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BIOMASS VALORIZATION TOWARD SUSTAINABLE ASPHALT PAVEMENTS

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In recent years, global attention has intensified due to the energy crisis and environmental concerns, prompting efforts to promote sustainable development by understanding the relationship between technology and the environment. The road industry is no exception. Transport contributes to about 15% of worldwide greenhouse gas emissions and over 20% of energy-related CO2 emissions, according to the International Road Federation. Notably, over 90% of pavements in many countries are asphalt-based, primarily derived from petroleum. However, with non-renewable oil reserves predicted to last only 46 years, addressing resource scarcity and environmental issues is crucial. In this context, this review summarizes the utilization of biomass materials in asphalt pavement. It categorizes biomass materials—bio-oil, bio-fiber, and bio-filler—exploring their definitions, preparation methods, performance, and applications. The study concludes by discussing the economic and environmental benefits of biomass-based pavements and outlining directions for future development.

Based on an analysis of existing literature, this paper initially classifies biomass materials with potential applications in pavement engineering according to their usage. Depending on their application forms, biomass materials with significant potential for practical use in pavements can be categorized into three main groups: bio-oil, bio-fiber, and bio-filler. These materials primarily originate from agricultural and forestry by-products, livestock manure, and kitchen waste. The literature review indicates that bio-oil is currently predominantly employed as an asphalt binder modifier and rejuvenator. Bio-fiber serves mainly as an asphalt mixture stabilizer, while bio-filler acts as a substitute for conventional fillers in asphalt mixtures. Among the various methods for producing bio-oil from solid biomass materials, fast pyrolysis remains the most mature and reliable technique. Hydrothermal liquefaction, on the other hand, is suitable for converting biomass materials with a high liquid content into bio-oil. The processes for producing bio-fiber and bio-filler are relatively straightforward and vary based on the raw materials and specific requirements.

The effect of the addition of pavement biomass materials on the performance of asphalt and asphalt mixture is analyzed and summarized. Furthermore, an evaluation of the economic and environmental advantages of utilizing bio-asphalt binder is presented.

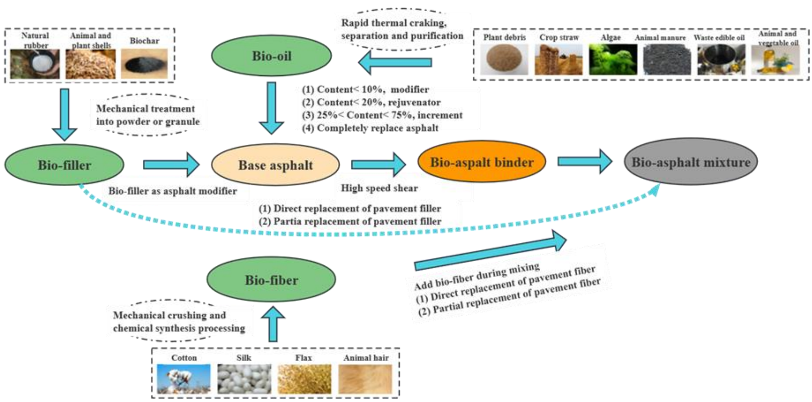

Fig. 1. Application method and classification of pavement biomass materials.

Most bio-oils demonstrate the capacity to enhance the low-temperature performance and fatigue resistance of asphalt binders. However, their effects on high-temperature performance and moisture resistance remain inconsistent. It is advisable to introduce materials such as SBS or other compounds (polymers or biomaterials) for enhanced modification, leading to bio-asphalt binders with superior performance. Functioning as a rejuvenator, bio-oil supplements the lighter components within aged asphalt. This counteracts certain aging effects and reinstates the high and low-temperature performance of the aged asphalt. Among the various regenerated asphalt mixtures with varying RAP content, specific bio-oil rejuvenators exhibit the potential to significantly enhance fatigue resistance and moisture resistance, consequently improving overall pavement performance.

Bio-fibers possess the ability to absorb free binder within the asphalt mixture, creating an interconnected network structure. This substantial enhancement in mechanical strength results in improved high-temperature stability, resistance against low-temperature cracking, and heightened moisture resistance of the asphalt mixture. Notably, the renewable and degradable nature of bio-fibers offers an advantage in aligning with pavement's environmental protection demands.

Bio-filler serves as a valuable tool for modifying asphalt mixtures and substituting conventional fillers. Specific bio-fillers have demonstrated the capability to enhance pavement performance to a certain degree. The inclusion of biochar, for instance, exhibits the ability to slow down the asphalt aging process, consequently bolstering its anti-aging properties. Furthermore, biochar contributes to augmenting the water purification and carbon sequestration capabilities of pervious concrete. Currently, limited research has been conducted on bio-fillers apart from biochar. A comprehensive investigation in this area remains largely untapped, revealing a promising reservoir of potential waiting to be unveiled.

The calculations conducted in this study reveal a promising cost-performance ratio for bio-asphalt binder that has the potential to outperform that of traditional asphalt binders. Leveraging the environmental advantages of biomass materials, it is anticipated that bio-asphalt binder could emerge as a viable alternative to petroleum-derived asphalt binders sourced from non-renewable reserves in the future. Concurrently, this study offers valuable insights to relevant authorities, revealing the promising application prospects of biomass materials within the realm of pavements.

While significant progress has been made in the application of biomass materials in road construction, the complete replacement of petroleum-based asphalt binders on road surfaces still poses challenges. In light of this, the following recommendations are put forth: (1) Establish a synergistic formulation system for bio-oil and asphalt binders to control the properties of bio-oil, thus enhancing the practicality of bio-asphalt binders;

(2) undertake in-depth research into the micro mechanisms of bio-asphalt modification, utilizing modern analytical testing techniques and numerical simulations to analyze interactions among various components; (3) The widespread adoption of bio-oil rejuvenators necessitates robust long-term empirical data from practical engineering applications; (4) The exploration of suitable composite modification materials, as well as relevant preparation and evaluation methods, is crucial. For instance, the pursuit of fossil-free alternatives to Styrene-Butadiene-Styrene (SBS) in binders is of particular significance.