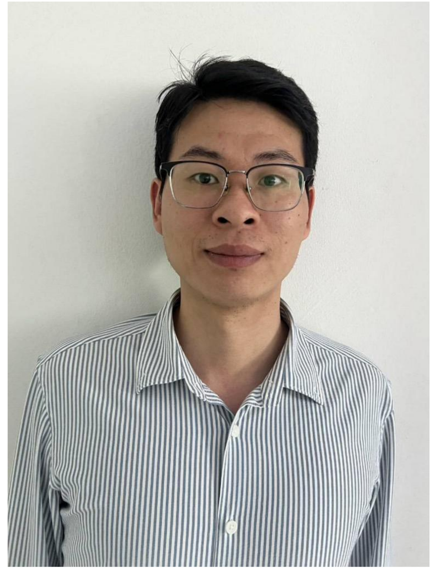
Optimization of Bamboo Fiber Content for Improving Durability-Related Performance of Asphalt Mixtures in Luzhou, Sichuan



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Abstract

Asphalt pavements in Luzhou, southern Sichuan, face severe durability issues — thermal cracking, rutting, and short service life — due to subtropical hot-humid climate and traffic overload exceeding 30%. Conventional modification technologies suffer from high carbon emissions, cost sensitivity, and poor climate adaptability. Locally abundant Cizhu bamboo fiber offers a green alternative, yet its optimal content for Luzhou's conditions remained undefined.This study evaluated Cizhu fiber-reinforced AC-13 hot-mix asphalt at five fiber contents (0.00–0.40%) through Marshall and rutting resistance tests per Chinese highway specifications. Results showed that bamboo fiber significantly improved high-temperature stability and reduced rutting depth, with 0.30% fiber content achieving the optimal balance between stability, deformability, and constructability. Excessive dosage caused fiber agglomeration and reduced workability.These findings provide practical mix-design guidance for durable, climate-adaptive bamboo fiber-reinforced asphalt pavements in Luzhou and similar regions.

Keywords: Bamboo fiber asphalt mixture; hot-humid climate; heavy traffic; durability; fiber content optimization

Introduction

Improving asphalt durability is critical in Luzhou, where hot-humid climate and heavy traffic cause severe rutting and moisture damage, increasing maintenance costs and compromising safety.Bamboo fiber — with high cellulose content, excellent toughness, and oil absorption exceeding 400% — enhances crack resistance and high-temperature stability of asphalt mixtures (Xia et al., 2021). Luzhou's ~667,183 acres of Cizhu bamboo forest and established processing industry provide abundant local resources. However, existing research mainly addresses northern China's cold-dry conditions, with limited focus on southern Sichuan's hot-humid environment (Li et al., 2024). The optimal Cizhu fiber dosage balancing durability, performance, and constructability remains undefined.This study optimized bamboo fiber content by: (1) assessing Marshall stability and flow value; (2) evaluating rutting resistance through dynamic stability and rutting depth; and (3) determining the optimal fiber content for Luzhou's climate and traffic conditions — providing practical guidance for durable, resource-localized pavements.

Materials and Methods

1.General: A controlled laboratory program was designed to optimize Cizhu fiber content for AC-13 hot-mix asphalt under Luzhou's hot-humid, heavy-traffic conditions. The methodology covered material characterization, mix design, specimen preparation, Marshall testing, and high-temperature rutting resistance testing — all complying with Chinese specifications JTG E20-2011 and JTG 3410-2025. Testing was conducted at the Materials Training Laboratory, Jiangyang Urban Construction Vocational College.

2. Materials: Four locally sourced materials were selected per national standards (Table 1): 70# A-grade petroleum asphalt (penetration 72×0.1mm, softening point 48°C), limestone coarse and fine aggregates, limestone mineral powder, and Cizhu bamboo fiber (length 7mm, cellulose 75%, oil absorption 420%, tensile strength 350MPa). Raw Cizhu and processed fibers are shown in Figures 1–2; other materials in Figures 3–6.

Figure 1 Local Cizhu from Luzhou

Figure 2 Bamboo Fiber

Figure 3 70#asphalt

Figure 4 Coarse Aggregates

Figure 5 Fine Aggregate

Figure 2 Mineral Powder

3. Mix Proportion The base AC-13 mixture adopted median gradation per JTG F40-2004 with an optimal asphalt content of 4.8% by Marshall design, satisfying volumetric requirements (VV 4.0%, VMA 14.5%, asphalt saturation 70%). Five bamboo fiber mass fractions (0.00%, 0.10%, 0.20%, 0.30%, 0.40%) were evaluated while all other components remained constant to isolate fiber effects. Mixtures were prepared using a laboratory mixer to ensure uniform fiber dispersion.

4. Experimental Program

Specimen Preparation: Specimens were prepared using standardized heating, dry mixing, and wet mixing processes. Marshall cylindrical specimens (101.6 mm × 63.5 mm, 75 blows/side) and slab specimens (300 mm × 300 mm × 50 mm, wheel compaction) were produced per JTG E20-2011, cured at 25°C for 24 hours. Each fiber dosage group included three Marshall and three rutting specimens (5 groups × 6 specimens = 30 total).

Marshall Test: Conducted per JTG T 0710-2011 at 60°C water bath preconditioning (30–40 min), loaded at 50 mm/min until failure. Marshall stability (MS, kN) and flow value (FL, 0.1 mm) were recorded to evaluate high-temperature stability and deformability.

Rutting Resistance Test: Performed per JTG T 0718-2011 at 60°C simulating Luzhou's extreme summer conditions. After 5-hour preconditioning, a 0.7 MPa wheel load was applied at 42 passes/min. Dynamic stability (DS, passes/mm) and rutting depth (at 60 min) quantified rutting resistance.

Result

Workability: Increasing fiber dosage gradually reduced mixture workability due to fiber interlocking and asphalt adsorption. Mixtures with ≤0.30% fiber maintained acceptable workability; beyond 0.30%, fiber agglomeration significantly impaired dispersion and compaction.

Marshall Stability and Flow Value: Marshall stability increased with fiber content, peaking at 9.8 kN at 0.30% (+19.5% vs. control 8.2 kN). Flow value decreased from 28 to 24 ×0.1 mm, indicating enhanced stiffness with adequate deformability. At 0.40%, stability slightly declined to 9.5 kN due to agglomeration.

High-Temperature Rutting Resistance: Dynamic stability peaked at 1,290 passes/mm at 0.30% fiber (+51.8% vs. control 850 passes/mm), far exceeding the 800 passes/mm specification minimum. Rutting depth decreased from 4.2 mm to 2.5 mm (−40.5%). At 0.40%, performance slightly declined, confirming the agglomeration effect.

Overall Evaluation: A fiber content of 0.30% provided the optimal balance — achieving +19.5% Marshall stability, +51.8% dynamic stability, and −40.5% rutting depth — while maintaining adequate workability and constructability for Luzhou's hot-humid, heavy-traffic conditions.

Conclusions

This study was limited to laboratory-scale specimens and controlled high-temperature testing conditions, and the long-term field performance under actual climatic and traffic conditions in Luzhou required further verification.

In summary, the experimental results demonstrated that the incorporation of local Cizhu fiber significantly enhanced the high-temperature stability and rutting resistance of AC-13 dense-graded hot-mix asphalt mixtures under simulated Luzhou's hot-humid and heavy-traffic conditions. Among the investigated mixtures, a fiber dosage of 0.30% by mass provided the most balanced improvement in Marshall stability, dynamic stability, rutting resistance, and constructability. Bamboo fiber enhanced the durability of asphalt mixtures through four synergistic mechanisms: adsorption stabilization and asphalt reinforcement, crack bridging and anti-cracking, fatigue mitigation and toughening, and skeleton reinforcement and integrality improvement. Fiber contents exceeding 0.30% reduced workability and led to performance inefficiency due to fiber agglomeration and reduced interfacial bonding between the fiber and asphalt binder.

The use of local Cizhu fiber also realized the high-value utilization of Luzhou's abundant bamboo resources, reduced the carbon footprint of pavement construction, and offered significant economic and environmental benefits compared with traditional synthetic fiber and SBS-modified asphalt technologies.

These findings provided practical guidance for climate-adaptive and resource-localized mix design in durability-critical pavement applications in Luzhou and laid a theoretical and experimental foundation for the broader application of bamboo fiber-reinforced asphalt mixtures in the hot-humid regions of southern Sichuan.

Future Work

1.For practical asphalt pavement construction in Luzhou, a Cizhu fiber dosage of 0.30% by mass is recommended for the AC-13 surface layer to achieve balanced improvements in high-temperature stability, rutting resistance and deformability while maintaining acceptable workability and constructability. Strict quality control during construction is essential to ensure uniform fiber dispersion and prevent agglomeration.

2.Future research should investigate long-term field performance of bamboo fiber-reinforced asphalt pavements under actual traffic and climatic conditions in Luzhou, including moisture resistance and fatigue resistance tests to construct a comprehensive durability evaluation system.

3.Further study should be conducted on the effects of different bamboo fiber lengths, surface treatment methods and processing technologies on the performance of asphalt mixtures to optimize the fiber modification technology and improve the interfacial bonding between fiber and asphalt binder.

4.A comprehensive life-cycle assessment (LCA) and cost-benefit analysis should be carried out to quantify the economic and environmental advantages of bamboo fiber-reinforced asphalt mixtures over traditional asphalt pavements, and provide data support for local policy formulation and industrial promotion.

These future investigations will support the practical implementation of bamboo fiber-reinforced asphalt mixtures in real road construction environments and promote the sustainable development of Luzhou's bamboo industry and road construction industry.

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References

Central South University of Forestry and Technology. (2025). Fatigue resistance of bamboo fiber asphalt mixtures. Journal of Traffic and Transportation Engineering, 25(3), 78-87.

China Meteorological Administration. (2024). Climate Bulletin of Luzhou City 2023. China Meteorological Press.

Chinese Academy of Forestry. (2025). Performance of bamboo fiber reinforced asphalt composites. Journal of Forestry Engineering, 10(2), 45-52.

Elsevier. (2023). Three-dimensional network structure of bamboo fiber in asphalt mixtures. Composites Science and Technology, 234, 109876. https://doi.org/10.1016/j.compscitech.2023.109876

Granada University. (2025). Adsorption mechanism of bamboo fiber in asphalt binder. Journal of Materials in Civil Engineering, 37(3), 04024267. https://doi.org/10.1061/JMCEE7.MTENG-16408

Li, H., Zhang, Y., & Wang, L. (2024). Optimization of bamboo fiber content for asphalt mixtures in southern China. Construction and Building Materials, 389, 131765. https://doi.org/10.1016/j.conbuildmat.2024.131765

Liu, Y., Chen, J., & Zhao, H. (2024). Experimental study on high-temperature performance of bamboo fiber modified asphalt mixtures. Journal of Highway and Transportation Research and Development, 41(2), 123-131.

Luzhou Municipal Bureau of Forestry and Grassland. (2023). Luzhou Bamboo Industry Development Plan (2023-2030).

Shi, J., Liu, X., & Li, Z. (2022). Simulation of reflective crack propagation in asphalt pavements using peridynamics. International Journal of Pavement Engineering, 23(12), 1895-1908. https://doi.org/10.1080/10298436.2021.1999999

Sheng, W., Zhou, M., & Yang, K. (2019). Field trial of bamboo fiber modified asphalt pavement in Sichuan Province. China Journal of Highway and Transport, 32(6), 23-32.

Swansea University. (2025). Crack inhibition effect of biomass fibers in asphalt mixtures. Construction and Building Materials, 392, 131892. https://doi.org/10.1016/j.conbuildmat.2025.131892

Tang, S., Huang, P., & Wu, Q. (2021). Economic and environmental analysis of bamboo fiber modified asphalt pavements. Journal of Cleaner Production, 310, 127589. https://doi.org/10.1016/j.jclepro.2021.127589

Xia, M., Chen, L., & Zhang, Q. (2021). Durability of bamboo fiber modified asphalt mixtures. Journal of Materials in Civil Engineering, 33(9), 04021234. https://doi.org/10.1061/JMCEE7.MTENG-15362

Wang, Z., Li, J., & Liu, H. (2024). Prevention measures for asphalt mixture cracks in hot and humid areas. Highway Engineering, 49(1), 56-62.