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Review

A comprehensive review of theory, development, and implementation of warm mix asphalt using foaming techniques

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HIGHLIGHTS

- This synthesis summarized previous studies related to foaming WMA.
- Reviews involve foaming theory and up to its implementation globally are summarized.
- Foaming based WMA has been widely used in the construction of asphalt pavement.
- It has demonstrated great potential in supporting sustainable development.
- It significantly decreased the fuel usage and stack emissions of greenhouse gases.

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ABSTRACT

Asphalt foaming techniques have been used over the last couple of decades as an alternative to the traditional method of preparing asphalt mixtures. Various efforts have been initiated to assess the technology and enhance its efficiency during production. In this article, a comprehensive review of foaming warm mix asphalt (WMA) techniques, foaming theory and mechanisms, research and development as well as characterization procedures are presented. This paper also summarized numerous research and paving applications using foaming WMA technologies in Europe, the United States, Canada, China, Australia, New Zealand and some other countries. Findings from laboratory tests and field performance are also presented. Based on several field trials, the performance of foaming WMA is comparable to conventional HMA. The United States was found to be the most active country working on research-based and field trial evaluations on WMA besides two European countries: Germany and Norway. In addition to reducing energy consumption, reductions in fuel usage have significantly reduced the stack emissions of greenhouse gases, such as carbon dioxide, sulfur dioxide, and nitrous oxide. This review concludes with some recommendations in terms of diversifying the foaming agent and selection of test parameters in order to have a better precision and repeatability of test results.

Contents

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1. Introduction

Hot mix asphalt (HMA) is commonly manufactured at a temperature range of 140–160 °C for better workability and long term performance. During manufacturing and construction of material, a great amount of greenhouse gases and other emissions are produced that may contribute to global warming and severe environmental conditions [1]. Moreover, due to the smoke and odor released during productions of asphalt mixtures, applications of asphalt materials are often limited to night construction in some urban areas. Based on the literature review of green asphalt technology [2–4], foaming based warm mix asphalt (WMA) has been widely used in constructions of asphalt pavement, and has demonstrated great potential in supporting sustainable development.

WMA technology is a practical solution in the asphalt pavement industry to reduce the energy consumption and emissions by reducing the mixing and compaction temperatures of asphalt mixtures (e.g. through lowering the viscosity of asphalt binder). It has also significantly reduced the emissions and fumes from asphalt plants and makes the working conditions better for construction crews and plant operators [5–11]. Drastic reductions in temperature have obvious benefits, including cutting the fuel consumption in manufacturing asphalt pavement. In addition, potential engineering benefits include better compaction of roads, ability to haul paving mix for longer distances, and to pave at lower temperatures. Vaitkus et al. [12] acknowledged that European countries and Australia called their attention to WMA in 2000. Several years later, North America also became interested in WMA. In the USA, WMA mixtures are mixed and compacted at temperatures 10–40 °C lower temperatures than conventional HMA mixtures. D'Angelo et al. [13] stated that WMA could be described as the asphalt mixture produced at a 20–40 °C lower temperature than HMA but at a temperature higher than the water boiling point, 100 °C. In addition, similar conditions have also been reported in European countries. According to Vaitkus et al. [12], sometimes WMA is also called "Low Temperature Asphalt".

The purpose of this synthesis is to summarize previous studies related to foaming WMA. Comprehensive reviews of the foaming theory in its implementation globally are summarized in this paper. The review is presented in five main sections, including descriptions of different foaming techniques, theory and mechanisms in the asphalt foaming process, its developments and field applications, mechanical foaming technology available in the market, and possible characterization methods of foamed asphalt binders and mixtures.

2. Foaming techniques

Foaming techniques have been widely used in many fields to modify material property or improve their performances, such as in the production of elastomers [14,15], poly (lactide-co-glycolide) (PLGA) [16], metals [17,18], and cement-based materials [19]. In regard to foaming technology in the asphalt industry, foaming WMA can be classified into two different techniques, which are water-based processes and water bearing additives [20,21]. The water bearing additive (also referred to as water-based additive or water admixture technique) is a system that uses moisture contained in the media solid to generate bubbles when it comes in contact with hot bitumen. The water-based process is a technique that relies on the expansion of water by a factor of approximately 1700 when it turns into steam after being applied to preheated asphalt binder [22]. This results in a reduction in the viscosity of asphalt binder by increasing the volume (5–15 times its original volume) and the surface area of asphalt binder, allowing for aggregate to properly coat and have better compaction at lower temperatures [11,23–26]. The foamed asphalt binder is typically produced through the injection of water, approximately 1–6% (based on the weight of asphalt binder), into hot asphalt [11]. The foaming techniques are widely used to produce WMA in different regions and countries [27]. Table 1 shows a list of foaming techniques that are used in producing WMA mixtures.

2.1. Water-based processes

The water-based process is a simple concept that relies on the foaming produced by water when it is introduced into preheated asphalt binder. When a small amount of water is added to the hot asphalt binder, the water vaporizes, increasing the volume of asphalt binder and decreasing the viscosity, which results in a better coating and workability of asphalt mixture. Because the foamed binder is constantly exposed to high temperatures during mixing processes, the bubbles then collapse, and it behaves as a normal binder. However, an excessive amount of water should be avoided to lower the tendency for moisture damage to occur (e.g. stripping). Additionally, anti-stripping agents can also be applied to bituminous mixtures to minimize moisture susceptibility of the WMA by promoting the interfacial adhesion between binder and aggregates. This water-based process permits a reduction in temperature of asphalt mixes ranging from 20 to 30 °C [23–25].

Various types of water-based systems are available to support the application of foaming WMA. One, for example, is a patented