the University of Moratuwa are exploring an innovative solution; Pyrolysis Carbon Black (PCB) derived from waste tires.

Unlocking the Potential of Pyrolysis Carbon Black (PCB)

The traditional way of disposing of end-of-life tyres is open-air burning and bare land dumping. However, with the rapid increase in vehicle usage, this high accumulation of waste tyres has become a severe environmental threat due to their slow degradation and harmful emissions [3]. As a sustainable method of addressing this issue, waste tyres are subjected to pyrolysis which is a thermal decomposition process conducted in the absence of oxygen [4]. This process breaks down waste tires into useful by-products, including pyrolysis oil, syngas, steel, and Pyrolysis Carbon Black (PCB). Both pyrolysis oil and syngas contain hydrocarbons, which can be directly utilized as fuel. Steel can be reused effectively while the Pyrolysis Carbon Black (PCB) requires further attention [5].

PCB is a fine black powder rich in carbon, obtained as a residue from the pyrolysis process. Normally, PCB has been considered a low-value by-product, often underutilized or discarded. However, recent advancements have highlighted its potential as an effective asphalt modifier, improving bitumen properties and enhancing pavement durability [6]. While previous researchers have investigated PCB in asphalt, limited studies have focused on its performance in tropical climates. The knowledge gap lies in understanding how PCB influences asphalt's durability, stability, and resistance to deformation, particularly in Sri Lankan conditions.

Methodology

We have undertaken an extensive study to evaluate PCB as a sustainable asphalt modifier at the Department of Civil Engineering at University of Moratuwa. The research focuses on two key aspects: Optimizing PCB Content in Bitumen and Evaluating PCB's Impact on Road Performance. A series of Marshall Stability tests were conducted to assess the effect of different PCB concentrations

on asphalt mixtures. Various PCB particle sizes, shear mixing parameters and mixing techniques (wet vs. dry) were analyzed to determine the optimum combination for strength and durability. The study examined improvements in stability, flow, and air voids of asphalt mixtures to assess PCB's effectiveness in tropical climates. Figure 1 presents the volumetric properties plotted against the varying modified binder content, where the red lines indicate the allowable range of properties for Sri Lankan context according to CIDA SCA05 specification [7]. For wet mixing phase, PCB bitumen modification was conducted using a high shear mixture (Figure 2) at 3000 RPM mixing speed for 15% PCB by weight of the total binder content.

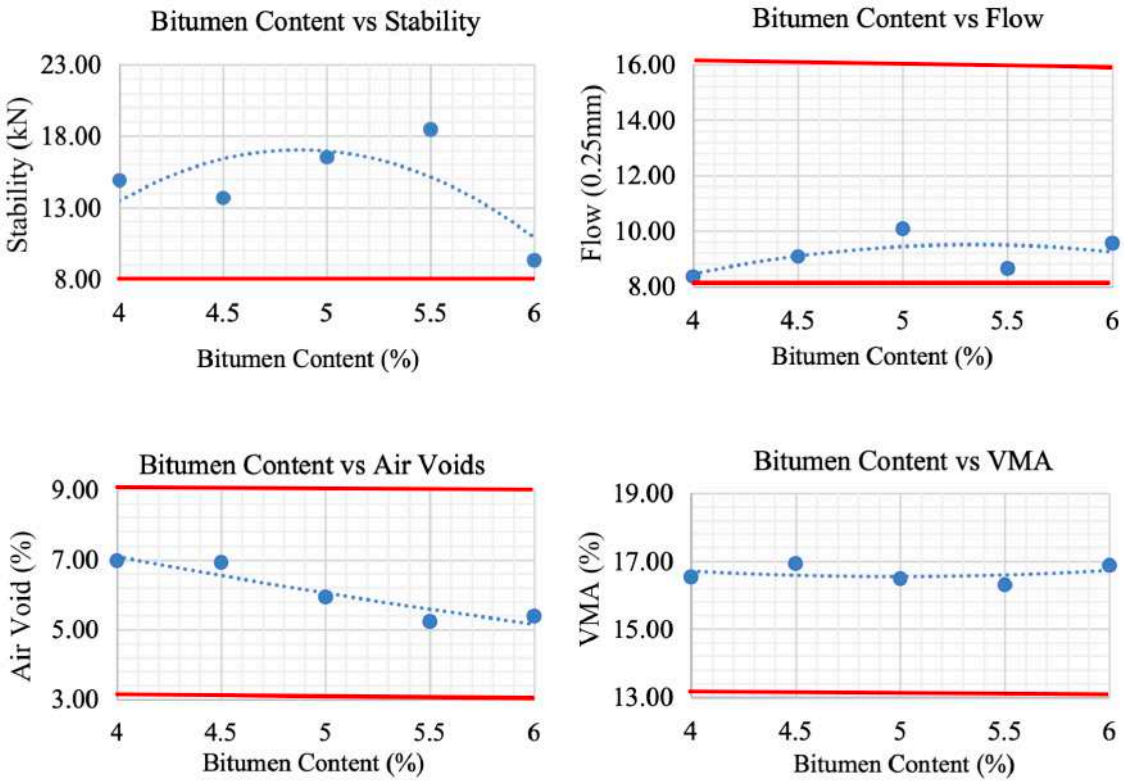


Figure 1: Determination of the optimum binder content with carbon black



Figure 2: High shear mixing of PCB with bitumen while maintaining the temperature within the 150-155°C range.

To further validate laboratory findings, we conducted field trials using the dry mixing method in 2021. In this approach, PCB was blended with aggregates before adding bitumen, ensuring uniform distribution and efficient interaction with the binder. As PCB incorporates without modifications to the binder, this method offers several advantages, including reduced mixing energy requirements and cost. We used the trial mixtures of PCB-modified asphalt for the boat yard access road at the University of Moratuwa (Figure 3). A trial road section utilizing PCB-modified asphalt was constructed along Meegahakumbura Road in Egaloya, Bulathsinhala, in collaboration with the Road Development Authority. This initiative aims to evaluate the long-term performance of the modified asphalt

under actual traffic and environmental conditions (Figure 4). Initial observations and the bi-annual performance evaluation revealed significant improvements in stability and rutting resistance, demonstrating the practical viability of PCB as a bitumen modifier. We continue the monitoring of this test section to analyze durability, cracking resistance, and maintenance requirements over time.



Figure 3: Constructing Boat yard access road using PCB modified asphalt



Figure 4: Meegahakumbura Road

Transformative Findings and Engineering Implications

The preliminary results indicate that PCB-modified asphalt exhibits superior performance compared to conventional bitumen [8]. The observations demonstrate that enhanced Marshall Stability reduces the risk of pavement failure under heavy loads. PCB modification shows a reduced temperature-induced rutting which is a common issue in tropical climates.

In conventional asphalt mixtures, bitumen is the expensive component, typically comprising around 3.5% to 4.5% of the total mix by weight. By our newly developed mixture, 22% - 33% out of the total bitumen content is replaced with PCB using a wet mixing process. This partial replacement significantly reduces construction costs without compromising the performance or quality of the pavement. Moreover, the incorporation of PCB not only enhances pavement properties but also contributes to sustainability by promoting the reuse of waste tires and reducing reliance on virgin materials [9].

As researchers from UoM's Civil Engineering Department, we highlight that, "Our study demonstrates that PCB can significantly enhance asphalt performance while promoting sustainable construction practices. The wet mixing procedure established in our research using a high-shear mixer will make the construction process easier than dry mixing in field application. Additionally, it will simplify quality control, making it as straightforward as conventional road construction"

The Road Ahead: Future Research and Societal Impact

After successful real-scale road construction trials, the long-term performance monitoring is now underway to assess PCB-modified asphalt under sustained environmental and traffic conditions. Future research will focus on refining the optimal PCB composition based on observed pavement behaviour, ensuring maximum durability and cost-effectiveness.

The adoption of PCB-modified asphalt has extensive implications for Sri Lanka.

- Economic Benefits: Reduced maintenance costs and long-lasting roads.
- Environmental Impact: A practical solution for recycling waste tires, reducing landfill accumulation.
- Infrastructure Resilience: Enhanced road performance under Sri Lankan weather conditions.

Currently for Sri Lanka, a country facing both economic and environmental challenges, UoM's research presents a practical, cost-effective, and sustainable solution for road construction. We are also working on industry collaboration to further advance this innovation and accelerate its implementation in large-scale infrastructure projects.

Acknowledgement

The authors gratefully acknowledge the laboratory staff of the Civil Engineering department of University of Moratuwa for providing all the laboratory facilities for experiments. As well as many thanks go to Ms. Iromi Ranasoma, Mr. Susantha Langappuli and the staff of Research and Development division, Road Development Authority, Sri Lanka and RR construction (Pvt) Ltd for facilitating real scale implementations of the PCB modification. Also, authors are thankful for the provision of raw materials to bitumen producer Bitumix (Pvt) Ltd and the tyre pyrolysis company Rivoga (Pvt) Ltd.

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