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Influence of foaming water content on foam asphalt mixtures

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HIGHLIGHTS

- We studied the influence of water content and addition of cold aggregate fraction in foamed asphalt mixture.
- We examine main parameters influencing foam asphalt mixture, mixing and compaction temperature.
- Gyratory and marshal compaction methods were implemented for compaction.
- Marshall stability test and ITS were used to analyze the influence of compaction and mixing temperature.
- Thermogravimetric analysis (TGA) analysis is made to determine the residual water content in the foam asphalt mixture.

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ABSTRACT

Warm mix asphalt technology using foamed bitumen is being used widely despite the fact that high air void content and poor coating of large aggregate remain major drawbacks require enhancement. This paper manly focuses on the investigation of water content influence on the foamed bitumen and the asphalt mixture. Influence of the water content in combination with compaction temperature has been investigated using gyratory compaction method. AC11N foam asphalt mixture is produced in the lab using lab foamer. Marshall stability and indirect tensile test was used to evaluate the foam asphalt mixture performance. The investigation revealed that the Marshall stability of foam asphalt mixture is highly influenced by compaction temperature compared to water content. Moreover, increasing the water content helps in coating large aggregates when the mixture is produced at low temperature, nevertheless using high water content reduces the Marshall stability to certain extent. In addition the amount of water trapped in the mixture after the mixing process was determined using thermogravimetric analysis. The amount of water remaining in the asphalt mixture is less than 1% relative to the bitumen mass.
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1. Introduction

Producing foam asphalt mixtures dates back to 1928 when the first hot bitumen foaming system was patented. First, it was a method to stabilize soil and later the technology was extended for stabilizing road bases. Since then, several improvements have been made such that foamed bitumen is currently used in many countries [1]. Originally, only foam asphalt mixtures with cold aggregates were produced resulting in rather high air void contents from evaporating the water added to produce the foam. Hence, large aggregates were only poorly coated. As a consequence, the performance of asphalt mixtures with cold aggregates was far beyond today's hot mix asphalt HMA and therefore only sufficient for base and foundation layers [2]. Recent developments dealt with warm or semi-warm foam asphalt by using warmed aggregates. By this way, coating of the aggregates was considerably improved with positive effects on the asphalt properties [3]. Moreover the amount of water was reduced resulting in asphalt pavements with low air void contents and a quality comparable to HMA [4,5]. However, these results are mainly based on laboratory experiments and not validated in field.

Warm-mix asphalt technologies in Europe include Aspha-Min, WAM-Foam, and Low-Energy Asphalt [6]. The Aspha-min technology uses finely powdered synthetic zeolite (sodium silicate hydrate), which is hydro-thermally crystalized. In this technology, Aspha-min is added at the same time with the bitumen to the

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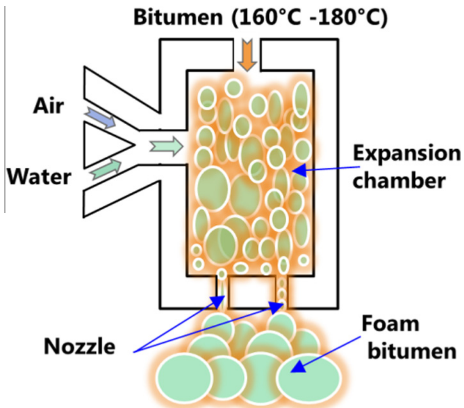

Fig. 1. Schema of foamed bitumen expansion chamber.

aggregate that allows release of water and eventually creates foamed bitumen during the mixing process [6]. WAM-Foam is produced using a two component binder system by coating the aggregate in the first stage with the soft binder component and in a second stage by adding foamed harder bitumen to the pre-coated aggregates. The combination of soft bitumen and foamed hard bitumen lowers the viscosity of the mixture and provides the necessary workability for compacting the mixture at lower temperature [7]. The Low-Energy Asphalt (LEA) technology relies on the fact that hot bitumen transfers to foam when in contact with moist aggregate. Different possible sequential drying and coating can be used for manufacturing the LEA at 95 ± 10 °C. Details of the method are explained in reference [8].

In this research foamed bitumen was produced using a lab foaming unit, where water is injected into the hot bitumen (160–180 °C) at an approximate pressure of 5 bar. After the mixing process in an expansion chamber, the foamed bitumen is sprayed through a nozzle attached to the chamber as schematically shown in Fig. 1.

2. Background theory

An investigation by Jenkins [9] indicates that the optimum water content (W.C.) for producing a good foam asphalt mixture can be found by characterizing the foam with an empirical parameter called "foaming index" FI which is calculated from the whole decay curve with time and incorporates both the half-life HL and expansion ratio ER; however, it needs accurate measurement of the decay curve [10]. The FI is the sum of the areas A1 and A2 as indicated in Fig. 2(a). The actual expansion ratio (ER_a) is determined by extrapolating the curve for the time of spraying (5 s) as presented in Fig. 2(a). A minimum expansion ratio $ER_{min} = 4$ is required for adequate mixing of the foamed bitumen asphalt [9]. The FI parameter can be used to optimize the amount of water in the foamed bitumen by taking the water content at the maximum of FI.

However, the FI concept, which is directly influenced by the water content, cannot be applied for all types of bitumen. Since the half-life is not continuously decreasing with increasing maximum expansion ratio [11,12], it is not always possible to determine the optimum water content from the FI as shown by Sunarjono [11]. A different approach by Saleh [12] showed that the optimum water content can be found from measurements using Brookfield rotational viscometer. The water content that produce the lowest average viscosity over a period of 60 s is considered as optimum water content. This means, that the mixing behavior of the foamed bitumen should be similar if two different bitumen's have the same viscosity but different expansion ratios and half-lives [12].

The Wirtgen approach [13] states that the minimum expansion ratio should be $ER_{min} = 8$ and the minimum half-life $HL_{min} = 6$. Moreover, the optimum water content can be found by taking the average of the two water contents required to meet the specified minimum criteria as shown in Fig. 2(b). The minimum expansion ratio and half-life recommendation from other literatures is presented in Table 1.

Moisture from the foamed bitumen can have a negative effect on the performance of foam asphalt mixtures. The main mechanisms of moisture damage include reducing the adhesion between the aggregate and the bitumen, reducing the cohesive properties of the binder through diffusive intrusion of water into the binder and expansion of the void system by swelling [20,21]. Reduction of adhesion and cohesive properties can result in lower strength and stiffness modulus of asphalt mixtures. Previous research has shown the effect of moisture content in warm mix asphalt [10,21–23]. Nevertheless, the knowledge and methods in quantifying the amount of residual water left in foam asphalt mixtures is limited. Residual water from foaming or moisture trapped in the asphalt mixture from incomplete evaporation during mixing at low temperatures may remain in asphalt mixtures even after compaction. This can result in an increase of moisture susceptibility and moisture damage. In this research thermo-gravimetric analysis (TGA) was used to quantify the amount of water left in the asphalt mixture after the mixing process.

3. Experiment plan

Based upon the literature review, the recommended criteria for optimum water content may not be applicable to other types of bitumen. For this reason, the paper focuses on investigating the influence of water content on the mechanical behavior of a foam asphalt mixture that corresponds to an asphalt mixture AC11N according to Swiss Standards [24]. The concept and steps for testing the asphalt mixture are presented in Fig. 3. Studies has shown that mixing time has influence in the lab when adequate time of mixing <2 min is used [11], in this research 3 min of mixing time was used for all cases to insure adequate coating of aggregate. The mechanical behavior of the mixtures was studied using Marshall Stability and indirect tensile strength test (ITS). Marshall compaction was performed with major emphasis on compaction temperatures 80 °C, 95 °C, 100 °C and 120 °C in combination with different water contents of the foam. Gyratory compaction was also performed at 40 °C, 60 °C, 80 °C and 100 °C to investigate the influence of water content on the degree of compaction of the AC11N foam asphalt mixture over time. The comparison between the two testing method can be made only 80 °C, 100 °C and 135 °C. In addition, all gyratory compacted specimens were cured to simulate long term curing and to investigate the mixture behavior after reaching its final stage before testing the compacted specimens with the ITS test. Moreover, the addition of cold aggregate fractions to the foam asphalt mixture was investigated for 1% and 4% water content in the foam bitumen for two different types of mixtures. The first mixture consisted of cold aggregate fractions of 4–11 mm in combination with the rest of aggregate heated at 110 °C (mixture CA 4/11) and the second mixture consisted of cold aggregate fractions of 8–11 mm with the rest of aggregate heated at 110 °C (mixture CA 8/11). The Marshall stabilities of the foam asphalt mixture with cold aggregates were compared to those of the foam asphalt mixture with all heated aggregates (HA). In addition, the corresponding AC11N hot mix asphalt (HMA) was compared to the foamed asphalt mixtures using Gyratory compaction, ITS and Marshall stability tests. Moreover, finite element method FEM (ABAQUS) was used for obtaining an idea on the temperature changes between binder and aggregates in an idealized geometrical setup. Finally, foam asphalt mixture specimens were prepared at different water contents including hot mix asphalt as reference for determining the residual water content in the mixture after mixing. The residual water content after mixing was determined using thermogravimetric (TGA) analysis.

4. Materials and procedures

Three aggregate fractions were used for producing the AC11N with 5.9 wt% bitumen in the laboratory as shown in Table 2. AC11N refers to asphalt concrete (AC), maximum aggregate size (11) and normal traffic (N) respectively; details can be found in the Swiss standard SN 640 431-1b-NA [24]. The bitumen 50/70 had a penetration of 51 * 0.1 mm and a softening point of 51.1 °C. The actual aggregate gradation after extraction from the foam asphalt mixture was determined

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