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Review article

Polymer modification of bitumen: Advances and challenges

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ABSTRACT

Advances and challenges in the field of bitumen polymer modification for road construction during the last 40 years are reviewed in this paper. The history of bitumen polymer modification is described chronologically. Some popular plastomers and thermoplastic elastomers in bitumen modification are discussed regarding their advantages and disadvantages, including polyethylene (PE), polypropylene (PP), ethylene–vinyl acetate (EVA), ethylene–butyl acrylate (EBA), styrene–butadiene–styrene (SBS), styrene–isoprene–styrene (SIS) and styrene–ethylene/butylene–styrene (SEBS). Although these polymers all improve bitumen properties to some extent, there are still some drawbacks limiting the future development of bitumen polymer modification, such as high cost, low ageing resistance and poor storage stability of polymer modified bitumen (PMB). Researchers attempted various ways to remove these drawbacks. Some technical developments for removing drawbacks are reviewed in this paper, including saturation, sulfur vulcanization, adding antioxidants, using hydrophobic clay minerals, functionalization and application of reactive polymers. The future development of polymers for bitumen modification is analyzed as well. Since it is currently challenging to perfectly achieve all expected PMB properties at the same time, some compromised recommendations are given in this paper, among which greatly enhancing the properties with an acceptably high cost, significantly reducing the cost with relatively poor properties and their combinations. Functionalization is emphasized as a promising way to enhance the properties of currently used polymers and develop new-type polymer modifiers with much greater success in the future. It is also recommended that future research on bitumen polymer modification focuses more on function development towards enhancing: adhesion with aggregates, long-term performance and recyclability.

Contents

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1. Introduction

Bitumen is one of the oldest known engineering materials [1]. It has been used for thousands of years [2] in various ways, e.g. as adhesive, sealant, preservative, waterproofing agent and pavement binder. Ancient inhabitants directly used the natural bitumen which is usually in the earth's surface [2]. In the early 1900s, refined bitumen was first produced by refining crude oil in the USA [1]. Since then, the world consumption of bitumen has increased rapidly, most of which was used in road construction. According to a joint publication of Asphalt Institute and Eurobitume in 2011, the current world consumption of bitumen is approximately 102 million tonnes per year, 85% of which is used in various kinds of pavements [3]. In fact, the chemistry composition of produced bitumen is very complex and variable; and the properties of produced bitumen are closely related to the crude oil sources and the refinery processes. By selecting good crude oil or proper refinery processes, some good bitumen properties can be obtained. However, the limited oil resources for producing good-quality bitumen and the lack of effective control actions during refinery, as well as the driving force of earning the maximum economic benefits, made industries pay more attention on bitumen modification [4]. Additionally, pavement industry has developed rapidly all over the world during the last few decades, especially in developing countries. Following the rapid development, increased traffic load, higher traffic volume, and insufficient maintenance led to many severe distresses (e.g. rutting and cracking) of road surfaces. The harsh reality was demanding more on bitumen quality. In order to obtain bitumen with enhanced quality, an increasing number of investigations also began to focus on bitumen modification. Among all attempted or investigated modification methods of bitumen, polymer modification has been one of the most popular approaches.

Polymer modification of bitumen is the incorporation of polymers in bitumen by mechanical mixing or chemical reaction [5]. During the last 40 years, more and more researchers began to concentrate themselves on polymer modification of bitumen and a rapidly increasing number of research articles have been published since 1970s. In these, the various investigated polymers included plastomers (e.g. polyethylene (PE), polypropylene (PP), ethylene–vinyl acetate (EVA), ethylene–butyl acrylate (EBA)) and thermoplastic elastomers (e.g. styrene–butadiene–styrene (SBS), styrene–isoprene–styrene (SIS), and styrene–ethylene/butylene–styrene (SEBS)) [6–12], although none of these were initially designed for bitumen modification. These polymers were reported to lead to some improved properties of bitumen, such as higher stiffness at high temperatures, higher cracking resistance at low temperatures, better moisture resistance or longer fatigue life [13–18]. In [2], an extensive summary was given that an effective polymer modification results in a thermodynamically unstable but kinetically stable system in which the polymer is partially swollen by the light components of bitumen. Some important factors, including the characteristics of the bitumen and the polymer themselves, the content of polymer and the manufacturing processes, determine the final properties of polymer modified bitumen (PMB) [5,19]. As polymer content increases, phase inversion may occur in some PMBs: from bitumen being the dominant phase to polymer becoming the dominant phase [20]. However, an ideal microstructure for PMB contains two interlocked continuous phases, which determines the optimum polymer content for bitumen modification [21]. With these two interlocked continuous phases, PMB usually shows better overall performance with respect to mechanical properties, storage stability and cost-effectiveness.

In addition to the reported advantages, researchers also encountered various challenges, including high cost, some PMBs' high temperature sensitivity, low ageing resistance, poor storage stability and the limited improvement in elasticity. In this, the combination of bitumen oxidation and polymer degradation was reported to cause PMB's ageing propensity [22], which seems especially challenging for some unsaturated polymers, e.g. SBS. The poor storage stability of some PMBs usually results from the poor compatibility between polymer modifiers and bitumen which is controlled by polymers' and bitumen's different properties such as density, molecular weight, polarity and solubility [23]. The chemical structure and reactivity of polymers, however, are also supposed to affect their compatibility with bitumen, which may have a direct relationship with the resulting PMB properties [24]. In order to conquer these challenges, researchers have tried different categories of solutions, such as saturation, sulfur vulcanization, adding antioxidants, using hydrophobic clay minerals, functionalization and application of reactive polymers (which also can be considered as new functionalized products).

Along with technical aspect, economical aspect is of course a huge driving force for the choice of technology. Different kinds of pavements have different demands on performance. From the economic aspect, it is not always better to achieve higher performance for a road. Only when the technology is cost-effective, can people get the maximum benefits from it and can it become popular. As for PMB, the cost is quite relevant with the dosage of the added polymer, while the polymer dosage usually has important influences on the final degree of PMB