The Influence of Short-Term Aging on Properties of the Asphalt Mixture in WMA Technology

Introduction

Growing volume of traffic and increasing load capacity of vehicles contribute to fast deterioration of road pavements. Therefore the pavements should be designed to have high durability parameters [2]. Unfortunately, during production, handling and placement, asphalt mixtures as well as the pavements in service are subject to adverse physical and chemical changes that occur in the composition of the binder and in its structure. These changes are called aging.

Aging of asphalt binders and asphalt mixtures is a complex process that is usually split up into two categories [3]: short-term aging and long-term aging.

Short-term aging starts when the asphalt binder is produced and continues through its storage. It intensifies during the asphalt mixture production, transport and placement [9], when the asphalt binder is subjected to elevated temperatures that accelerate the process [2].

Long-term aging occurs after construction and extends as a slow process throughout the life of a pavement. The process is significantly influenced by climatic conditions and other environmental factors such as the action of water, the use of de-icers, aggressiveness of rainwater, etc. [8].

The aging process occurs mainly during the production of asphalt mixtures, when a thin layer of bitumen on the aggregate grains is subjected to a short-term action of high temperature (approx. 180°C) and of oxygen from the air. Two main phenomena take place: the oxidation of bitumen and evaporation of oil fractions. To make this process slower, the technology is now used, which allows production, placement and compaction of the asphalt mixture at lower temperatures with the same physical and mechanical parameters maintained. Traditional asphalt mixtures, HMA (Hot Mix Asphalt), produced at temperatures from 140°C to 180°C are being replaced with the mixtures produced at temperatures in the range 100°C to 140°C – in the technology defined as WMA (Warm Mix Asphalt).

Appropriately high workability of the mixture in the WMA technology is obtained in two ways:
• chemicals that improve the workability of the asphalt mixture (e.g. through a change in the bitumen viscosity) are added to the bitumen,
• bitumen is foamed in the presence of water [6].

The main advantages of this technology lie in the reduced energy consumption and reduced emissions of harmful compounds. This ecological solution improves the working comfort of the workers at the construction site, extends the construction season and allows transport of the mixture over larger distances without the risk of worsening its technical and functional properties [7].

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Materials and study plan

The paper presents the results from own study divided into three stages:

- laboratory tests of bitumen PMB 45/80-65 with an addition of F-T synthetic wax before and after short-term aging in the RTFOT in accordance with PN-EN 12607-1,
- optimization of the synthetic wax amount in bitumen PMB,
- laboratory tests of the SMA asphalt mixture produced in HMA technology (with bitumen without the wax addition) and in WMA technology (with bitumen to which the optimum amount of wax is added) before and after the short-term aging process in the STOA to SHRP A-383.

In the tests, the input binder was the Polymer Modified Bitumen (PMB) 45/80-65, which is used mainly for wearing courses under heavy and very heavy traffic load. High polymer content and high viscosity of the binder make it quite difficult material for placement during unfavourable weather conditions (fast stiffening of the layer, compaction problems). Very high softening temperature and high level of modification make this binder suitable for use in places where high tensile strength and resistance to fatigue are required together with very good low-temperature properties [1].

Fischer-Tropsch wax was used to reduce the viscosity of the bitumen and consequently facilitate proper coating of the aggregate grains in the asphalt mixture at the lower temperature. The synthetic wax belongs to the group of alkenes, has a high melting point (> 99°C), and diffuses very easily in bitumen. At temperatures below the melting point (that is under pavement in-service conditions), the crystallites of the synthetic wax produce a spatial structure in the bitumen, providing rigidity for the binder and increasing the resistance of the asphalt mixture to permanent deformation [6]. At temperatures above 100°C, F-T wax significantly decreases the viscosity of the bitumen thus allowing the reduction of compaction temperature of the asphalt mixture of approximately 20–30°C [5].

Laboratory tests of PMB 45/80-65

Polymer modified bitumen PMB 45/80-65 was chosen for studying the influence of short-term aging on the properties of the asphalt binder. Fischer-Tropsch synthetic wax was used as a viscosity-reducing modifier in the amounts from 1.5% to 3.5%, with a step increase of 0.5%.

The specimens were tested in a laboratory to determine the following properties:

- penetration at 25°C to PN-EN 1426,
- softening point using the ring-and-ball apparatus, in accordance with PN-EN 1427,
- Fraass breaking point, to PN-EN 12593,
- elastic recovery, to PN-EN 13398,
- dynamic viscosity at temperatures 60°C, 90°C and 135°C.

These parameters were measured on unaged and aged specimens. The RTFOT method was used to simulate the aging process under laboratory conditions.

Results relating to rheological parameters of the bitumen, i.e. penetration and softening point, plus dynamic viscosity are discussed in detail further in the paper and summarized in Table 2 together with other investigated parameters.

Changes in penetration and softening point based on the amount of the modifier used before and after short-term aging are presented in Figures 1 and 2.
Analysis of the results suggests that the increase in the synthetic wax content has a significant effect on the changes in selected bitumen characteristics. The addition of the modifier reduces penetration and causes a proportional increase of the softening point. Irrespective of the synthetic wax content, the short-term aging raises the rigidity of the bitumen. The smallest penetration drop (of about 5x0.1mm) and the highest increase in softening point (over 2°C) in relation to the status before aging were observed for bitumens modified with a 3.5 % content of the synthetic wax.

Assessment of the influence of aging on dynamic viscosity of PMB 45/80-65 with synthetic wax content was an important element of the study. The dynamic viscosity results obtained at temperatures 60°C, 90°C and 135°C before and after short-term aging are shown in Figures 3 and 4.
The results indicate that both before and after the short-term aging, at a temperature of 60°C that corresponds to the maximum temperature of pavements in summer, dynamic viscosity of the bitumen increases with increasing content of the synthetic wax. At the placement temperature (135°C), the situation is different – dynamic viscosity decreases with increasing content of the modifier. In all modification cases, dynamic viscosity values following the RTFOT were higher than those before aging.

**Optimisation of synthetic wax content in the bitumen**

The preliminary stage of the study required determination of the F-T wax content. For that purpose, an optimisation algorithm was used. The procedure was performed globally for the complete range of investigated parameters. The set of parameters used for the optimisation together with their weights is shown in Table 1.

The selection of the parameters to be optimised was based on design requirements and expert opinions. Parameters such as softening point and dynamic viscosity were assigned the weights two times larger than those assigned to other parameters in order to obtain a bitumen composite that would exhibit high liquidity at manufacturing temperatures (longer distances covered) and high stiffness at in-service temperatures (resistance to rutting). Equivalent bitumen temperatures corresponding to viscosity of 2 and 20 Pa·s (viscosity range for asphalt mixture compaction) were determined from variability results for dynamic viscosity in the temperature range of 60°C to 135°C.
To specify a set of optimum solutions in terms of F-T wax content, a utility function derived by Harrington [8] was used. The use of this function helps aggregate all the results for the bitumen and express them as one measure. This variable takes values from 0 to 1. The values below 0.37 belong to the range of unacceptable results, while the values from 0.37 to 0.63 are satisfactory.

Based on the adopted criteria (transport duration and resistance to rutting), the optimum (maximum) content of synthetic wax was established to be 2.5%.

An addition of more than 2.5% F-T wax will cause excessive stiffness of the bitumen and increase the brittleness of the asphalt mixture at low temperatures.

**Laboratory tests of the stone mastic asphalt mixture SMA**

To evaluate the influence of short-term aging on the properties of the asphalt mixture produced in the WMA technology (bitumen with an addition of 2.5% wax), the tests were conducted on the stone mastic asphalt mixture SMA 8 intended for the wearing course under the KR 5 traffic volume, according to WT-2 2010 [10].

For comparison, the same mixture in the HMA technology was made (no wax added to bitumen).

The framework composition of the SMA mixture is presented in Table 3.

**Table 1. Parameters used for optimisation**

<table>
<thead>
<tr>
<th>Amount of wax</th>
<th>Pen</th>
<th>Pen RFTOT</th>
<th>T(_{\text{pik}})</th>
<th>T(_{\text{frass}}) RFTOT</th>
<th>T(_{\text{frass}}) RFTOT</th>
<th>Recovery</th>
<th>Recovery RFTOT</th>
<th>T(2Pa·s)</th>
<th>T(20Pa·s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>42.4</td>
<td>28.2</td>
<td>69.9</td>
<td>71.2</td>
<td>-17</td>
<td>-15.5</td>
<td>85</td>
<td>81</td>
<td>133.8</td>
</tr>
<tr>
<td>1.5 %</td>
<td>34.1</td>
<td>15.7</td>
<td>79.6</td>
<td>80.2</td>
<td>-16</td>
<td>-15</td>
<td>79</td>
<td>75</td>
<td>131.9</td>
</tr>
<tr>
<td>2 %</td>
<td>28.4</td>
<td>15.1</td>
<td>85.5</td>
<td>85.7</td>
<td>-15.8</td>
<td>-14.5</td>
<td>77</td>
<td>74</td>
<td>130.8</td>
</tr>
<tr>
<td>2.5 %</td>
<td>24.3</td>
<td>11.8</td>
<td>86.1</td>
<td>87.4</td>
<td>-14.8</td>
<td>-13.3</td>
<td>76</td>
<td>64</td>
<td>130.5</td>
</tr>
<tr>
<td>3 %</td>
<td>17.4</td>
<td>10.8</td>
<td>87.5</td>
<td>89.5</td>
<td>-14</td>
<td>-12.5</td>
<td>74</td>
<td>55</td>
<td>129.6</td>
</tr>
<tr>
<td>3.5 %</td>
<td>12.3</td>
<td>7.68</td>
<td>90</td>
<td>92.1</td>
<td>-12.5</td>
<td>-10.5</td>
<td>73</td>
<td>51</td>
<td>129.1</td>
</tr>
</tbody>
</table>

With quartzite as the chief aggregate in the mixture, the WETFIX BE bonding agent was added to provide proper adhesion between the bitumen and the aggregate grains, in the amount of 0.3% relative to the bitumen.

To retain the excessive amount of bitumen on the aggregate grains and to prevent it from running off, VIATOP cellulose fibres in the amount of 0.5% relative to the asphalt mixture was used as a mastic stabilizer in the SMA mixture.
The content of the bitumen in the designed stone mastic mixture was 7.2%. This amount was established based on previous tests and according to WT-2 2010 [10].

Compaction temperature of the SMA mixture produced in the WMA technology was 130°C, and that of the mixture produced in the HMA technology was 145°C.

Two basic tests were conducted for the SMA mixture, in accordance with WT-2 2010, to determine:
- void contents,
- resistance to water and frost.

These properties were tested before and after short-term aging, which under laboratory conditions were simulated using the STOA method.

Figure 5 shows the average void contents ($V_m$) of the SMA mixtures before and after the short-term aging in the STOA.

The results from the tests indicate that void contents in both mixtures before aging lie between the limits laid down in the requirements (from 2 to 3.5%). The SMA mixture without the synthetic wax after the short-term aging exhibits high void content ($V_m$>3.5%). This is caused by an excessive increase in bitumen stiffness due to the short-term aging. As a result, the mixture had poor workability. After aging, during the compaction of the mixture with 2.5% F-T wax, low workability of the modified bitumen led to a significant reduction in the compaction coefficient, which translated into higher compensation of the SMA mixture.
The results in Figure 7 showed that the SMA mixtures under investigation obtained the required level of resistance to water and frost, ITSR = 90%. It was found that regardless of the manufacturing technology used, the resistance to water and frost of the aged SMA specimens was higher than that of the unaged specimens. Despite lower temperature of production and compaction, the SMA mixture produced in the WMA technology had the highest ITSR value after the short-term aging.

Owing to the fact that aging is compensated in the SMA mixture by the presence of the F-T wax, the distance the mixture can be transported will be considerably longer.

Conclusions

Basing on the analysis of the test results the following conclusions can be drawn:

- synthetic wax modified bitumen caused the stiffening effect of the binder, thereby it affected the increase in the resistance of mix asphalt permanent deformation,
- short-term aging cause the decrease in penetration, the rise in softening point and the increase in the dynamic viscosity at 135°C regardless of variant of dosage
- the bitumen composition consisted of 2.5% synthetic wax amount in road bitumen Orbiton 45/80-65 is optimal,
- Stone Mastic Asphalt in Warm Mix Asphalt technology is characterized by better properties: voids content and water and frost resistance, especially after short-term aging.
- owing to considerable decrease in stiffness of the bitumen after aging process it’s possible to transport bituminous composite much more farther.

Abstract

The paper deals with the influence of short-term aging on the properties of the Stone Mastic Asphalt mixture (SMA) produced in warm-mix asphalt technology (WMA). Fischer-Tropsch wax was used as a bitumen viscosity-reducing modifier. Basic properties of the modified bitumen were tested. The content of the low-viscosity agent in the bitumen was optimised. The results from the tests of the SMA mixture produced in the WMA technology with the optimum wax were compared with those from the tests of the traditional SMA mixture produced in the HMA technology. The SMA mixture manufactured in the WMA technology was found to have better properties than the traditional SMA mixture.

Keywords: Warm Mix Asphalt, short-term aging, synthetic wax, optimization

ODDZIAŁYWANIE STARZEŃIA KRÓTKOTERMINOWEGO NA WŁAŚCIWOŚCI MIESZANKI MINERALNO-ASFALTOWEJ WYTWORZONEJ W TECHNOLOGII WMA

Streszczenie

W artykule zaprezentowano wpływ starzenia krótkoterminowego na właściwości mieszanki mastyksowo-grysowej SMA wytworzonej w technologii “na ciepło” (WMA). W roli modyfikatora obniżającego lepkość asfaltu zastosowano wosk syntetyczny Fischer-Tropscha. Wykonano badania podstawowych właściwości modyfikowanego asfaltu. Dokonano optymalizacji środka niskowiskozowego w asfalcie. Przedstawiono wyniki badań mieszanki SMA wykonanej w technologii “na ciepło” z optymalną zawartością wosku syntetycznego oraz tradycyjnej mieszanki SMA w technologii “na gorąco”. Stwierdzono, że mieszanka SMA wytworzona w technologii WMA posiada lepsze właściwości od tradycyjnej mieszanki SMA.

Słowa kluczowe: mieszanka mastyksowo-grysowa, technologia WMA, optymizacja, wosk syntetyczny
References


